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ECOLOGY OF FISHES IN THE KAFUE RIVER

Report prepared for
the Food and Agriculture Organization of the United Nations
(acting as executing agency for the United Nations Development Programme)

by

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ABSTRACT

The University of Idaho, under contract to FAO, completed two years of research (April, 1969 - March, 1971) on the ecology of fishes in the Kafue River. The study assessed potential effects of Kafue Gorge Dam on the fishes of the Kafue River and flats. Specific objectives were to determine: physico-chemical regime of the Kafue River and floodplain; movements of several important fish species; ecological preferences and biology of several fish species. We also predicted effects of water development schemes on ecology of certain fishes of the Kafue River.

Flood waters in the Kafue remained higher longer in 1970 than in 1969. Water transparency was highest at high water and ranged from .75 to 4.6 meters in sites sampled. Conductivity reached a high of 325 ~~µohm/cm~~ µmho/cm in low water, and a low of 90 ~~µohm/cm~~ just before peak flood. Water temperature extremes reached 17 and 33 C, with lowest temperature in July and highest in February. Most 24-hour temperature fluctuations were 1 to 2 C.

Fishes of the Kafue River moved onto the floodplain in December and January with the new flood, and off the plain as water receded in May, June and July. Of 10,341 fish taken in day and night sets of gill nets (equal time sets) 70% were taken at night. We correlated catches with limnological variables.

Some species were captured more easily in nets set near the surface; others were more easily captured near the bottom. Dissolved oxygen and conductivity correlated most closely with fish catches in gill nets.

We examined the food habits, fecundity, and growth of several important fishes. The most significant result was that extent and duration of flooding significantly affects growth. Higher, longer floods increase growth of *Tilapia*, for example.

We determined age of *Tilapia* successfully, and learned from scale analysis that flood size accounted for most of the variation in annual growth of *T. andersoni*. Catch data indicate that survival of this species also is greater in years of high flood. We also learned that relatively old fish make up a large part of the age structure of *T. andersoni*.

Tests of dissolved oxygen tolerance of selected species convinced us that *T. andersoni* can survive until dissolved oxygen reaches .60 to .40 ppm, but shows stress below 1 ppm. Other species of *Tilapia* tolerated dissolved oxygen as low as .25 ppm, but were stressed below .8 ppm.

We dried grasses from the flats to assess dryness at which we could burn the grass, and learned that 5 weeks of drying were required.

We concluded that intensity of fishing, at least to date, has no effect on catches in subsequent years, but that yield in year n was correlated with height and duration of flooding in year n-1 and year n-2.

We recommended that water regime should be regulated to permit at least 5 weeks of drying on as much of the floodplain as possible, and those areas of the flats which are not heavily grazed should be burned before the rainy season, to reduce B.O.D. in the next flood. The reservoir should be allowed to rise soon after the flats are burned, to minimize nutrient losses, and should rise slowly enough to allow aquatic grasses to keep pace.

We recommended that Lochinvar Ranch and Blue Lagoon be opened to fishing. Available tagging data suggest a fishing mortality rate of less than 10%. That fact, and our data on age structure, absence of correlation between fishing and subsequent yields, and absence of several harvestable species in presently-used gill nets, all suggest that the fish stocks in Kafue River are underharvested.

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1. INTRODUCTION

The University of Idaho sent a three man research team to study the effects of a water regulation scheme on ecology of fishes in the Kafue River in Zambia. The study, contracted from the Food and Agriculture Organization of the United Nations, began in March, 1969 and ends in February, 1971. The hydrology and flooding regime of the Kafue River, described in Volume III of the Kafue River Basin Report (1968a) will change after the Kafue Gorge Dam becomes operable in 1971. This will affect the ecology of fishes in the river and floodplain with consequent effects on important commercial fisheries on the Kafue River.

Our study is one of several evaluations of effects of the Kafue Gorge Dam. A closely-allied research effort by the University of Michigan emphasizes the effects of the altered flow regime and flooding upon abundance of fish and fishery yields in the Kafue River above the dam. The final report by the University of Michigan research team, (to be Technical Report No. 2, FI:SF/ZAM 11) whose field work terminated in December, 1970, will complement our report. Both research efforts have proceeded concurrently and cooperatively.

The objectives of our study were:

1. To assess the physico-chemical regime of typical segments of the Kafue River and floodplain, with special reference to dissolved oxygen.
2. To assess movements of several fish species in representative environments in the Kafue River and floodplain.

3. To define ecological preferences and biology of several fish species in environments in the Kafue River and floodplain.

4. To predict effects of water development schemes on the ecology of certain fishes of the Kafue River.

In this report we have gone beyond the scope of the usual scientific paper. In the final two sections we predict the ecological effects of the altered flooding regime, speculate rather freely based on information available, and then propose positive management practices that we believe will benefit commercial fishery harvest. We know that the Republic of Zambia will soon make management decisions and that time will not permit further research and definition of ecological facts after the Michigan team completes its work. We therefore state what we think should be done. This will provide a platform for argument.

We also recognize that fishery matters are only part of the planning hierarchy. The government cannot maximize benefits from fisheries alone or from game alone, or from hydropower alone. Optimization of total benefit flow from the river system demands compromise of the several resource systems. In other words, optimization of benefits from the entire system demands compromise among sub-systems. We consider this point in segments of our report, but take this opportunity to remind government planners that someone must integrate systems to maximize total flow of benefits.

2. DESCRIPTION OF KAFUE RIVER AND FLOODPLAIN

We summarize in this section some of the many descriptions of the Kafue River and floodplain (Fig. 1) for the benefit of readers who may not have read them before.

2.1 General

A. J. van Rensburg (F.A.O. 1968b) in Volume IV of the UNDP/FAO Kafue Basin Survey briefly describes the lower Kafue catchment or floodplain as follows:

> "The lower Kafue catchment between Meshi Teshi in the Southern Province and Kafue in the Central Province lies approximately between 15°15' to 16°15' latitude and 26°10' longitude. The Kafue floodplain attains its maximum width of about six miles (9.7 km)[1] approximately half way between Meshi Teshi and Kafue, east of the Chibila River outlet in the north and the Munyeke/Mutama outlets at Mbeze and Beengwa in the south. From this point the area more or less tapers eastwards and westwards.
>
> The altitude varies from 3350' to 3210' (1021.1-978.4 m). The average river bank height at Meshi Teshi is 3250' (990.6 m) and at Kafue 250 miles (402 km) along the river channel it is 3210' (978.4 m), indicating the remarkably small fall over this vast flat expanse.
>
> The average annual rainfall is 33 inches (84 cm) with considerable variation from place to place and from season to

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[1]We have changed all measurements in quotes to metric system and degrees centigrade using conversion tables

season, sometimes exceeding 43 inches (109 cm), while at other times it is below 20 inches (50 cm).

There is also a marked temperature variation with an average of 70 to 75 F (21-24 C) at Mazabuka, while in October/November the maximum temperature is up to 98 (36.7 C) and the minimum 58 (14.4 C) and the minimum temperature in July is 89 F (29.4 C)."

2.2 River and Flood

Volume III of the Kafue Basin Reports (FAO, 1968a) describes the river and flooding regime as follows:

"The Kafue River after passing through Meshi Teshi gap, enters a vast flat country, called Kafue Flats, which extends from Meshi Teshi to Kafue Rail Bridge. The straight line distance between the two gauging stations is about 150 miles (240 km), whereas the length of the river along its course between the same two points is more than 250 miles (420 km). This shows how much the river meanders as it flows through this flat country.

In the upper reach of about 150 miles (240 km) the gradient of the river is steeper than it is in the lower reach of 100 miles (161 km). During minimum water level (November 1964) the river dropped 30 ft (9.1 m) in the upper reach and only 5 ft (1.5 m) in the lower reach. The river gradient is thus about 0.2 ft per mile (3.8 cm/km) in the upper reach and 0.05 ft per mile (0.9 cm/km) in the lower reach. With such a flat gradient, the river flows very sluggishly along the Kafue Flats and particularly so in the lower reaches. As a result, the time taken for a flood peak to travel from Meshi Teshi to Rail Bridge is about 80 to 90 days.

Between the Kafue Rail Bridge and the Kasaka gauging station, both of which are near the head of Kafue Gorge, there is a high section in the river bed which acts more or less like a control weir. Upstream of this, the river channel forms a trough as a result of which the water surface stretches back almost horizontally for nearly 100 miles (161 km). The main depression of this trough is more or less opposite Luwato Lagoon, to the north, and Lochinvar Ranch, to the south. In this shallow depression there is permanent inundation, never less than about 0.3 million acres (0.14 million hec). Since in the low season the water in this depression is shallow, it supports wild life and provides an important center of fisheries in Zambia.

The catchment area of the Kafue River between Meshi Teshi and Rail Bridge is about 17,500 square miles (4,532,500 hec). A number of tributary streams which drain the area flow into the Kafue Flats. These streams carry considerable flows in the rainy season, but most of them dry up almost completely soon after the dry season starts.

The topography of the Flats shows some special features. Along both sides of the main channel of the Kafue River, there are slightly raised but not continuous natural "levee" banks, from which the ground slopes gently away from the river.

Also, because of changes in the meandering course of the river, old channels and "oxbows" exist. Where the tributary streams from the uplands enter the floodplains, the formed channels of their upper courses gradually disappear. Between these "deltas" and the "levee" banks of the main river, the floodplains include a number of depressions, in many cases unconnected, or partially connected, to the main river.

In the rainy season, the Flats are flooded by the combined effects of three contributions--direct rainfall on the Flats, inflows from the tributary streams and spill from the main Kafue River. Direct rainfall and inflows from tributaries arrive relatively quickly and cause flooding from about December. Flood flows in the main river from its upper catchment begin to arrive at Meshi Teshi somewhat later and, after reaching the bankful rate, they begin to spill on to the floodplain. The combined effects of all contributions result in the flooding building up to a maximum, first in the western part of the Flats, normally about February/March. As the rainy season progresses, the maximum level and extent of flooding moves slowly through the Flats and may reach the head of Kafue Gorge by about April/ May, when the rains are practically at an end, or even later in some exceptional years. During the dry season from May onwards, the flooding recedes and the floodplains begin to dry up, except in lagoons and depressions where the inundation extends throughout the year.

This description outlines the normal pattern of the flood regime in the Kafue Flats. But it must be remembered that the amounts of rainfalls and inflows and the resulting depths, extents and timings of the flooding, vary considerably from year to year."

2.3 Vegetation

Van Rensburg (FAO 1968b) subdivides the Kafue grassland and floodplain as follows:

	Area in: square miles	Area in: hectares
Oryza barthii floodplain grassland	849.5	220,020
Vossia cuspidata, *Phragmites mauritianus*, Swamp areas	467.0	120,953
Acroceras macrum, *Oryza barthii*, *Leersia hexandra*, Swamp areas	385.6	99,870
Echinochloa pyramidalis, *Oryza barthii*, and *Vetiveria nigritana*	179.8	46,568
Oryza barthii, *Vossia cuspidata*, Swamp areas	176.0	45,584
Echinochloa pyramidalis, *Oryza barthii*, *Setaria avettae*	18.2	4,714
Hyparrhenia rufa, *Panicum coloratum* and *Setaria sphacelata*	18.1	4,688
Acroceras macrum, *Echinochloa pyramidalis*, *Setaria avettae* and *Vetiveria nigritana*	19.8	5,128
Tristachya hitchockii, *Sporobelus spicatus* and *Sporobolus marginatus* on saline soil	13.8	3,574
Displachne fusca and *Typha sp.* on saline, swampy areas	21.7	5,620
	2149.5	556,719

2.4 Wildlife

Volume V (FAO 1968c) of the Kafue Basin Report describes present populations of wildlife. The most important wildlife species on the Kafue Flats, from our fisheries-oriented viewpoint, are the red lechwe, hippopotamus, and water fowl and shore birds. These forms interact with fishes in the aquatic system. Red lechwe, largely confined to Lochinvar and Blue Lagoon ranches, number 20-50,000. Their feeding and excrement in shallow waters convert plant-bound nutrients (e.g. NO_3, PO_4) to free nutrients which immediately re-incorporates into new plant production. Water birds and hippopotamus have similar interactive importance, especially along the shallow flooded margins of the flood waters. Birds such as cormorants and pelicans consume many fish at times, releasing fecal nutrients again which enter plant production.

2.5 Fisheries

Fish, fisheries, and fish ecology of the Kafue River and floodplain were described in Volume V of the Kafue Basin Report (FAO, 1968c) in Williams (1960), Carey (1965), Williams (1969), and in other papers to which we will refer later. The commercial fishes of the Kafue are listed below (most important species asterisked):

*Clarias ngamensis	Haplochromis carlottae
*C. gariepinus	H. codringtoni
*Labeo molybdinus	H. frederici
Serranochromis macrocephala	Synodontis macrostigma
S. robustus	*Schilbe mystus
S. thumbergi	*Hepsetus odoe
*S. angusticeps	Alestes lateralis

*<u>Tilapia sparrmani</u>	<u>Gnathonemus macrolepidotus</u>
*<u>T. melanopleura</u>	<u>Petrocephalus catostoma</u>
*<u>T. andersoni</u>	<u>Barbus marenquensis</u>
*<u>T. macrochir</u>	<u>Mormyrus lacerda</u>

The fishermen along the Kafue River harvest fish with seines or drawnets from the river channel during low water in August to mid-November. Low water seining thus depends on the flood in the previous year and onset of rainfall in October or November. Many fishermen use gill nets on the floodplain to catch fish during high water and in permanent lagoons or arms of quiet water.

From 1959 through 1968 the median catch of fish from the Kafue River was about 5600 short tons (5080 metric tons) while the median total catch in all areas in Zambia was 30,000 short tons (27,210 metric tons). The Kafue River produced roughly 18% of the fish catch in Zambia in the 10-year period through 1968.

3. METHODS AND MATERIALS

3.1 Limnology

To study limnology on the Kafue floodplain we established four sampling sites in the central floodplain area (Fig. 2). These sampling areas were concentrated in the Nampongwe-Nyimba area within 13 kilometers of the Nyimba village complex. The four areas sampled represented the four major vegetation-water types of the floodplain.

Following is a brief description of the sampling stations.

Station No. 1, at Chunga, was located near the floodplain margin. The area dries annually and when flooded has vegetation comprised primarily of lily pads--*Nymphaea sp.*, a yellow flowering legume--*Aeschynomene fluitans*, and a pseudo-lily--*Ottelia sp.* In this area we took samples in a large open water area and in adjacent vegetation.

Station No. 2, on the Nampongwe River, was on the upper section of river between Chunga and the main Kafue River. This station dries for only a short period of time and is covered by deeper water than the Chunga site. The vegetation along the Nampongwe channel is primarily a thick mat of *Echinochloa sp.* We took samples in mid-river in open water and on the edge of the river into vegetation approximately 50 meters. The Nampongwe River varies 50 to 200 meters wide in this area.

Station No. 3, at Nyimba, was located at the confluence of the Nampongwe and the main Kafue Rivers. Vegetation along the river banks was almost entirely *Vossia cuspidata*. Samples in this area came from open water areas only.

Station No. 4, at Chulwe, was in a lagoon which is separated from the main Kafue River at low water. Shore vegetation consisted of *Vossia cuspidata* and *Cyperus papyrus*, while open water vegetation was primarily *Ceratophyllum sp*. Limnological samples in the lagoon came from open water and shore vegetation. Water depth in the lagoon varied from 3.5 to 4.3 meters at high flood to 1.5 to 1.8 meters at low water during the 1969-70 flood year.

At each of the various sampling stations we recorded temperature and dissolved oxygen at surface, mid-depth, and bottom. If the water depth became less than 2.5 meters we took only a top and bottom sample. In water 1 meter deep only one sample was taken and in water 0.6 meters deep or shallower we took no sample. At approximately three-week intervals we sampled each station over a 24-hour sampling period with samples taken at 0600, 1200, 1800, and 2400 hours. To sample all four locations in a sampling period required a minimum of four days. Limnological sampling commenced at Chunga, Station 1, May 28, 1969; at Nampongwe, Station 2, May 6; at Chulwe, Station 4, May 21; and at Kafue River, Station 3, October 16. We sampled for one year in most areas and recorded a complete hydrologic flooding cycle.

From June, 1970, until August, 1970, we conducted a one day limnological subsample at each station once every three weeks to supplement the previous one year's data. This subsample consisted of recording temperature, dissolved oxygen, transparency, conductivity, pH, and depth all during a single day. Temperature and dissolved oxygen values for these later samples thus represented only values for one specific time of day.

We used a Kemmerer water bottle to collect the water samples for temperature and dissolved oxygen simultaneously. We recorded water temperature to the nearest 0.25 C on a standard 50 C thermometer. We determined dissolved oxygen by the modified Winkler method, titrating samples not later than 8 hours after fixation, and recorded the results to the nearest 0.1 ppm oxygen.

At midday we observed water transparency with a 30 cm secchi disc and recorded the findings to the nearest 0.1 meter. We analyzed water conductivity at mid-depth on an electrolytic conductivity measuring bridge, recording in μmho/cm. We determined depth at the time of sampling to the nearest 0.5 foot (15 cm) with a sonar type depth recorder. In each location we took water from mid-depth for pH readings on a Radiometer pH meter and colormetric determination from a portable chemical Hach Kit.

We monitored flooding in the Nampongwe area during the 1969-70 flood year by placing a gage board near the Chunga sampling site and recorded gage readings in cm at irregular intervals throughout the flood season. Rainfall records which supplement the flooding cycle data were obtained from Mr. Wm. Greasley, Game Ranger, Lochinvar Game Reserve.

3.2 Fish movements and habitat preference

We determined location of fish on the floodplain by capturing fish at the four limnological sampling stations with multimesh gill nets. Each station represented a particular type of floodplain habitat and stations were spaced far enough apart to indicate fish movement patterns.

Four Zambian fish guards collected the gill net data from the four sampling stations. They took five days to sample all four stations. Gill net sampling was conducted during the same week as limnological sampling which permitted us to compare fish numbers and movement with limnological data. Fish sampling commenced at the same time as limnological sampling in 1969 and continued until June 1970.

From May, 1969, to January, 1970, the multimesh gill nets were composed of 10 panels, each 9.1 meters long when hung by the half and 2.4 meters deep. From mid January until June, 1970, we used multimesh gill nets with an equal number of meshes in each of the 10 mesh sizes. The meshes in both types of multimesh gill nets were the same, 3.8 through 15.2 cm, increasing by 1.3 cm increments. The equal length multimesh gill nets caught too many small fishes, and too few of the larger, commercially important ones. The equal mesh gill nets resolved these two problems and lessened the time required to fish the nets. We used a conversion table to keep the unit of effort equal for both net types changing equal length net catch to equal mesh net catch.

Two surface and two bottom nets were used for each sample. One surface and one bottom net were set in the selected habitats. The remaining two nets were set adjacent to the habitats. The fish guards set two nets within the habitat as near to 0700 as possible and fished them the following day at 0700. The nets adjacent to the vegetation were set at 0700, fished at 1600 and again at 0700 the following day. The cumulative catch of all nets constituted one sampling unit. Following is a list indicating where we had fish guards set nets at each station.

Station No. 1, at Chunga, fish guards pushed a top and bottom net down through the vegetation and set two nets along the habitat bordering open water.

Station No. 2, in the Nampongwe River, fish guards set two nets (a top and bottom) in a narrow channel in the matted vegetation and a top and bottom net along vegetation bordering the river.

Station No. 3, at Nyimba, all nets were set in the Kafue River adjacent and parallel to the river bank vegetation. Fish guards set a top and bottom net both upriver and downriver from the Nampongwe-Kafue confluence.

Station No. 4, at Chulwe Lagoon, fish guards set top and bottom nets in mid-lagoon and top and bottom nets adjacent to the shore grasses. All nets were set in the open water of the lagoon during low flood cycle.

At each station we had the fish guards record the fork length of each fish caught to the nearest half centimeter, and record the catch separately for each net and each mesh size in a net. The data from each net contained details of species caught, length, mesh size, top or bottom set, day or night or 24 hour set and water depth. In nets adjacent to vegetation direction of movement of fish when entering net was also noted. This directional data gave information as to whether fish moved in or out of vegetation.

3.3 Biology of selected fish species

Hepsetus odoe: In October 1969 we commenced taking extensive biological data on *Hepsetus odoe*, the "Kafue pike." In our sampling program we endeavored to collect each month four females and four males from each 2 cm length interval. The bulk of Hepsetus captured came from the multimesh gill nets used in the fish movement portion of the study. Seining, rod and reel, and chemofishing supplemented gill net catches when necessary.

Data recorded on individual specimens included: length, weight, sex, state of sexual maturity, and stomach content whenever full stomachs were examined. Scales and opercular bones were also taken from individual fish for age determination. We collected scales from above the lateral line in the area just below the anterior region of the dorsal fin. The left opercle bone was taken to aid in age determination.

Ripe ovaries were taken and preserved in Gilson's fluid for fecundity determination. Gilson's fluid hardens eggs and breaks down ovarian tissue enabling an observer to easily count the number of eggs.

When we examined stomach contents we identified fish in stomachs and recorded their length, estimating length of partially digested individuals. We examined invertebrates and plant matter under a binocular microscope.

We examined H. odoe opercles for age determination using a Nikon Profile Projector at 10 x magnification. Opercle bones were scraped and put in a hydrogen peroxide solution for cleaning prior to examination. We dry mounted scales between glass microscope slides for examination on a scale projector.

Because of the scarcity of large numbers of Hepsetus in 1969-70 we used length data collected in 1968 to compile length frequency histograms for Hepsetus. Mr. G. Everett, Kafue Research Officer, collected these length frequency data by extensive seining near Nyimba villabe, at the confluence of the Nampongwe and Kafue Rivers in 1968.

Clarias gariepinus and C. ngamensis: We initiated age and growth work on the two Clarias species in October 1969. Data collected from Clarias specimens were the same as for Hepsetus odoe. Means of age determination of Clarias differed from Hepsetus in that pectoral spines and vertebrae were used to determine age of Clarias. During the month of November, 1969, we took both vertebrae and pectoral spines for age growth studies. From December, 1969 until June, 1970, we took only vertebrae. We saved vertebrae No. 5, 6, and 7, which lie posterior to the fused vertebrae 1 to 4.

Age and growth pattern can be seen directly on vertebrae under low power magnification. Pectoral spines were sectioned, honed tissue-thin, and examined under a binocular microscope to see growth pattern and age. Both vertebrae and spines have concentric growth rings similar to those found on scales.

Data collected by Mr. G. V. Everett in 1968 from seine nets were used in compiling length frequency histograms for both Clarias species.

We analyzed stomach content and fecundity of Clarias using the same procedure and materials as used for Hepsetus odoe.

Tilapia andersoni, T. macrochir, and T. melanopleura: During the first two weeks of each month, from October 1969 to July, 1970, we examined up to 70 specimens each of Tilapia andersoni, T. macrochir and T. melanopleura. We captured these fish in the multimesh gill nets ~~used for fish movement studies~~, in supplementary gill nets, in draw seines, and occasionally by electro-and chemo-fishing. We collected *Tilapia* with seine nets mainly during low water in October, November and December. During high water (April through June) we did some limited seining along the floodplain margin for juveniles.

The seine net used during low water had 7.6 cm mesh, and measured 100 meters long and 2.5 meters deep. The seine net used for juveniles during high water had 1.9 cm stretch mesh on the wings and 1.3 cm mesh in the bag and was about 90 meters long.

We used the fork length of each *Tilapia* to the nearest mm, weight to the nearest 15 gms, and determined the sex and maturity of each specimen.

For the sexual maturity portion of the study we classified the gonads of the specimen with the numbers 1-6 using the following criteria:

1. Males - a very thin tube extending to the anterior end of the coelomic cavity.

   Females - a thicker translucent tube extending 3/4 of the way to the anterior end of the coelomic cavity, in which ova were visible only under a microscope.

2. Males - the tubes appeared thicker than in (1), often with a prominent blood vessel along the ventral side.

   Females - similar to (1) but less translucent with tiny ova visible to eye if examined carefully.

3. Males - testes well developed but no sperm seen when testes were cut and squeezed.

   Females - ova easily seen but still small and not easily separated from each other.

4. Males - sperm visible at cut edges of testes.

   Females - ova large and easily separated.

5. Running ripe both sexes

6. Males - spent, testes reddish-pink flaccid.

   Females - spent, very few large ova.

We took scale samples from the center of the left side of each fish, directly anterior to the second lateral line and ventral to the center of the dorsal fin. Brief examination of each scale allowed us to discard regenerated scales, which were quite numerous.

We subsequently examined the scale samples on a scale projector at a magnification of 38 diameters. We measured total scale radius and the distance of each annulus from the scale focus (to the nearest mm). In May, 1970, we collected the left opercular bone from each specimen in order to examine it for annular marks. Opercle aging provided a check for aging with scales.

During low water, 1969, we collected large numbers of Tilapia by seine net for length frequency determinations to help validate scale aging techniques. We measured and determined the sex of all these fish but did not take scale samples from all of them.

~~During April, 1970, we examined and took scale samples from all Tilapia caught in multimesh gill nets in another effort to determine the length frequency and age frequency distribution of these species.~~

We collected juvenile Tilapia along shore by seine each month from February through May to determine length frequency, growth, and food habits of the juveniles.

3.4 Dissolved oxygen tolerance of selected fish species

To gain general knowledge of the oxygen tolerances of selected Kafue fishes we carried out some simple laboratory studies. We studied the following species: *T. andersoni*, *T. macrochir*, *T. melanopleura*, *T. sparrmani*, *Haplochromis codringtoni*, *Schilbe mystus*, and *Gnathonemus macrolepidotus*.

Test fish were placed in three aquaria with subsurface screens to prevent fish from reaching the surface. Fish acclimated to the tank environment for 4 to 12 hours. All except two *T. andersoni* tests were conducted in 42 liter (l) plexiglass aquaria. In two of the *T. andersoni* tests we used 27 l glass aquaria.

We used three aquaria in each test; one control tank with supplementary aeration and two test tanks. In the two test tanks we placed paraffin (kerosene) on the surface to exclude oxygen.

Using the azide modification of the Winkler method we determined oxygen levels in the test tanks every 3 to 6 hours. During some of the experiments aquarium heaters controlled water temperature. Since we knew the volume of water present in the tank at any time we also estimated oxygen consumption of the species tested by computing the decrease in total milligrams of oxygen per time period.

3.5 Plant drying studies

On June 10, 1970, we initiated an experiment to determine the length of time required for grasses of the Kafue flats to dry under natural condition before they could be burned. For our experiments we used three common Kafue grass species: *Vossia cuspidata*, *Echinochloa* stagnina, and Leersia hexandra. V. cuspidata grows near flowing water, E. stagnina in deep still water, and L. hexandra in shallow water near the floodplain periphery. We sometimes observed grass stands containing all three species.

After collecting six mature individual plants of each species from the aquatic habitat we placed them on a moist plot of ground near our laboratory, 10 miles from the collection site. The plants lay on top the moist ground while the roots were in saturated mud. This situation simulated the natural occurrence of receding flood water. The ground began immediately to dry and from this point on the plants were exposed to the effects of open air drying, unshaded ground, and the daily winds of June and July. At 8 to 13 day intervals we took two samples of each species of grass. We tried to burn one sample with an open flame to see if it would readily ignite. The remaining sample was weighed, dried in an oven at 70 C for 24 hours, and then reweighed to determine water content by weight. Five tests were conducted with the final test completed on July 22, 1970.

4. RESULTS

4.1 Limnology

Water depth: In a central portion of the Kafue flats, the water depth fluctuated 3.9 meters from a high in May, 1969 to a low in December 1969 (Fig. 3). From a low in December, 1969, the flood rose 3.3 meters to the next high in March, 1970. The smaller difference between high and low flood water between 1969 and 1970 was because the flood waters did not drop to within the river banks during the 1969 low water cycle.

Rainfall: In the Nampongwe area rainfall totaled 28.5 inches (72.4 cm) during the 1969-70 rainy season. This is 4.5 inches (11.4 cm) below the 33 inch (83.8 cm) average (FAO, 1968b). The first rains of the 69-70 rainy season fell October 3, 1969 and the last on April 22, 1970 (Fig. 3). Almost half of the total rainfall, 13.5 inches (34.3 cm) fell during December.

Transparency: Water transparency (Fig. 4) related directly to the flood level cycle on the flats. Transparency was highest at high water and lowest at low and rising water and ranged from 0.75 to 4.6 meters over all sampling sites.

Conductivity: Water had the highest conductivity during low water and lowest just prior to peak flood (Fig. 5). Conductivity ranged between 90 and 325 μohm/cm with highest conductivity recorded in the main Kafue River above the mouth of the Manpongwe. We recorded the lowest conductivity on the floodplain in the Chunga area.

Water temperature: The temperature of the Kafue River and floodplain waters depended primarily on the prevailing air temperature. We observed lowest temperatures in July and highest temperatures in February (Fig. 6). Mean temperature of top, mid and bottom waters over 24 hours ranged between 17.7 and 29.1 C. The individual extreme readings were 17.0 and 35.5 C, both recorded from the top of the water column.

Between October and May many of our observations in the Kafue River and in the mouth of the Nampongwe River indicated warmer water at the bottom of the water column. In April and May water temperatures on the bottom in all open water areas averaged slightly warmer than the top. Vegetation areas remained warmer at the top of the water column throughout the year.

Water temperatures in the Nampongwe River averaged slightly colder than in the Kafue River throughout the year. Temperature difference averaged as much as 1 C.

Variation in water temperature over a 24-hour period oscillated as much as 6 C. But most 24-hour temperature fluctuations were in the range of 1 to 2 C (Table 1). For open areas of the floodplain and river the largest surface temperature variation over 24 hours was at the Chunga and Chulwe sampling sites. In these two areas mean 24-hour surface temperature fluctuated approximately 2.0 C. Average diel fluctuation of water temperature at the bottom for all areas was approximately 1 C. Vegetation areas had a greater temperature oscillation over 24 hours than open areas. The Chunga vegetation site had the highest mean fluctuation of surface temperature.

Table 1

MEAN TEMPERATURE FLUCTUATION IN C AT FOUR SAMPLING SITES OVER 24 HOURS,

KAFUE RIVER AND FLOODPLAIN, 1969-70

Area		Chunga		Nampongwe		Chulwe		Kafue River
Vegetation		Open	Weeds	Open	Weeds	Open	Weeds	Open
Number of samples taken	Top	16	16	16	18	18	12	11
	Bottom	16	15	18	17	18	4	11
Range in temperature fluctuation	Top	1.0-3.5	1.25-4.5	0.0-3.0	0.5-6.0	1.5-3.25	1.0-4.0	0.5-2.25
	Bottom	0.0-2.5	0.5-2.0	0.0-2.5	0.0-2.0	0.4-1.5	0.75-2.0	0.75-2.0
Mean temperature fluctuation	Top	1.95	2.70	1.56	2.09	2.03	2.25	1.37
	Bottom	1.18	1.04	0.83	0.94	1.06	1.29	1.10

Generally, the water became coldest at 0600 hours and warmest at 1200 or 1800 hours. This merely reflects the cooler air temperatures during the night.

Dissolved oxygen: Mean or average dissolved oxygen (D.O.) ranged between 7.5 and 0.1 ppm (Figs. 7 and 8). We derived mean D.O. values by averaging oxygen readings taken over 24 hours at the 6-hour intervals for top, middle, and bottom depths. In some individual observations I could find no measurable D.O. Low D.O. occurred between January and March before peak flood. Open water at Chulwe Lagoon, vegetation at Chunga and open water at Chunga had higher D.O. than the other sampling areas. The Nampongwe site had consistently low D.O.

In January the D.O. dropped drastically. In a three week period D.O. in Chulwe Lagoon dropped from approximately 7.2 to about 0.5 ppm. Dissolved oxygen decreased in all areas in this three week period. The Chunga vegetation area was the only one sampled where the oxygen never dropped below 3.0 ppm over a full year cycle.

Hydrogen ion concentration: In the central floodplain pH values ranged between 6.3 and 8.3 (Table 2). Hydrogen ion concentration varied considerably between stations and with time indicating high photosynthesis and low chemical buffering of the water. Generally pH was higher at the Chunga station near the floodplain margin while lowest in the Kafue River. This probably denoted some decomposition of organic material on the flats which made water more acidic by the time it reached the main river. It also suggested that many of the salts in the water were probably removed before reaching the main Kafue River.

Table 2

pH VALUES OF FOUR SAMPLING STATIONS OVER ONE COMPLETE FLOOD CYCLE, TAKEN WITH RADIOMETER pH METER AND CHEMICALLY BY HACH KIT, CENTRAL KAFUE FLOODPLAIN, 1969-70

Chunga Station 1

Date	pH vegetation	pH open
28/5/69	7.0	7.1
19/6/69	7.4	7.4
8/7/69	6.7	6.4
31/7/69	7.5	7.4
21/8/69	6.6	8.2
8/9/69	7.4	7.4
28/9/69	7.2	7.1
19/10/69	7.4	7.6
4/1/70	7.1	7.3
2/2/70	7.5	7.1
16/3/70	7.2	7.0
6/5/70	8.0	7.6
18/5/70	7.5	7.4
10/6/70	8.1	7.8
1/7/70	8.1	7.8
Mean	7.38	7.37

Chulwe Lagoon Station 4

Date	pH vegetation	pH open
11/6/69	6.6	6.5
1/7/69	6.3	6.4
23/7/69	7.4	7.5
13/8/69	7.5	7.9
4/9/69	7.6	7.4
12/9/69	6.9	7.5
21/10/69	7.6	8.0
9/12/69	---	8.1
1/1/70	---	7.1
15/1/70	---	6.3
5/2/70	6.8	6.9
19/3/70	6.8	6.8
6/5/70	6.9	6.8
21/5/70	7.0	7.0
8/6/70	---	7.1
1/7/70	7.0	7.5
Mean	7.03	7.18

Nampongwe Station 2

Date	pH vegetation	pH open
6/5/69	7.0	7.0
4/6/69	6.8	7.0
25/6/69	7.1	7.1
15/7/69	7.4	7.2
7/8/69	7.1	7.1
28/8/69	8.3	7.6
22/10/69	7.2	7.0
3/1/70	7.1	7.1
3/2/70	7.0	7.1
17/3/70	6.8	6.8
6/5/70	7.2	6.9
19/5/70	6.6	7.1
10/6/70	7.1	6.9
1/7/70	7.2	7.2
Mean	7.14	7.08

Kafue River Station 3

Date	above	below*
16/10/69	6.9	7.1
2/1/70	6.9	7.1
14/1/70	6.4	6.4
4/2/70	6.8	6.9
18/3/70	6.6	6.6
6/5/70	7.3	6.9
20/5/70	7.1	6.9
8/6/70	7.8	---
1/7/70	7.6	7.4
Mean	7.04	6.91

* indicates above and below the mouth of the Nampongwe River

4.2 Fish movement

By season and location: Fishes in the Kafue River moved onto the floodplain in December and January with the new flood. In November, 1969, before the flood began, 734 fish entered our gill net sampling unit at the Kafue River sampling site. In late December we caught 400 fish and in mid-January, after the flood commenced and dissolved oxygen decreased we collected only 59 fish at the Kafue River station. Forty-nine fish from the January catch of 59 fish were air-breathing *Clarias*.

As the water rose cichlids carrying young or eggs moved to the margin of the floodplain and deposited eggs and young there. The adults then dispersed and left their young to rear in the productive marginal waters. In January we caught many Tilapia at Chunga while in February large catches came from the Nampongwe station (Figs. 9 and 10). In April *Tilapia* became numerous again at the Kafue River station. The distribution of other non-predator fish also fluctuated with the flood cycle and time (Figs. 11 and 12).

Not correct spawning takes place prior to water rise.

Clarias gariepinus and *C. ngamensis* migrated into the first small rivulets washing in from the floodplain. These rivulets were caused by the first rains in November and December. Fry of these *Clarias* remained in the highly oxygenated water along the floodplain margin while the adults, after spawning, redistributed themselves over the entire floodplain. *Clarias gariepinus*, the more common of the four species in the Kafue, was generally equally abundant at all sampling stations (Fig. 13). During October, in sampling period 9, we caught large numbers of *C. gariepinus* at the Nampongwe station. This was just as the first rains started and these *Clarias* moved up the Nampongwe to the floodplain to spawn.

Many of the predator species of the Kafue, Serranochromis sp., Schilbe mystus, and Hepsetus odoe remained near the floodplain margin after spawning (Figs. 14 to 17). These predators left the main Kafue area in January and remained in large numbers near the floodplain margin until the first of May. In May, as the water level dropped, these predators again returned to the main Kafue River. During May and June predatory fish fed actively on the young fish coming into the Kafue River.

Fish moved off the floodplain with the receding water level. During 1969-70 most fishes returned to the main Kafue River in May, June and July. Reduced water depth probably caused this return to the main river.

Day vs. night: We compared day and night gill net catches to determine the best time to catch the various species of fish. Gill nets captured several species more at night than in the day time (Figs. 18 to 23): Clarias gariepinus, C. ngamensis, Schilbe mystus, Synodontis macrostigma, Serranochromis angusticeps, Gnathonemus macrolepidotus, and Hepsetus odoe. Of 10,341 fish taken in day and night set gill nets, 70% were captured at night (Table 3). But the highly valued Tilapia andersoni entered our nets equally day or night.

4.3 Fish habitat preference

Location on floodplain: We compared catches of fish (Table 4) for the four station habitats by using species diversity index numbers. Station 1 at Chunga near the floodplain margin had an average species diversity index of 3.3. Station 4 at Chulwe Lagoon rated second with an index of 3.0. Station 2 on the Nampongwe had a species diversity index of 3.0. Station 2 on the Nampongwe had a species diversity index of 2.87 while the catches on the main Kafue River yielded an index of 2.37.

Table 3

FISH CATCH BY SPECIES IN NIGHT AND DAY SETS OF GILL NETS AT FOUR STATIONS, 1969-70

	Chunga		Nampongwe		Nyimba		Chulwe		Total	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Clarias gariepinus	75	100	78	252	6	72	46	300	205	764
C. ngamensis	7	13	32	80	0	16	17	54	56	163
Schilbe mystus	152	579	129	280	21	3	30	381	332	1243
Synodontis macrostigma	10	309	112	565	0	2	0	30	112	906
Tilapia andersoni	65	88	141	155	82	52	46	111	334	406
T. macrochir	3	10	4	11	1	0	2	7	10	28
T. sparrmani	104	64	35	47	13	1	142	322	294	434
T. melanopleura	6	22	1	1	19	3	6	18	32	44
Serranochromis robustus	12	30	21	1	0	0	6	9	39	40
S. macrocephala	60	44	74	46	1	0	45	130	180	220
S. angusticeps	55	148	87	129	59	24	62	240	263	541
S. thumbergi	20	26	12	20	0	0	4	10	36	56
Haplochomis sp.	69	77	55	49	2	0	63	157	189	283
Petrocephalus catostoma	0	0	0	3	0	0	0	0	0	3
Gnathonemus macrolepidotus	13	204	41	324	19	37	0	134	73	699
Mormyrus lacerda	0	10	0	5	0	1	0	14	0	30
Hepsetus odoe	135	409	82	228	33	10	33	143	283	790
Alistes lateralis	39	56	32	5	0	0	76	129	147	190
Barbus sp.	2	19	2	1	0	0	0	0	4	20
Labeo molybdinus	266	262	136	99	0	0	36	83	438	444
									3,037 (29.4%)	7,304 (70.6%)

Table 4

FLOODPLAIN STATIONS WHERE SPECIES WERE MOST ABUNDANT

Station at Chulwe	Station at Nampongwe	Station at Chunga
Alistes lateralis	*Clarias ngamensis*	*Mormyrus lacerda*
Tilapia sparrmani	*Gnathonemus macrolepidotus*	*Hepsetus odoe*
Serranochromis macrocephala	*Synodontis macrostigma*	*Labeo molyhdinus*
Serranochromis rubustus		*Schilbe mystus*
Haplochromis sp.+		*Synodontis macrostigma*+
		Tilapia melanopleura
		Tilapia macrochir
		Tilapia andersoni
		Serranochromis angusticeps
		Serranochromis thumbergi
		Haplochromis sp.+
C. gariepinus is equally abundant at all stations		
+ Equal mean number/sample at two stations		
Mean Annual Dissolved Oxygen		
3.1 mg/liter	1.3 mg/liter	4.7 mg/liter

Limnological variables: Dissolved oxygen (D.O.) and conductivity were the two most important limnological variables in determining fish species distribution (Table 5). Conductivity was related to both depth and D.O. Therefore depth should also be considered an important determinant of fish distribution. However, D.O. was the most important limnological variable (Figure 24). Comparing species diversity with D.O. we found a correlation coefficient of 0.6, using D.O. levels between 0 and 2.0 ppm. This suggests that oxygen affects species diversity at the lower concentrations. At 2 to 7 ppm D.O. we found a correlation of 0.31, indicating less than 10% of variation in species diversity could be accounted for by D.O.

Water at Chulwe Lagoon contained very little oxygen as the water rose in 1969 (Fig. 7). We observed dead fish and caught few fish in gill nets shortly after a water connection developed with the floodplain. By April, 1970, the water had a D.O. content of 1.7 ppm, and fish had repopulated the lagoon.

Catches of the predator species, *Hepsetus odoe*, *Serranochromis angusticeps*, and *Schilbe mystus* correlate closely with D.O. Increased catch corresponded to increased D.O. Catches of *H. odoe* correlated best with temperature. *H. odoe* catches increased as mean temperature decreased.

Conductivity was an important factor in three species tested: *Synodontis macrostigma*, *Serranochromis macrocephala*, and *Gnathonemus macrolepidotus*. Increased conductivity correlated with an increased catch of these three species. Since conductivity had a high negative correlation with depth and positive correlation with D.O., these three species may also be affected by depth and D.O.

Table 5

RANK OF IMPORTANCE OF SIX LIMNOLOGICAL VARIABLES IN DETERMINING THE DISTRIBUTION OF 11 SPECIES OF FISH ON THE KAFUE FLOODPLAIN, 1969-70. FROM ANALYSIS USING STEPWISE MULTIPLE REGRESSION

Species	Limnological Variables					
	Dissolved O_2	Temperature	Conductivity*	Sampling Period (Time)	Transparency	Location
Schilbe mystus	1 (0.29)**	6 (0.00)	3 (0.01)	5 (0.00)	4 (0.00)	2 (0.04)
Serranochromis angusticeps	1 (0.27)	3 (0.02)	2 (0.04)	4 (0.01)	6 (0.00)	5 (0.01)
Haplochromis sp.	1 (0.19)	2 (0.04)	3 (0.02)	6 (0.00)	4 (0.01)	5 (0.01)
Tilapia melanopleura	1 (0.10)	4 (0.00)	3 (0.00)	2 (0.04)	5 (0.00)	6 (0.00)
Hepsetus odoe	2 (0.06)	1 (0.18)	5 (0.01)	3 (0.01)	6 (0.00)	4 (0.01)
Clarias gariepinus	2 (0.02)	6 (0.00)	3 (0.03)	5 (0.00)	1 (0.19)	4 (0.04)
Gnathonemus macrolepidotus	3 (0.02)	2 (0.05)	1 (0.14)	6 (0.00)	4 (0.02)	5 (0.01)
Serranochromis macrocephala	3 (0.00)	4 (0.00)	1 (0.19)	2 (0.14)	5 (0.00)	6 (0.00)
Synodontis macrostigma	4 (0.01)	5 (0.01)	1 (0.22)	3 (0.07)	6 (0.02)	2 (0.14)
Tilapia sparrmani	6 (0.00)	3 (0.06)	1 (0.02)	2 (0.02)	4 (0.01)	5 (0.00)

* Conductivity correlates very closely with depth

** Number in parentheses is the coefficient of determination, r^2, which is the proportion of variation which can be accounted for by that particular variable

Catches of Clarias gariepinus correlated with transparency. When transparency was low, the catch of C. gariepinus was high. Catches of both C. gariepinus and C. ngamensis increased as D.O. decreased. Peaks in catch of C. gariepinus per unit of fishing effort occurred in Chulwe and in the river channel as the water rose. Peaks also occurred at the Nampongwe station at times of reduced D.O. Either anaerobic conditions were favorable for C. gariepinus or such conditions stimulate activity of this species.

Catches of Tilapia melanopleura and Haplochromis sp. positively correlated with D.O. Because T. melanopleura feeds on vascular plant material it was caught in the oxygenated water where plants were growing. The catch of T. sparrmani did not correlate significantly with any of six limnological variables.

Distribution of Tilapia andersoni was rather wide spread and catch of this species in nets related to sampling period or time of year. From June 1969 to May 1970 T. andersoni became more abundant in our net catches. Temperature had a slight effect on catches of T. andersoni, i.e. catch increased as mean temperature increased. Dissolved oxygen had no effect on catches of T. andersoni.

Top or bottom of the water column: Because we set nets at each station with two at the surface and two on the bottom, we were able to calculate catches in top and bottom sets. In Figures 25 to 30 we graphed top and bottom catches for several species. Fifty-two percent of 6,535 captured fish of seven species entered nets set on the top (Table 6). Species taken best in bottom sets included Schilbe mystus, Serranochromis macrocephala, Serranochromis angusticeps, and Haplochromis sp. Species taken more in top sets included Hepsetus odöe, Tilapia andersoni, and Clarias gariepinus.

Table 6

TOP AND BOTTOM GILL NET CATCHES OF SEVEN SPECIES OF KAFUE FISHES
ONLY CATCHES FROM WATER DEEPER THAN 2.4 METERS INCLUDED

	Catch			
	Top		Bottom	
Species	number caught	percent	number caught	percent
Hepsetus odöe	858	63.2	499	36.8
Tilapia andersoni	609	59.6	412	40.4
Clarias gariepinus	601	53.0	533	47.0
Schilbe mystus	597	46.5	686	53.5
Serranochromis angusticeps	383	45.9	451	54.1
Haplochromis sp.	120	29.3	289	70.7
Serranochromis macrocephala	133	26.9	364	73.1

4.4 Biology of selected fish species

Biology of Hepsetus odöe: Analysis of 137 H. odöe stomachs indicated that this fish fed entirely on fish. Hepsetus apparently fed on the most available species, and only Clarias and Synodontis did not appear in stomachs sampled from H. odöe. Approximately 31 percent of the fish found in Hepsetus stomachs were cichlids (Table 7). The largest cichlid, a 19 cm S. macrocophala, was ingested by a 44.6 cm Hepsetus. Most Hepsetus measured less than 36 cm, and the largest cichlid consumed by a Hepsetus of that size group was 10.5 cm. The largest non-cichlid taken was a 20 cm Schilbe mystus which we found in the stomach of a 45.4 cm Hepsetus.

Table 7

NUMBER AND PERCENTAGE OF FISH IN STOMACHS OF 137 HEPSETUS ODOE, KAFUE RIVER, SEPTEMBER 1969 TO MAY 1970

Species	January-May Number	January-May Percent	September-December Number	September-December Percent	Total Number	Total Percent
Tilapia sp.	15	14.6	2	5.9	17	12.4
Serranochromis sp.	3	2.9	0	0.0	3	2.2
Haplochromis sp.	16	15.5	2	5.9	18	13.1
Unidentified cichlids	4	3.9	0	0.0	4	2.9
Total cichlids	38	36.9	4	11.8	42	30.6
Barbus sp.	28	27.2	4	11.8	32	23.4
Schilbe mystus	4	3.9	16	47.1	20	14.5
Gnathonemus macrolepidotus	21	20.4	4	11.8	25	18.2
Ctenopoma multispinus	2	1.9	3	8.8	5	3.6
Alistes lateralis	5	4.9	2	5.9	7	5.1
Labeo molybdinus	1	1.0	1	2.9	2	1.5
Hepsetus odoe	3	2.9	0	0.0	3	2.2
Petrocephalus catostoma	1	1.0	0	0.0	1	0.7

Stomach samples that we took as the flood water rose, January to May, contained more cichlids and Barbus and considerably fewer Schilbe than samples taken in September to December as the flood water receded.

Hepsetus odoe spawn at the end of their second year of life and rarely live more than three years. We found the maximum length of sexually mature males was 40 cm, females 46 cm. Minimum length of sexually mature females was 40 cm.

We estimated the number of eggs from 10 H. odoe females. The range was 4,659 to 10,457 eggs (Table 8). The average number was 8,246. There was no relationship between length of fish and number of eggs.

Table 8

NUMBER OF EGGS IN FEMALE H. ODOE OF SEVERAL LENGTHS

	Length in cm									
	40.2	40.3	40.5	41.1	41.5	41.9	42.6	43.0	45.8	45.9
Number of eggs	9353	3549	7059	8853	8875	7611	8251	10457	8260	9081

Clarias: Of the four species of Clarias found on the floodplain we captured two; Clarias gariepinus and C. ngamensis.

C. gariepinus and C. ngamensis first entered ephemeral streams to spawn in the first week of December after extremely heavy rains. We captured 99 individuals on their spawning migration on December 16. Of the 99 Clarias captured, 80 were C. gariepinus and 19 were C. ngamensis. This ratio of 4:1 was the same ratio in which the two species entered our gill nets. Spawning C. gariepinus ranged in size from 58 cm to 125 cm while C. ngamensis ranged between 44-64 cm.

We calculated the number of eggs from three C. gariepinus of different lengths. A 68.8 cm female contained 158,730 eggs; a 76.6 cm female, 307,638; and a 100.8 cm female, 435,565. C. ngamensis were smaller than C. gariepinus and therefore contained fewer eggs. From a sample of 10 female C. ngamensis we estimated the average number of eggs per female as 36,364. Size ranged between 40.5 and 45.9 cm with egg counts of 17,207 and 53,290 respectively.

Clarias spawning took place in shallow freshly-inundated ponds at the head of small rain fed rivulets. The fry emerged in about 4 days. After another 3 weeks in the ponds and rivulets the fry attained a size of 40-50 mm, absorbed their yolk sac, and then dispersed into the aquatic vegetation. From the time the 50 mm fry dispersed into the vegetation until they attained a size of 20-30 cm and entered our gill nets we were unable to capture them.

Clarias feed mainly on animal matter. Invertebrates form all or part of Clarias diet until the fish grow to 30 cm. The fry less than 50 mm long feed mainly on aquatic invertebrates such as Hemiptera and Ostracods. Traces of Coleoptera, Ephemeroptera, arachnids and oligachaetes were also found in stomach samples of fry. Seven C. gariepinus between 20-30 cm examined on November 28, 1969 contained only Diptera, Coleoptera and Mollusca. C. gariepinus larger than 30 cm feed almost entirely on fish. Fish species taken most by C. gariepinus were mainly (80% by number) in the cichlid family and Barbus genus. The largest cichlid we examined in a Clarias stomach was 15 cm long. Besides fish and aquatic insects we found large terrestrial insects, bones of birds and a small crocodile in stomachs of Clarias. In January 1970 we observed great numbers of copepods in stomachs of adult Clarias. Corbet (1960a) found similar food habits for C. mossambicus in Lake Victoria basin.

C. ngamensis consumed more invertebrates and less fish than C. gariepinus. About 50% of the food contained in stomachs of adult

C. ngamensis was insects. Of 23 C. ngamensis adults only four contained fish. The adults which fed on fish were larger than 48 cm. The largest of three cichlids found in adult C. ngamensis was 12.5 cm long.

Observation of Clarias fry in the marginal waters of the rising flood indicates that the accessory breathing apparatus, which enables the adults to live in deoxygenated water, does not develop until after the fry are 35-40 mm long. This important factor may limit fry numbers in dry years when marginal oxygenated waters are scarce.

Biology of Tilapia: Four species of Tilapia occur on the Kafue Flats: Tilapia andersoni, T. macrochir, T. melanopleura, and T. sparrmani. (The small related species Pelmatochromis rhuweti also occurs on the Flats and resembled the young of Tilapia.)

The Tilapia species often account for more than 60 percent by number of the commercial draw-net catch, and occasionally account for over 80 percent. Tilapia andersoni and T. macrochir comprise the majority of Tilapia in the draw-net catches. Although less abundant in gill-net catches, the Tilapia species often account for more than 15 percent, and at times over 60 percent by numbers.[2]

Our work with Tilapia included the examination of growth, especially the effect of variations in flooding level on growth. We verified the scale aging technique for Tilapia from the Kafue flats, and calculated mean growth values for each species. We found that the extent of flooding significantly affects growth. We briefly examined the survival of juveniles, food habits, and spawning data.

We limited our Tilapia work to T. andersoni, T. macrochir, and T. melanopleura.

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[2] Fisheries statistics (Natural Waters) 1968, Republic of Zambia Central Statistical Office, P. O. Box 1908, Lusaka, Zambia. Price 35n.

Age determination

Scales of T. andersoni, T. macrochir, and T. melanopleura show definite annular marks. These marks consist of a fairly obvious wide space between the usually closely-spaced circuli in the middle portion of the anterior field of the scale. In the lateral portions of the anterior field the annual marks consist of an overlapping of new circuli on old. We often had difficulty in identifying an annulus when the clear area in the anterior field was not well developed. We encountered annuli of this sort in the younger areas of scales of all three species, and had great difficulty in identifying the first annulus. To solve this problem we consulted length frequency, and body-length: scale-length relationships for the species in question. Since year-class 1 and year-class 2 are easily separated by size, we could determine if the first annulus found represented the end of the first or of the second year of growth. Annuli representing ages 2 through 5 were easily identified and separated but those representing ages 6 through 10 were harder to distinguish and were often close together. Annuli on scales of female T. melanopleura became crowded and difficult to identify after the second year of growth and could not be used in calculations. (Fig. 31 contains a photograph of a typical scale of T. andersoni.) Opercular bones also had marks but we did not examine them in detail.

In order to ~~prove that~~ the marks form annually, we examined scale samples collected each month for formation of a new annulus at the scale margin. We found that annulus formation occurs during October, November, December and January (Table 9).

Table 9

PROPORTION OF FISH HAVING AN ANNULUS NEAR THE MARGIN
NO ANNULI WERE NEAR THE MARGIN IN OTHER MONTHS

Tilapia andersoni (sexes combined)

Length range	October	November	December	January
0-22.9 cm	9/30	19/27	13/21	0/17
23.0-29.9	8/15	27/27	28/40	0/43
30.0+	8/39	20/43	7/23	9/37

Tilapia macrochir (sexes combined)

Length range	October	November	December	January
0-22.9	5/31	31/44	30/36	0
23.0-29.9	1/3	21/51	41/55	4/6
30.0+	0	0/3	2/4	1/3

Tilapia melanopleura (sexes combined)

Length range	October	November	December	January
0-22.9	20/38	22/25	6/13	0
23.0-29.9	2/19	8/17	2/5	0
30.0+	0/17	4/16	1/10	0

The time of annulus formation coincides with the onset of warmer weather. Although immature fish often show less distinct annuli, the occurrence of annuli on such fish rules out the possibility that spawning causes the marks. However, spawning may delay annulus formation in mature fish. Minimum water level and associated stresses also occur during the spawning period and may help cause annulus formation.

Length frequency distributions constructed from data collected during the low water period of 1969 (October through December) demonstrate the validity of the scale aging technique (Fig. 32). Even though we captured an adequate cross section of only the younger age groups for *T. andersoni* and *T. macrochir*, the data for both sexes of *T. andersoni* and for the female *T. macrochir* confirm the scale aging technique. We failed to capture sufficient numbers of *T. melanopleura* for length frequency work.

Calculated growth of *Tilapia*

In order to calculate the growth of *Tilapia* we calculated the body-length:scale-length relationship for both sexes of each species. The linear relationships are as follows:

L = body length   s = scale length (38 diameters magnification)

Tilapia andersoni

Males	$L = 2.0549\ s + 2.6073$
Females	$L = 1.8198\ s + 4.1736$

Tilapia macrochir

Males	$L = 1.7253\ s + 2.9032$
Females	$L = 1.6364\ s + 3.7391$

Tilapia melanopleura

Males	$L = 1.7289\ s + 1.2844$
Females	$L = 1.5637\ s + 2.5910$

Since DeBont (1966) found that the growth of *Tilapia* scales may not be concurrent with body growth, we used only data from fish collected during the period of annulus formation (October through December) to calculate the above relationships.

Since all the body length - scale length regression lines had correlation coefficients greater than R = .96, we used the linear relationship as the basis for growth calculations.

We found that the mean calculated growth of males was greater than that of female fish for *Tilapia andersoni* and *T. macrochir*. The difference becomes more evident as the fish get older and results in different maximum sizes in each sex of all three species (Figs. 33, 34, and 35). Male *T. andersoni* reach a maximum length of 45 cm, while female specimens rarely grow longer than 36 cm. Male *T. macrochir* grow to 33 cm, but females barely reach 30 cm. Similarly, *T. melanopleura* males often reach 40 cm while females rarely grow bigger than 36 cm.

All three species grow more slowly after the third or fourth year. After the sixth year, growth increments are very small and accordingly age groups 6 through 9 vary little in length.

We determined the growth of juvenile *T. andersoni* and *T. macrochir* during their first six months of life by collecting and measuring fish during each month from February through May. By February 10, 1970, *T. andersoni* had grown to a mean length of 5.85 cm. By May the mean length was 10.38 cm. We calculated the mean lengths of *T. macrochir* in February and May as 5.79 cm and 8.88 cm respectively (Figs. 36 and 37). Thus, by the middle of May both these species had completed about 75 percent of their growth in length for the first year.

The maximum size of *T. macrochir* is smaller in the Kafue than elsewhere. Of 44 *T. macrochir* captured in multimesh gill nets, Kelley (1968) found 14 larger than 33 cm and two larger than 40 cm. In the Kafue we captured no *T. macrochir* larger than 33 cm. Kelley also found 9 of 86 *T. andersoni* larger than 45 cm while on the Kafue we rarely found *T. andersoni* larger than 45 cm. The difference in size of *T. andersoni* may have resulted from our irregular use of 7-inch (17.8 cm) gill nets. Since older *T. andersoni* and *T. macrochir* in the Kafue River grow little, a shorter life span caused by overfishing is not the cause of the smaller size fish in the Kafue.

Variation of growth with flood size

Since *Tilapia* in the Kafue spawn and form annuli during the onset of the warm rainy season, the period of growth calculated from the scales corresponds exactly to the seasonal flooding cycle. The scales contain a record of growing conditions during past cycles, and we examined calculated growth increments to find if any flood produced significantly better *Tilapia* growth than the others. To do this we wrote a computer program which we designed as follows:

Scale measurements, read from decks of data cards for each species, are converted into body growth increments. These are stored in an array indexed by calendar year of growth, age during that year, and sex. The data for each age group, for example all 3-year olds, is then retrieved and analyzed as a simple analysis of variance with unequal sample sizes. The analysis compares the growth made by 3-year old fish in various years. The program calculated and printed an analysis of variance for 39 sets of data. Each set contained information concerning one age for one sex of one species.

Most of the analyses of variance had high F values which indicated that significant differences in growth existed from year to year.

By using a stepwise multiple regression technique to analyze data for male *T. andersoni*, we found that variation in flood size accounted for a large portion of the yearly growth variation. A straight-line equation, using flood size as the only factor, accounted for about 85 percent of the yearly growth variation in one-year-old male T. andersoni (Fig. 38). For this regression we used water level data collected by the Government of Zambia hydrology department at the Kasaka gauging station. We used the area under the plot of water depth over 16 feet on the first of each month as an index of flood size. Other factors tested for their effect on the variation in calculated growth included: yield of the commercial fishery which is a measure of fish abundance, area under 18.3 C (65 F) on the air temperature-versus-time chart from the Kafue polder meteorological station which indicated the severity of the cold season, and calendar year. By using calendar year as a factor we accounted for variation in growth caused by Lee's phenomenon.

No single factor accounted for a large part of the variation in growth of two-year-old male T. andersoni. In three-year-old fish the year accounted for about 64 percent of the variation, but water level could account for about 65 percent of the remaining variation as could temperature. Since we had even less data for older fish we did not try to assign causes to their yearly growth variation.

The one-year-old fish of male (described above) and female T. andersoni (Fig. 39) both grew better during years of high water. One-year-old males of both T. macrochir and T. melanopleura also grew better during years of high flood (Figs. 40 and 41). Female T. macrochir did not exhibit such a pattern and we could not read the scales of female T. melanopleura well enough to get growth data from past years (Fig. 42).

The flood size in past years has significantly affected the growth of one-year-old Tilapia. Not only did fish from high flood years grow faster; they also undoubtedly grew under conditions that were better for survival.

Effect of water level on survival of Tilapia

The better growing conditions that exist during high flood years, as indicated by better growth of one-year-olds, appear to enhance the survival of juveniles as well. Seine net collections made along shore during June and July of 1969 and 1970 show great differences in the relative abundance of 0+ and 1+ age T. andersoni and T. macrochir. In early July 1969, a high water year, we collected approximately 50 age 0+ T. andersoni and 110 age 0+ T. macrochir while capturing a total of about 30 older fish of each species. On the other hand, in 1970 we had great difficulty finding age 0+ fish and a seine net collection in late June yielded only 11 age 0+ T. andersoni to 45 older fish of the same species. In the same net we captured 346 older T. macrochir (mostly age 1+), but caught only a few age 0+ fish.

Changes in the commercial catch of T. andersoni reflect an abundance of older fish in 1968 compared to 1969 (Fig. 43). (Source of data for this figure was G. V. Everett, Mansangu Fisheries Station, Zambia). The fish greater than 37 cm are males about 6 to 8 years old. Fish aged 6 and 7 survived their first year on the high floods of 1962 and 1963. Apparently they survived better than the succeeding year classes since the mode at 39 cm disappeared in the 1969 catch.

Spawning of Tilapia

In both T. andersoni and T. macrochir the female carries the eggs and young in the mouth. T. melanopleura spawn in a nest built on the bottom. All three species spawn primarily during October, November and December, and in January to a small extent.

In the Kafue T. andersoni rarely spawns at less than three and usually not under four years of age.

Of 53 male and 73 female T. andersoni under 26 cm that we examined during these months, we found none that were in spawning condition (condition 4, 5, or 6). We found only 1 of 32 males and 2 of 10 females in the 26 to 29 cm size range that were in spawning condition, while we found that approximately 50 percent of fish over 30 cm of both sexes were in spawning condition. No fish examined after January had gonads in spawning condition.

In ponds Mortimer (1959) found female T. andersoni could spawn at sizes as small as 16 cm. However, he concluded that sexual maturity was determined by age and other factors rather than by size. He also concluded that T. andersoni in ponds would breed at a smaller size than in natural waters. We do not know what factors determine sexual maturity for T. andersoni in the Kafue.

We examined fewer T. macrochir and T. melanopleura but found that they both start spawning at the end of their second and possibly their first year.

Food habits of Tilapia

Although we did not collect stomach samples of adult Tilapia regularly, we gained a general knowledge of their food habits.

T. melanopleura of all adult sizes fed on vascular aquatic plants, mostly the submerged types.

We had greater difficulty in identifying the stomach contents of T. andersoni and T. macrochir. Both contained large amounts of diatoms and detritus. Both species also contained many small inorganic particles although T. macrochir contained less of these. Mortimer (1959) found similar particles and had other evidence to show that T. andersoni is a bottom feeder. The large number of diatoms supports this hypothesis. Some large specimens of both species contained about 80 percent filamentous algae while the smaller ones had more detritus. Monthly stomach samples revealed that the juveniles had feeding habits similar to the adults. Stomachs of even very small specimens (2-3 cm long) contained mostly diatoms although they usually had more animal matter than the adults.

4.5 Dissolved oxygen tolerance of selected fish species

Tilapia andersoni: We tested the oxygen tolerance of Tilapia andersoni in three separate experiments. All but one T. andersoni survived until the oxygen concentration dropped below 1.0 ppm. One T. andersoni died at an oxygen concentration of 2.0 ppm but probably for reasons not associated with oxygen level since all 11 other fish survived until oxygen levels were below 0.60 ppm (Fig. 44). We concluded that under test conditions T. andersoni can survive until oxygen concentrations reach 0.60 to 0.40 ppm.

Observations of test fish revealed that T. andersoni showed definite signs of stress in oxygen concentrations below 1.0 ppm. At such concentrations T. andersoni actively tried to reach the surface of the test water and in a few cases pushed through the sub-surface screen and jumped out of the aquarium. Oxygen consumption of T. andersoni decreased slightly with decreasing oxygen concentrations.

Tilapia macrochir, T. melanopleura, and T. sparrmani: These three species of Tilapia exhibited a tolerance to low oxygen similar to T. andersoni. All three species showed stress at concentrations below 0.80 ppm, but could tolerate concentrations as low as 0.36 ppm for T. macrochir, 0.25 ppm for T. melanopleura, and 0.32 ppm for T. sparrmani (Figs. 45, 46 and 47). The oxygen consumption of these three species of Tilapia decreased slightly with decreased oxygen concentrations. The oxygen consumption of T. melanopleura and T. sparrmani rose slightly as the oxygen concentrations dropped below 4.0 ppm and then dropped again when concentrations went below 2.0 ppm. This slight peak on oxygen consumption occurred at approximately 1200 hours and may not be related to oxygen concentrations. The temperature at 1200 hours was 22 C while four hours earlier it was 20 C. This temperature rise could have caused higher oxygen consumption.

Haplochromis codringtoni: This species of Haplochromis breathed more slowly and exhibited a distinct lack of activity by the time the oxygen concentration had dropped to 1.2 ppm (55.75 hours after the experiment started). When the oxygen concentration was 0.72 ppm (at 69 hours) we found all three fish swimming near the water surface. All fish died before oxygen concentration reached 0.40 ppm (Fig. 48).

Data on oxygen consumption for H. codringtoni show a slight drop as oxygen concentrations drop. These data also show unmistakable peaks at about 1200 hours each day. A change in temperature from 21 C at night to 22 C at 1200 hours may have caused the oxygen consumption peaks. Although the fish were tested indoors the natural lighting conditions could also have affected oxygen consumption patterns.

Schilbe mystus: S. mystus swam near the surface and tried to get through the subsurface screen without regard to light or shadow when the oxygen concentration dropped below 1.0 ppm. Control fish at oxygen concentrations of 7.0 ppm remained in shaded portions of the tank but often swam near the surface. Control fish never showed the gulping pattern of breathing exhibited by the test fish at low oxygen levels. All S. mystus survived until oxygen concentrations dropped below 0.5 ppm (Fig. 49).

Oxygen consumption slowly decreased as oxygen concentrations decreased to about 1.0 ppm. Below 1.0 ppm oxygen consumption decreased sharply. The oxygen consumption value for one aquarium (mean fish weight - 7.6 g) was lower for a given oxygen concentration than that in the other aquarium which contained smaller fish (mean weight = 5.6g). Apparently smaller S. mystus had higher oxygen consumption rates.

Gnathonemus macrolepidotus: In testing G. macrolepidotus we used two groups of test fish and one group as a control. All G. macrolepidotus survived until the oxygen concentrations dropped below 0.5 ppm (Fig. 50), but breathed faster at oxygen concentrations below 1.5 ppm. All test fish except one died within 45 minutes of the time the oxygen concentration dropped below 0.5 ppm. No control fish died at oxygen concentrations between 7.5 and 8.2 ppm.

As oxygen concentration dropped, oxygen consumption of *G. macrolepidotus* first rose and then dropped. The experiment did not last long enough to show any definite patterns of oxygen consumption.

4.6 Plant Drying Studies

After 33 days drying in the open *Vossia cuspidata*, *Echinochloa stagnina*, and *Leersia hexandra* would all burn in an open flame (Table 10). When water content reached 5 to 8%, the three grasses burned. However, *V. cuspidata* stems did not ignite readily even after 42 days. We conducted drying tests in June and July, the coolest months of the year. Air temperature fluctuated between 15-25 C. In a reservoir situation with a draw-down in August and September, temperatures would be higher and drying time shortened. In conclusion we recommend a 5-week drying period to allow some extra time for Kafue grasses to dehydrate in order that they may be burned.

Table 10

RATE OF DRYING OF THREE SPECIES OF KAFUE GRASSES EXPOSED TO NATURAL DRYING, 1970. RATE OF DRYING EXPRESSED AS PERCENTAGE OF WATER CONTENT AND EASE OF BURNING

Date	Grass Species		
	Vossia cuspidata	Echinochloa stagnina	Leersia hexandra
June 11 (Day 1)	69.8 would not burn	46.9 would not burn	76.3 would not burn
June 24 (Day 14)	30.7 would not burn	11.8 edges and small leaves partially burn	20.1 would partially burn
July 2 (Day 22)	8.7 would not burn	6.9 would partially burn	6.8 would burn
July 13 (Day 33)	6.5 would burn, stems difficult to ignite	5.4 would burn	8.1 would burn
July 22	5.5 would burn, stems difficult to ignite	6.9 would burn easily	7.5 would burn easily

5. DISCUSSION

Rising water in the Kafue River, coupled with the beginning of the rainy season, causes the river to breach its banks and flow up tributaries onto the floodplain. The extension of aquatic habitat, the change in limnological characteristics of the river, and the spawning urge stimulate fish in the river to move onto the floodplain. The floodplain fringe zone provides a breeding and nursery area for many of the Kafue River fishes.

Of all the limnological variables we checked, oxygen and conductivity related closest with fish catches in gill nets. As the flood rose in December and January the floodplain margin or fringe zone was the only area where we found high levels of D.O. During this period it was also the area of highest catches of fish. Not only were well-oxygenated waters along the water margins preferred by the adults during December and January but such areas are probably necessary for survival of the young. We collected fry of cichlids as well as <u>Clarias</u> along the floodplain margin. Presence of <u>Clarias</u> fry in the highly oxygenated marginal water suggests that the accessory breathing apparatus does not function in the small <u>Clarias</u> and they need highly-oxygenated water. The adult <u>Clarias</u>, however, were dispersed over all the floodplain after the fish spawned in November.

All fish must live in the river channel and isolated lagoons at low water each year. Dissolved oxygen remains moderate to high (above 3 ppm) at this time. As the flood begins, organic matter flushes into both lagoon and riverine sections. Dissolved oxygen drops drastically in these river and lagoon waters when a water connection to the floodplain develops and poorly oxygenated water drains from the floodplain. Fish then leave their riverine and lagoon confines to enter desirable habitats near floodplain margins for breeding and feeding.

Tait (1965b) stated that the oxygen levels he found in the Kafue River varied mainly between 2 and 8 mg/1 (mg/1 = ppm). But he noted a drop in oxygen values at peak flood in two areas to 0.5 and 0.79 mg/1. He attributed this drop in oxygen at peak flood to lagoon water, which moved into the river water. Our dissolved oxygen data showed that lowest oxygen levels occurred as the flood waters rose. The drop in D.O. which occurred in Chulwe Lagoon resulted as river water moved through the vegetation into the lagoon; not the reverse as stated by Tait. Overall our D.O. readings were lower than those found by Tait (1965a).

The severe drop in D.O. in January related to the rising flood water and heavy rainfall in December. The rising water covered dead plant and organic material, establishing a large oxygen debt in the water. Thus the biological oxygen demand (B.O.D.) was quite high during January.

Fish kills we observed in Chulwe Lagoon and Luwato Lagoon coincided with low D.O. levels. In Chulwe Lagoon it probably was not the absolute low oxygen that caused the fish mortality but rather the severe drop from 7.2 to 0.5 ppm in such a short period of time. In the fish kill at Luwato Lagoon dissolved oxygen levels of less than

0.5 ppm occurred in the open lagoon while next to vegetation we found readings of less than 1.0 ppm. Since we observed oxygen readings in Luwato Lagoon at midday the low over 24 hours would be less. On occasions when we observed fish kills there was also the smell of hydrogen sulfide in the areas near by. Thus, low oxygen may have been accompanied by toxic chemicals in the water.

Tait (1965b) observed one fish kill in the Nampongwe Lagoon area of the flats during July, a relatively cold month. Dissolved oxygen values were not extremely low (upper Nampongwe Lagoon, 0.9 ppm; lower, 8.2 ppm). However, temperatures recorded by Tait were quite low, reaching 13 C in the upper Nampongwe. This was 4 C colder than the lowest temperatures we recorded. Also, Tait must have recorded his data at midday when daily water temperatures were highest. Therefore, minimum water temperature was probably 1 to 2 C lower than the 13 C he found. At temperatures at or near 10 C and accompanying low oxygen, fish would probably die. Actual oxygen available to fish at 10 C and 0.9 ppm D.O. would be much less than at 15 C and 0.9 ppm D.O.

The fish species tested showed stress at oxygen concentrations below 1.0 ppm but could survive until oxygen concentrations dropped below 0.5 ppm. Dusart (1963) reported similar results for *Tilapia macrochir* and *T. melanopleura* from the Mwadingush barrage in the Congo.

Oxygen consumption of all fish except *G. macrolepidotus* decreased slightly with decreasing oxygen concentrations while activity increased slightly. Ahmed and Magid (1969) reported a similar drop in oxygen consumption for *Tilapia nilotica* (L). They also found that irrespective of fish activity, oxygen consumption remained low at low oxygen concentrations.

The species tested cannot tolerate oxygen concentrations below 0.5 ppm. Oxygen concentrations on the Kafue Flats sometimes drop below 0.5 ppm and can cause fish mortalities.

All fish species examined in December, 1969 and January, 1970, were either preparing to spawn or had recently spawned. This spawning seems to be timed to the flood, and allows young fish to rear in a highly productive area with an abundance of food and cover. In our analysis of male *T. andersoni* we found that growth of fish correlated with extent and length of time of flooding (R = 0.92). Size of flood accounted for 85% of the variation in growth of one-year-old male *T. andersoni*.

Conductivity related positively to catches of fish. Conductivity decreased as the flood water rose due to dilution of dissolved salts and other organic substances. Also conductivity was less at the Chunga station near the floodplain margin. This was probably because growing plants removed nutrients and salts from the water. Although we show a relationship between catch and conductivity, indirectly we are demonstrating a relation between catch and flood cycle of depth. The conductivity range we recorded (90-330 μohm/cm) was not abnormal and supports the information of Tait (1965a) who found a conductivity range for the Kafue River between 135 and 350 μohm/cm.

Dissolved oxygen was not an important factor in determing distribution and catch of *T. andersoni*. Catch of *T. andersoni* correlated with sampling period of time. This suggests that from June, 1969 until May,1970, *T. andersoni* catches progressively increased. The increase in catch with time was the result of high production in the 1969 year class. This increased production was due to an extended and extremely high flood during 1969.

Catches of T. melanopleura correlated with D.O. This relationship exists because of the close association of T. melanopleura to food provided by growing vegetation. New and growing aquatic plants exchange gases with the surrounding water and on balance add oxygen to the water mass.

6. PREDICTION OF EFFECTS OF WATER REGULATION

6.1 Kafue Gorge Dam

The top of the Kafue Gorge Dam (Fig. 51) is at 3220 feet (981.5 m) above mean sea level and the top and bottom of the spillway lie at 3212 ? and 3175 feet (979.0 and 967.7 m) respectively. The bottom of the head-race lies at 3170 (966.2 m), and power generation is possible at water heights above that elevation. the Headrace at 3170 (966.2 m) could drain the Kafue Flats completely to the elevation of the base of the road bridge near Kafue Township.

One thousand cubic feet per second (28.3 m^3/sec) will be needed for each of four generators. The first generator will begin furnishing electricity in June, 1971, and three more will come on line at three-month intervals. Engineers will draw the water level down to inspect each generator once each year for three to five years after the generator becomes operative.

Government policy states that the operators of the dam must do everything possible to keep the level of the reservoir at 3204 feet (976.6 m) as long as possible each year to generate power efficiently. When they draw down the water to inspect the generators, the pool will drop to 3170 feet (966.2 m) and remain there for about one month. After the dam closes in October of 1970 or later, the river will rise on the floodplain more rapidly than at present, remain higher longer, and drop to minimum level more quickly than at present.

The "live" storage capacity of Kafue Gorge Dam will be 600,000 acre feet (740,000,000 cu m), or about 200,000 surface acres (81,000 surface hectares). In 1963, when a record high natural flood occurred, about 1,360,000 acres (550,375 hectares) flooded. Hence the storage area above the dam will occupy about one-sixth or 14% of the area covered by the highest flood on record.

Itezhitezhi (formerly Meshi-Teshi) Dam, if built in 1976 or later as anticipated, will make it possible for the government to stabilize or regulate flooding on the Kafue Flats. Before completing Itezhitezhi, the government has only modest latitude in controlling the hydrologic regime.

6.2 Limnology

At Namwala the Kafue Gorge Dam will affect the flooding regime little or not at all. At Nyimba the regime will become one of extended high water with much shorter dry periods. At downstream points the high water will remain high longer and the dry periods will become even shorter.

In years of high rainfall the flood water should rise relatively earlier at all points and remain high longer. At Nyimba and downstream in years of high rainfall the flood will crest above 3204 feet (976.6 m) and remain higher longer at Nyimba than at Kafue Rail Bridge.

In the first five years after the dam closes flood water will remain high longer, drop more quickly, remain low more briefly, and rise more quickly, except in the more upstream part of the floodplain (Fig. 52). Above Nyimba we expect little effect of water control on the hydrologic regime.

After the first 5 years, in the middle and lower parts of the floodplain the flood water will remain high longer, drop quickly to a low water level higher than at present, then rise quickly after a brief period of "low" water to flooded level again. At Namwala we expect only slight changes in the flood regime.

If, after dam closure, the river is drawn down within its banks and the exposed flats are burned, the only marked ecological change will be a delay in the arrival of low water coupled with a faster rise in the water level following low water. This effect may cause dissolved oxygen to reach its lowest point during November and December rather than January and February. Water transparency will also reach a low point slightly earlier. Conductivity, which is more or less dependent upon the rainfall and flood cycle, will most likely not be affected. Temperature patterns will probably change only slightly. The water may become slightly cooler during the colder part of the year as increased areas are exposed to cool air.

The faster rise of the water level may affect dissolved oxygen of the floodplain water and thus indirectly the fish. With rapidly rising water we can expect a downward crash in dissolved oxygen as occurred in 1969-70. If water level comes up rapidly, B.O.D. will be high, and we can expect dissolved oxygen to drop below 1 ppm, accompanied by local fish kills. These kills will occur more frequently after the dam closes if the flats do not have sufficient time to dry in low-water periods.

The limnology of impounded year-round open water areas will be similar to the conditions we found in Chulwe Lagoon. That is, oxygen levels will remain higher before flooding. In the areas removed some distance from the main river, such as Chunga in the Nampongwe area, there may not be a rapid decline in dissolved oxygen after flooding. We believe this would be a result of a lower B.O.D. debt in lily pad areas.

6.3 Vegetation

Although the Kafue River below Kafue Gorge Dam was not a concern of our study, we feel intuitively that manipulations of the reservoir should be constrained by a need to maintain some minimum flow downriver, to protect ecological systems there.

We believe that delayed decline in water level on the floodplain and an accelerated rise in water level could leave grasses and other vegetation in integrated form. The grasses may remain too wet for burning and be exposed for so short a time that livestock or wildlife will not have time to consume the material. In one plant-drying experiment we demonstrated that approximately 5 weeks were needed to dry three selected grass species. Therefore if managers use burning to remove dead plant material 5 weeks of drying will be required. If plant material is not burned or consumed the B.O.D. after water first covers the floodplain could cause extensive fish kills.

Shortened dry periods may be insufficient for grass species to germinate and may change species succession. The 1969 and 1970 floods differed strikingly in vegetative species composition and quantity. In 1969, after the floodplain had dried thoroughly in 1968, grasses grew almost everywhere and the *Nymphaea-Aeschynomene* complex covered areas not in grasses. In 1970, the lower flood followed a year in which much of the plain never dried out. Grasses were absent from vast areas of the plain; *Nymphaea* was scarce; and floating mats of sudd shifted about on the water. *Aeschynomene* grew where *Nymphaea* and *Aeschynomene* had been the year before. Larger areas of open water prevailed over a great portion of the flood area.

Thus we contend that drying is important for grass production, and that since grasses seem to offer preferred habitat for commercially important fish species, and also related wildlife, the hydrologic regime and land practices should consider grass conservation.

In the controlled hydrologic regime bacteria will decompose more of the plant biomass left after foreshortened dry periods. The resultant consumption of oxygen could conceivably deteriorate the environment for fish.

On Figure 53 we depict generalized vegetational patterns at Nyimba under several hydrologic regimes. Between the mouth of Nampongwe and Itezhitezhi, less shift to aquatic plants will occur. Downstream from the Nampongwe, e.g. at Blue Lagoon and Luwato Lagoon, relatively more shift to aquatics will occur. More land will be underwater in all anticipated regulation schemes. In all water levels but a permanent one at 3204 feet (976.6 m) the flats in the upper Kafue will be relatively little affected by the Kafue Gorge Dam.

6.4 Wildlife

Certain effects on wildlife as a result of altered flooding regimes can be foreseen. As the mean low water line moves higher, lechwe and hippopotamus will have access to less total land area. Waterfowl and shore birds will use less of the Flats. Fish-eating birds will find fish slightly less accessible.

In the evolutionary time scale, ecological interactions on the floodplain before man interfered probably included consumption of aquatic vegetation by wildlife. Occasional lightning-caused fires may have burned just prior to the rainy season. Gradually wildlife have assumed less importance as herbivores around the water margin (except on Blue Lagoon and Lochinvar). Livestock and fire have taken the place of wildlife as consumers and converters of biomass of vascular aquatic and pseudo-aquatic plants.

Whatever the agent of consumption of exposed organic matter on the floodplain, the net effect is a release of nutrients available for re-incorporation. Lechwe, hippopotamus, and some birds have special importance at the floodplain margin because they consume vascular aquatic plants, which few fish consume, and release nutrients for periphyton production or provide detritus that fish can consume. We cannot prove this relationship, but consider it as a real ecological interaction. Unfortunately a sampling program designed to test the effect of nutrient release was not completed by a cooperator who moved to another job in 1969.

Management of the water regime for benefit of the lechwe which are dependent upon pseudo-aquatic grasses will also benefit fish. Cover and food provided by grasses are important for good fish habitat.

6.5 Fisheries

Extension of the flooded period should benefit growth of fish, as we noted earlier, provided cover and food do not decline in quality or quantity. The correlation between yield of fish in the Kafue fishery in each year and the area beneath the plot of water depth the previous year at Kafue Rail Bridge (Fig. 54) is significant (r = 0.72, significant regression at .01 probability level). The area beneath the plot of water depth provides an index to the duration of the flood and areas covered by water. Fish yield in each year plotted atainst extend of flood years previous (Fig. 55) also correlated significantly (r = 0.56, significant regression at .01 probability level). We conclude that a combination of high and long flooding increases fish yield in the subsequent year and two years. Of course other variables may be involved.

The research team from the University of Michigan (1970) found that by far the greatest amount of fish biomass was in the vegetation areas of open lagoons. In open water of lagoons they estimated a mean ichthyomass of 335 kg/ha, in lagoon true aquatic vegetation 2662 kg/ha. From this we can predict that with more permanent flooded areas, more true aquatic vegetation will grow, and consequently more fish biomass could develop.

That part of the Kafue flats reservoir which will be continually inundated will be similar to Chulwe Lagoon. The species which do best in the Chulwe habitat should do best in the reservoir. Many species prefer habitats at the floodplain margin over open water lagoons. Most fish seem to prefer areas where nutrients are recycled annually, where surface cover is available, and where dissolved oxygen remains high. For this type of habitat to be present in the Kafue Flats reservoir, there must be an annual draw down of the marginal water. The water must remain down long enough for the exposed aquatic vegetation to decompose and for the seeds to germinate.

We also plotted fish yield on the Kafue River in each year against yield one year earlier and against mean yield over the preceding two years. This relationship crudely examines the idea that heavy cropping in one or two recent years would reduce subsequent yield. In the data in Figure 56 we found no relationship between catches and subsequent yields.

7. RECOMMENDATIONS FOR MAXIMIZING FISH PRODUCTION

The research team from the University of Michigan will assess fish stock biomass and both natural and fishing mortality rates. Their preliminary report (1970) projected that the Kafue River fishery, especially the open lagoon areas, was grossly underfished. They also will extend and improve our assessment of vegetation patterns on the floodplain, and extend biological knowledge on *Serranochromis sp.*, *Schilbe mystus*, and *Gnathonemus macrolepidoptus*. Obviously the Michigan group will modify and extend recommendations after they have all their research results. At this point we propose some recommendations for maximizing fish production. They will form a basis for argument.

First, we suggest that the water regime permit at least 5 weeks of drying on as much of the floodplain as possible. In those areas of the Flats which do not receive heavy grazing by cattle or wildlife, we propose burning to reduce B.O.D. in the next flooded cycle.

The reservoir should be allowed to rise shortly after burning to minimize nutrient losses due to wind erosion. The water should not surge onto the floodplain. We have observed that low lying areas on the floodplain have no immergent aquatic grasses. We believe this phenomenon results from quick flooding such that the water rises too fast for growth of aquatic grasses to keep pace.

Second, we propose that Scudder's scheme[3/] to expand and develop mounds for fishing villages on the floodplain be adopted. We believe distribution of fishermen could be improved, and that most Kafue fisheries are underharvested, at least in the central floodplain. Further, gill net

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3/ Scudder, T. 1970. The Kafue Dam and the lake basin fishery -- a tentative development program. Draft of report to FAO, May, 1970. 8 pp typed.

fisheries must take the place of seine fisheries in the lower floodplain, and distribution of fishermen will influence gill netting effort. Williams (1969) tagging data suggest a fishing mortality rate of less than 10% and probably less than 5%. Together with our data on (1) age structure of Tilapia andersoni, (2) the absence of correlation between fishing and subsequent yields, (3) positive correlation between extent of floods and subsequent fishery yields, and (4) the absence of several harvestable species in presently-used gill nets - - the picture is one of underharvest. Scudder's mounds offer a means of expanding the fishery.

Third, we recommend that Lochinvar Ranch and Blue Lagoon be opened to fishing. Harvestable stocks there are available.

Fourth, we recommend that mesh restrictions on gill nets be re-evaluated. Several fish species are now not harvested, and our data show that small-mesh nets will harvest few young Tilapia.

Fifth, we recommend that research on ecological and stock assessment be continued on the Kafue Flats. We think a good start has been made and that we and the Michigan group are moving rapidly toward adequate knowledge on which to base management of the Kafue Fishery when harvests eventually approach maximum sustained yield.

Lastly -- we predict an outstandingly successful fishery on the Kafue River in 1970. Draw nets should reap a record harvest in low water this year. We base this opinion on the extent and height of the flood of 1969 and the relatively abundant habitat available in late 1969.

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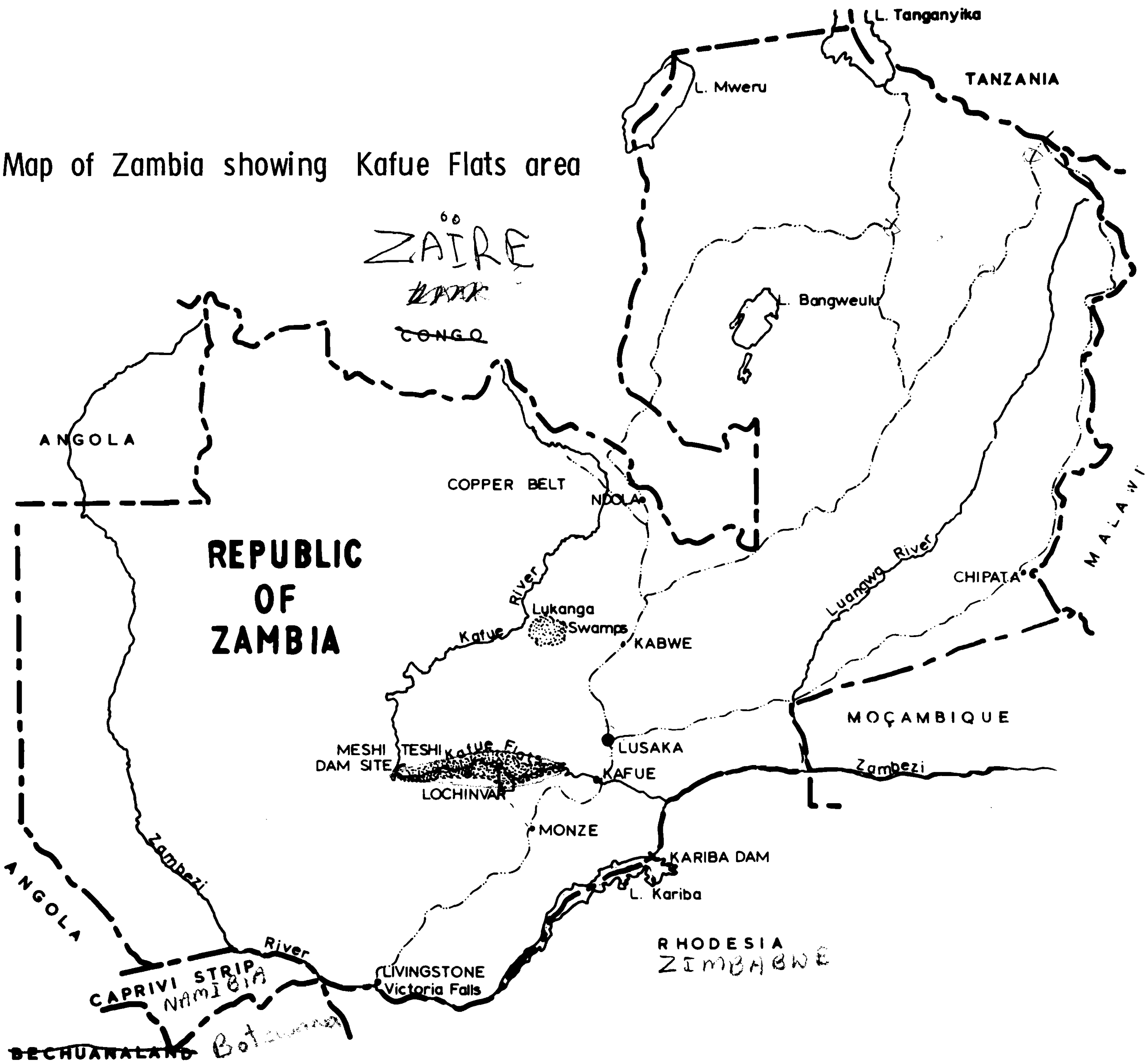
Figure I. Map of Zambia showing Kafue Flats area



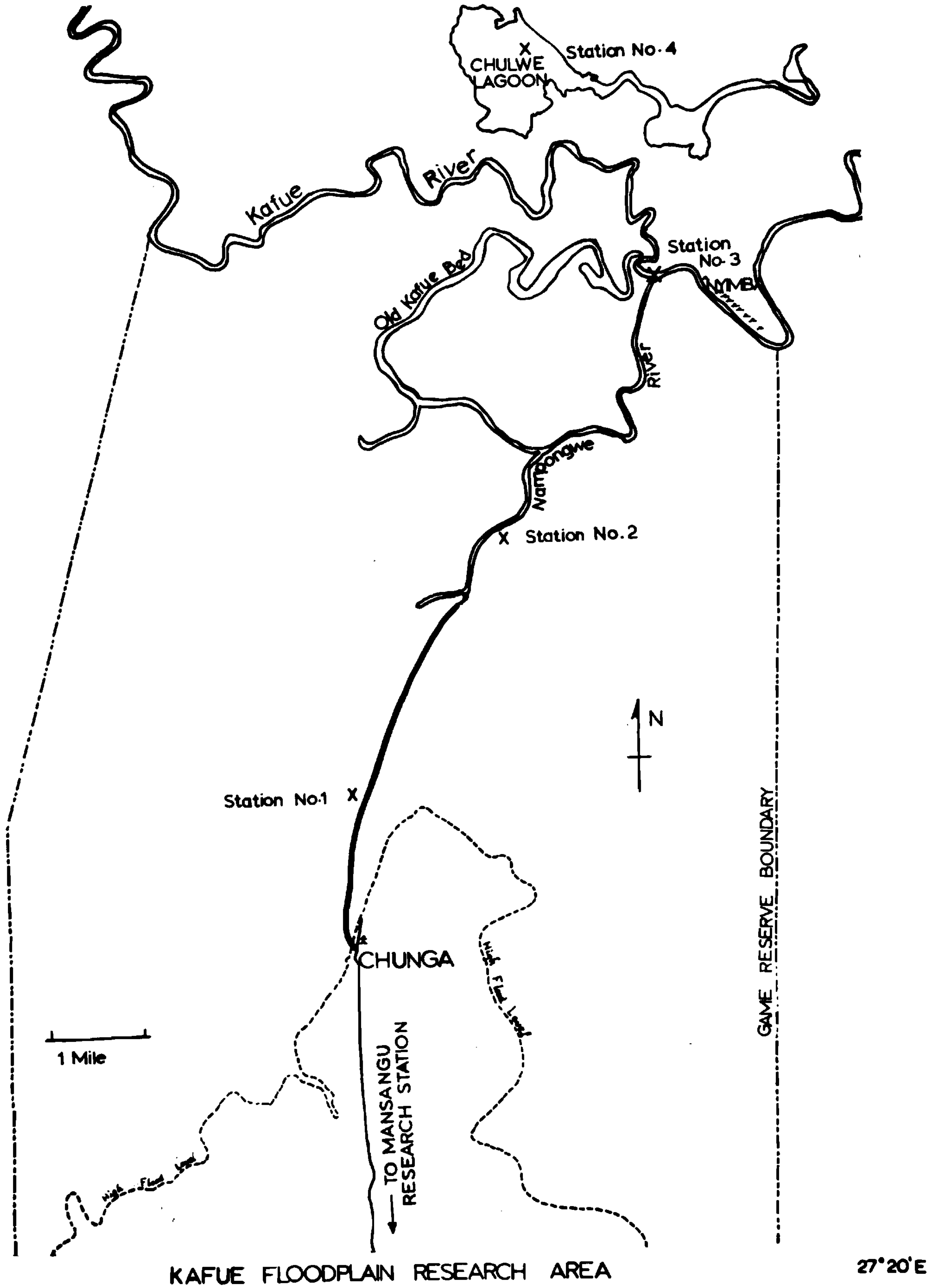


Figure 2. Location of four ecological sampling stations on Central Kafue floodplain.

Figure 3. Water level in Nampongwe Lagoon and rainfall, 1969-70. Rainfall plotted at 2-day intervals.

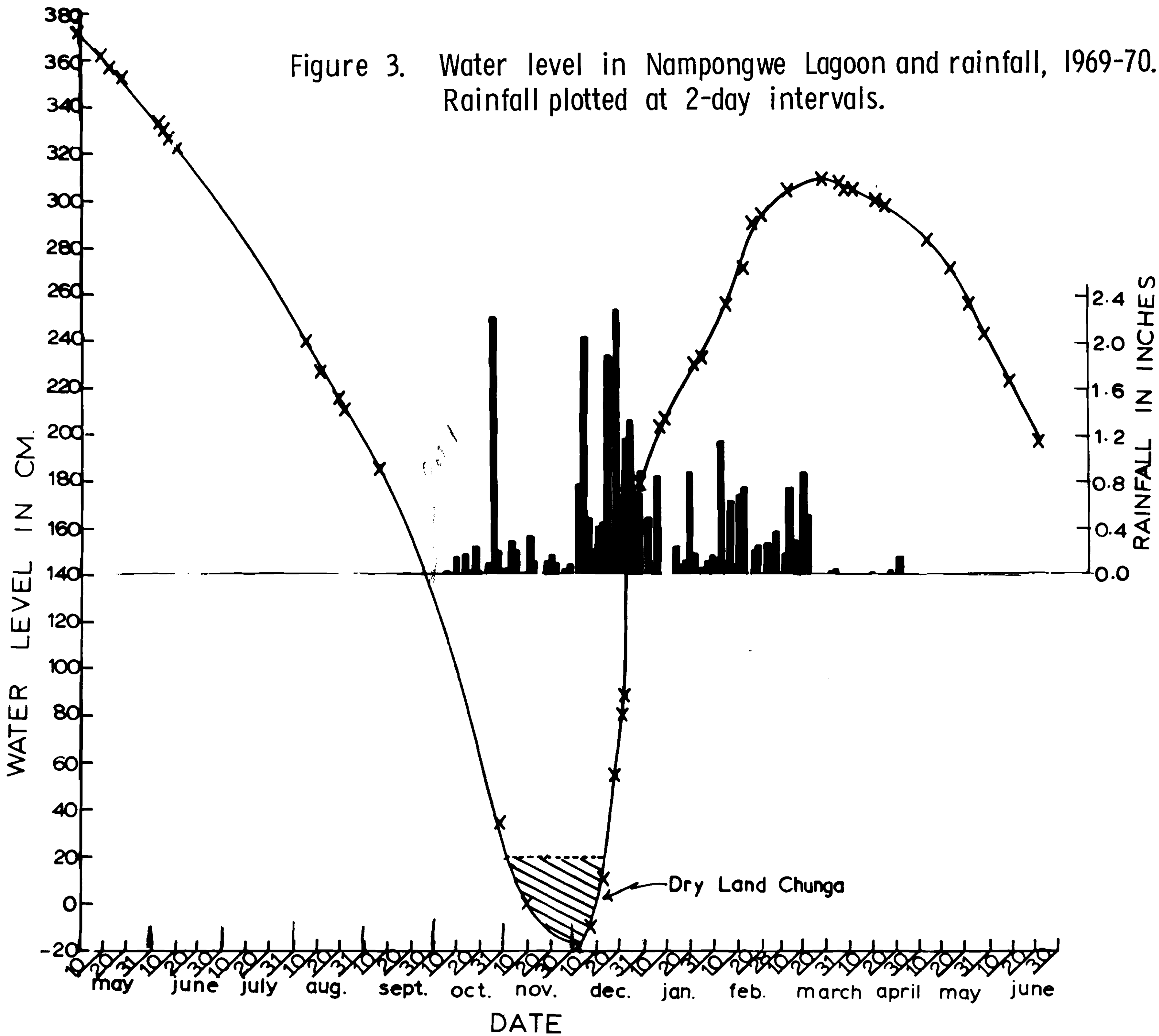


Figure 4. Water transparency at four sampling sites using 30 cm secchi disc, Kafue River floodplain, 1969-70.

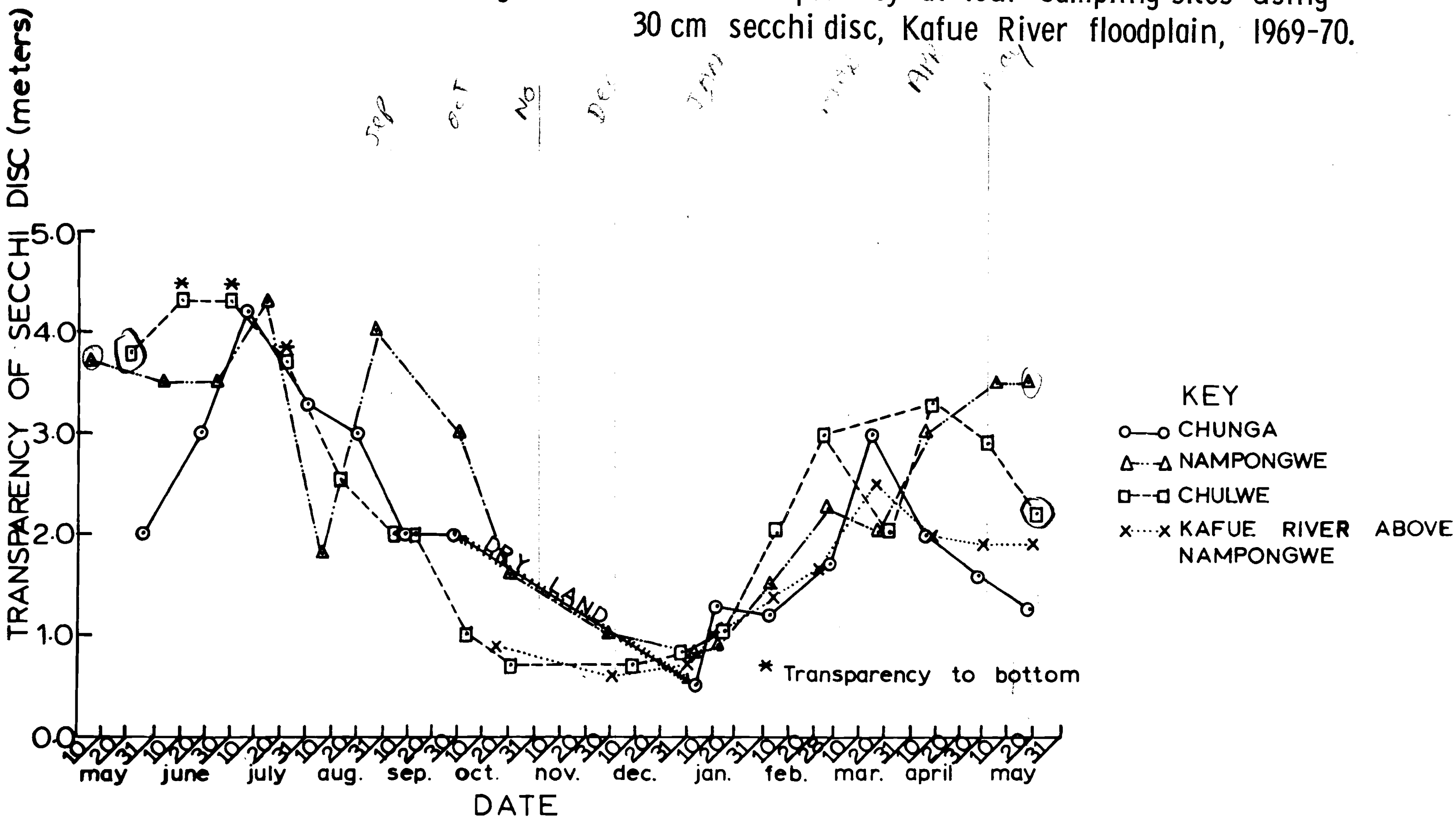


Figure 5. Conductivity at four sampling sites, Kafue River floodplain, 1969-70.

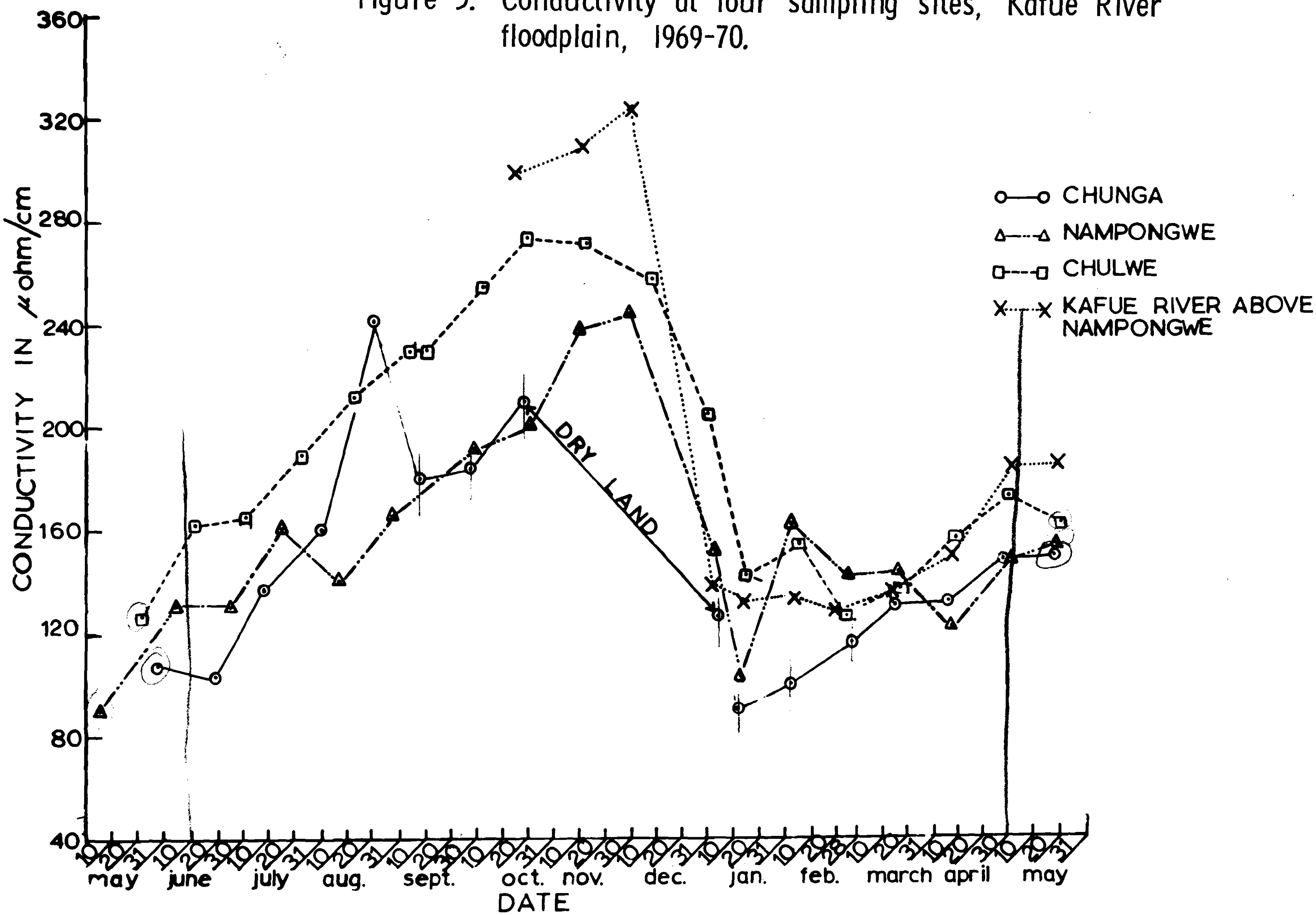


Figure 6. Average temperature of water column over 24 hours, four open water sampling areas, Kafue River floodplain, 1969-70.

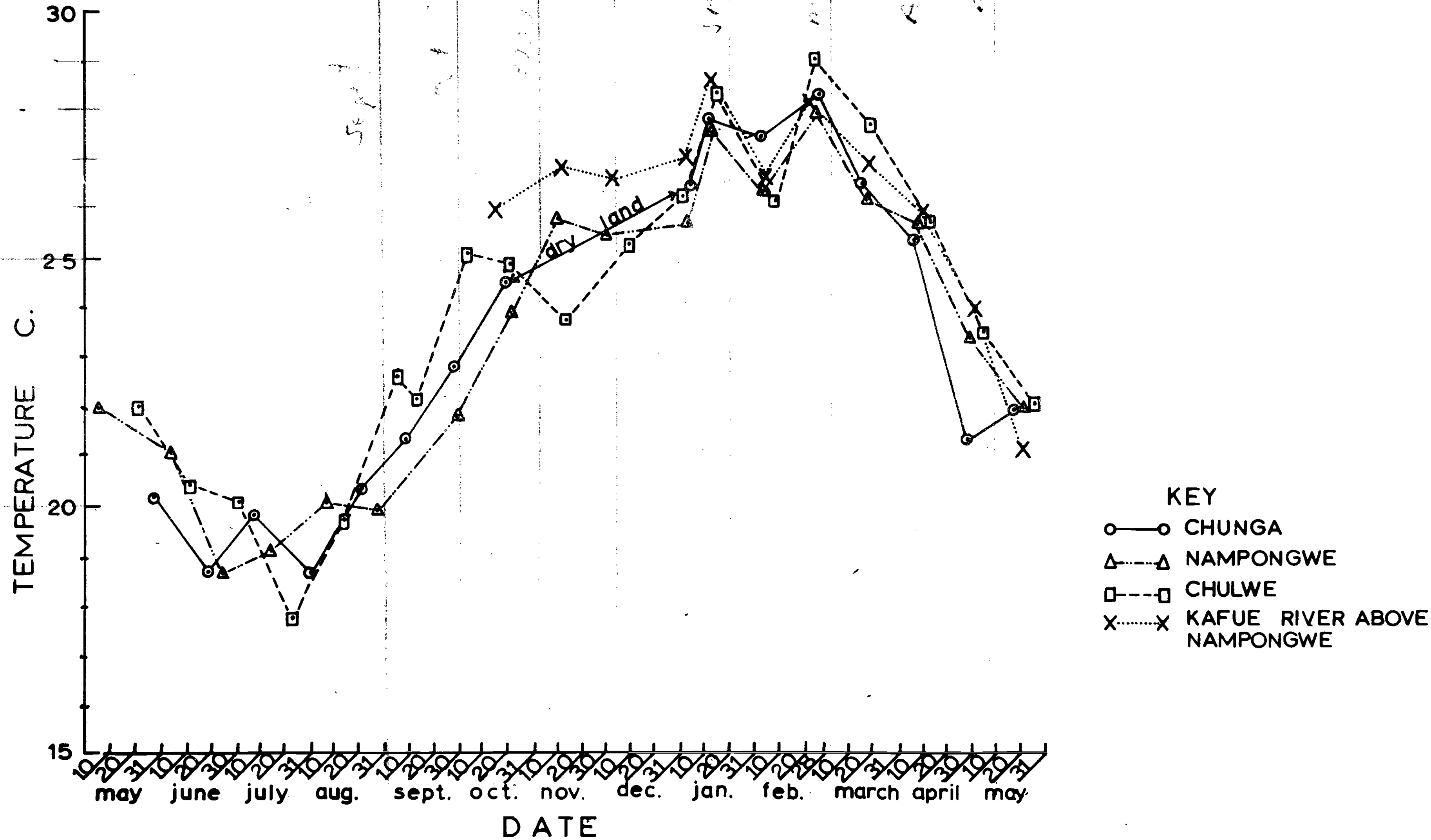


Figure 7. Average dissolved oxygen of water column over 24 hours, four open water sampling areas, Kafue River floodplain, 1969-70.

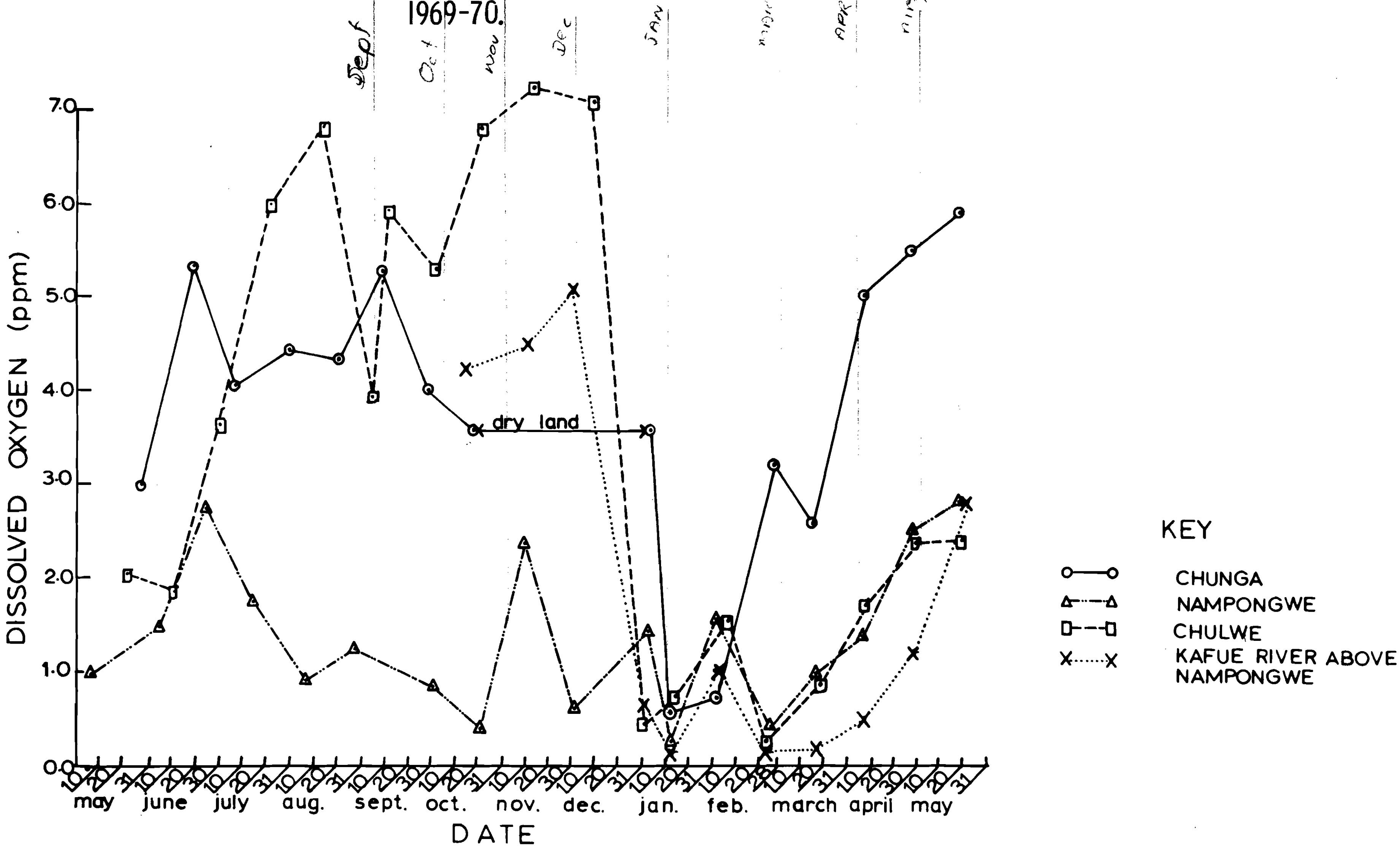
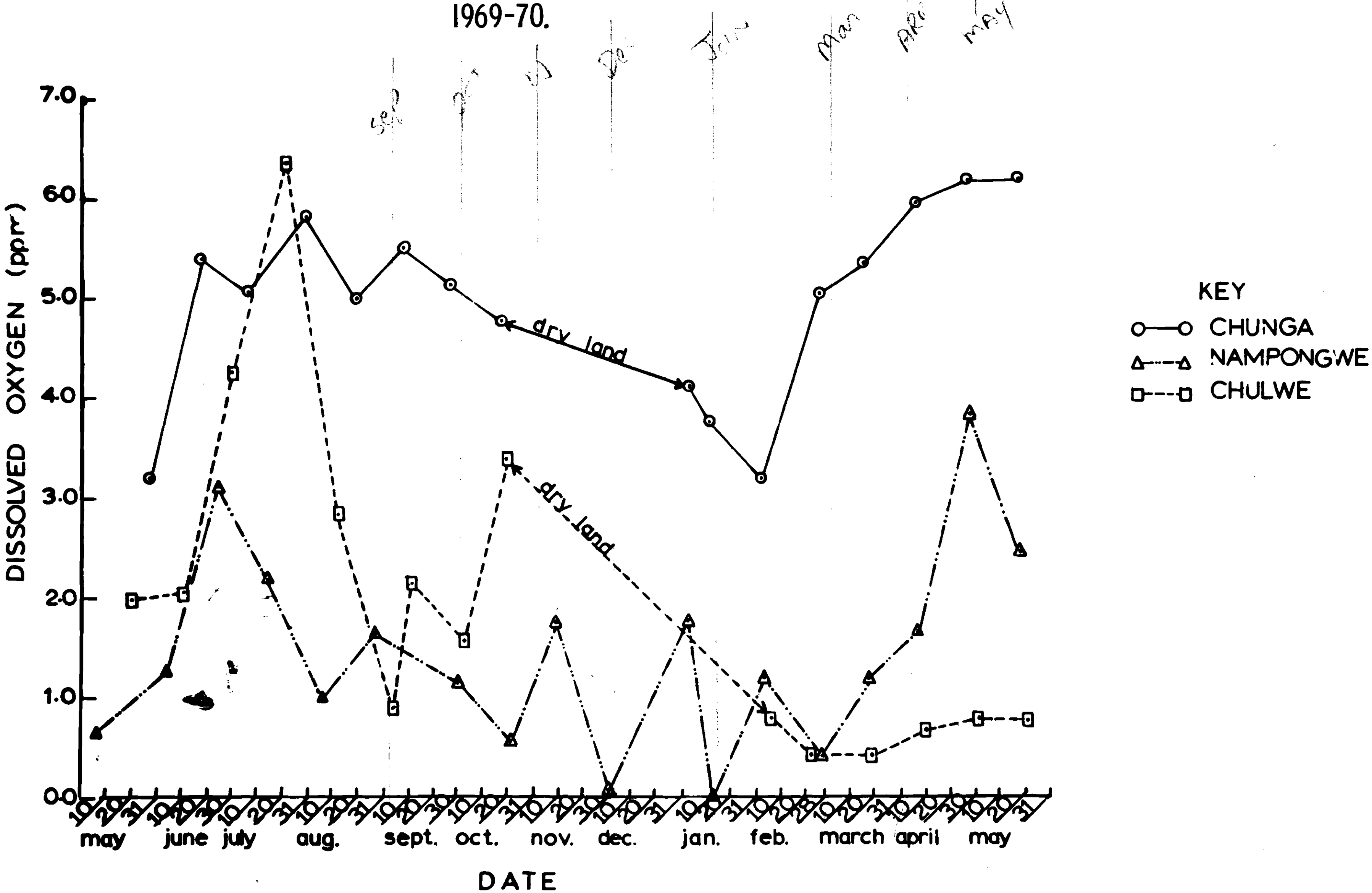


Figure 8. Mean dissolved oxygen of water column over 24 hours, three vegetation sampling areas, Kafue River floodplain, 1969-70.



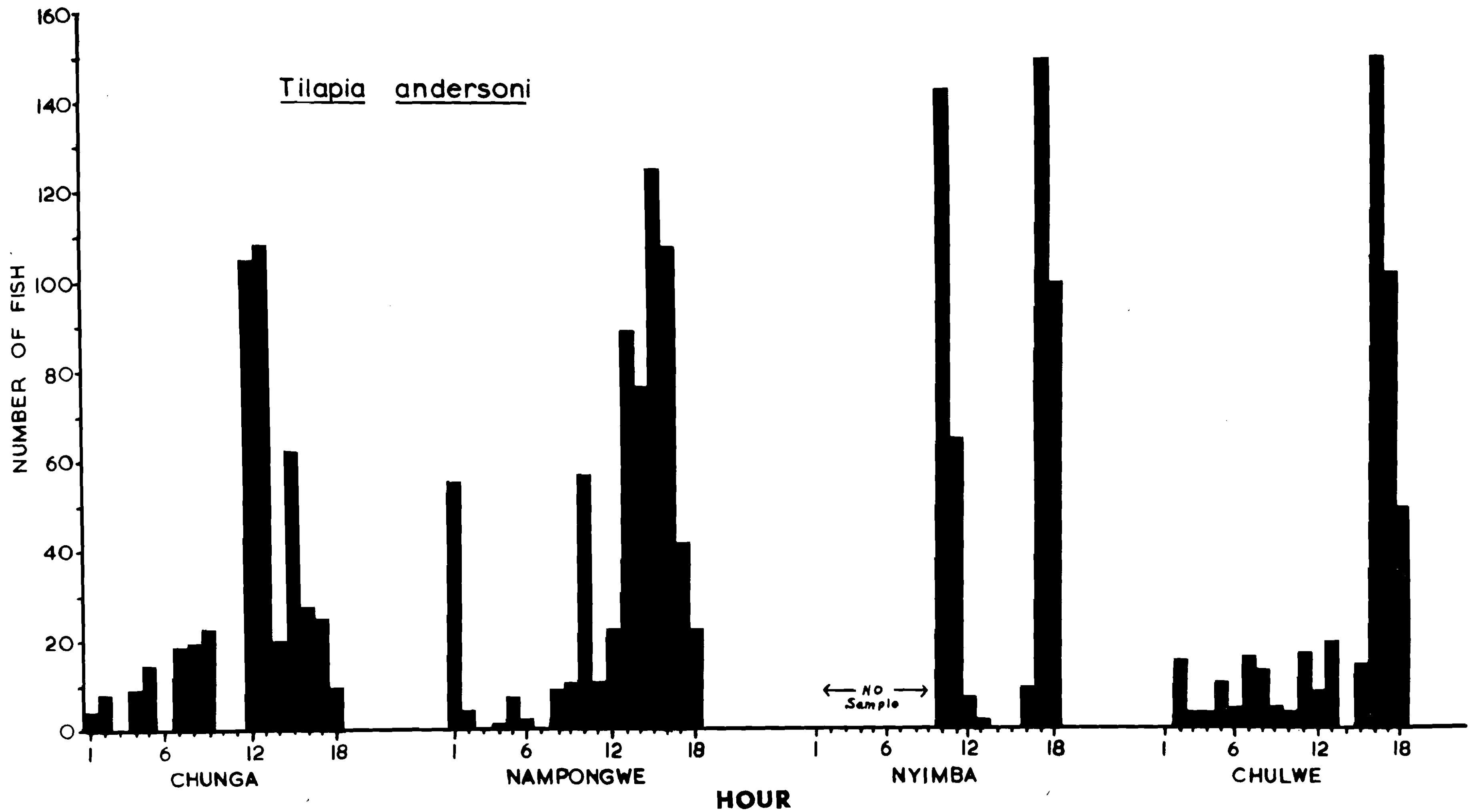


Figure 9. Total catch of *Tilapia andersoni* by sampling period and location, Kafue River floodplain, 1969-70.

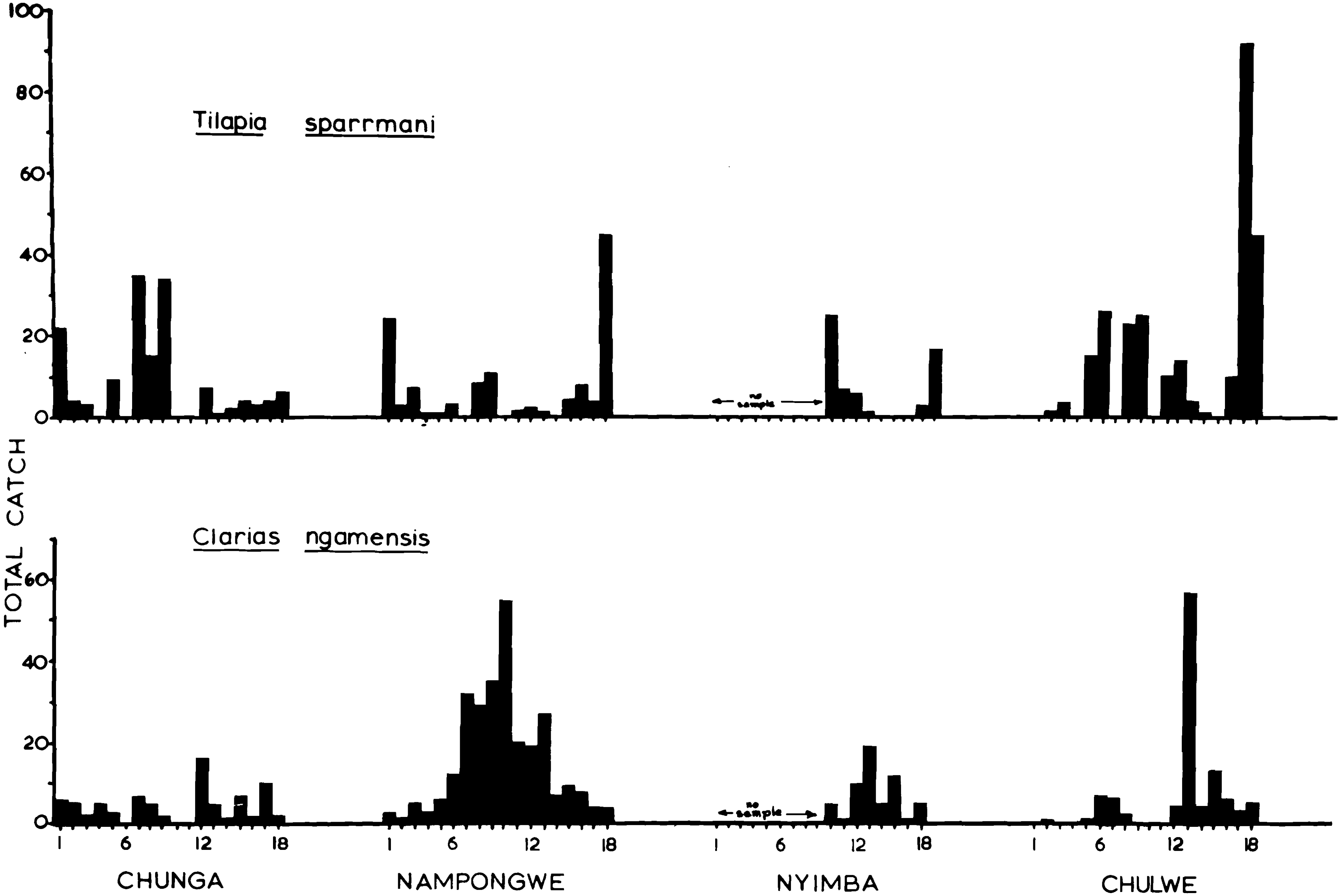


Figure 10. Total catch of Tilapia sparrmani and Clarias ngamensis by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

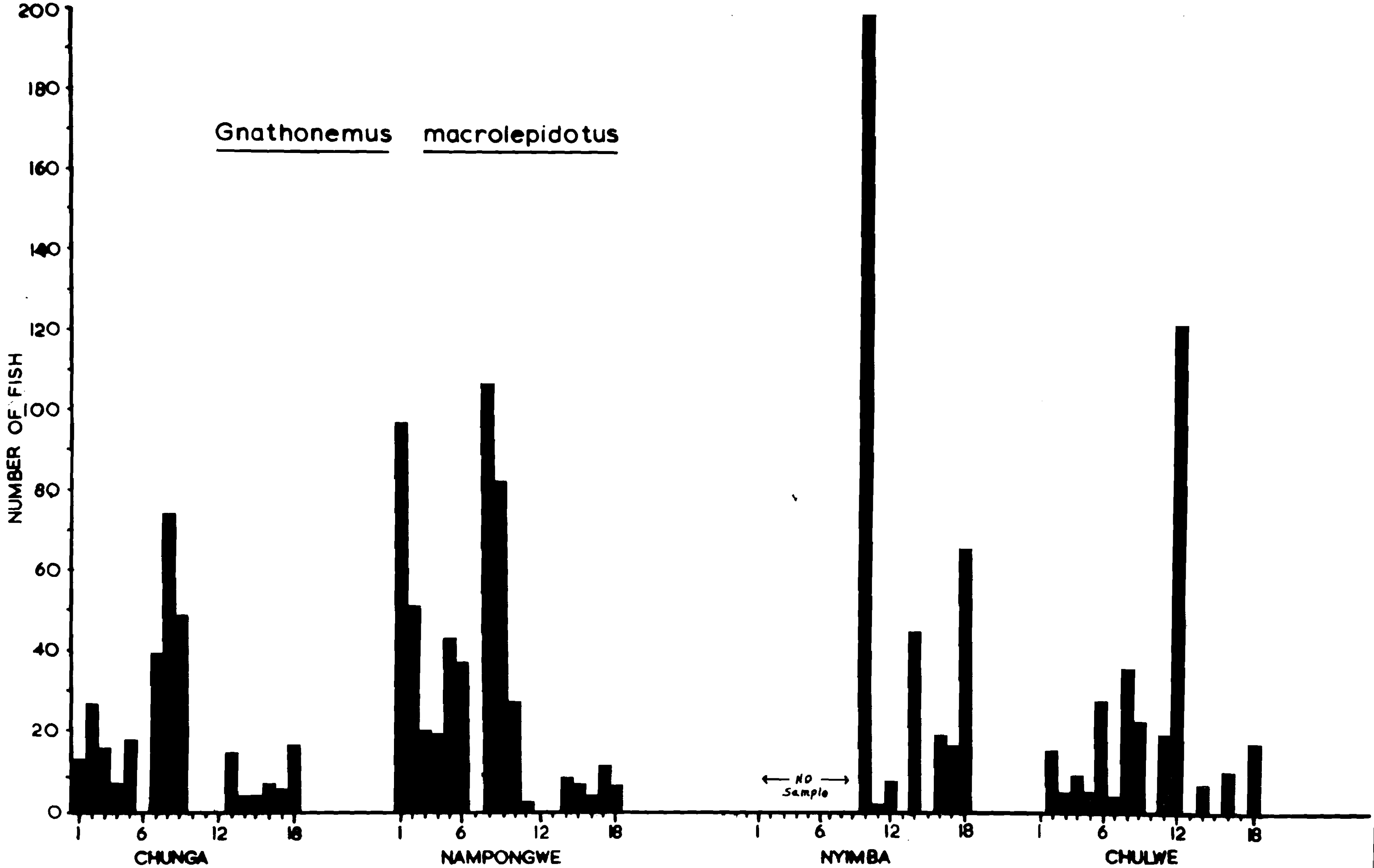


Figure 11. Total catch of Gnathonemus macrolepidotus by sampling period and location, Kafue River and floodplain, June 1968 - May 1970.

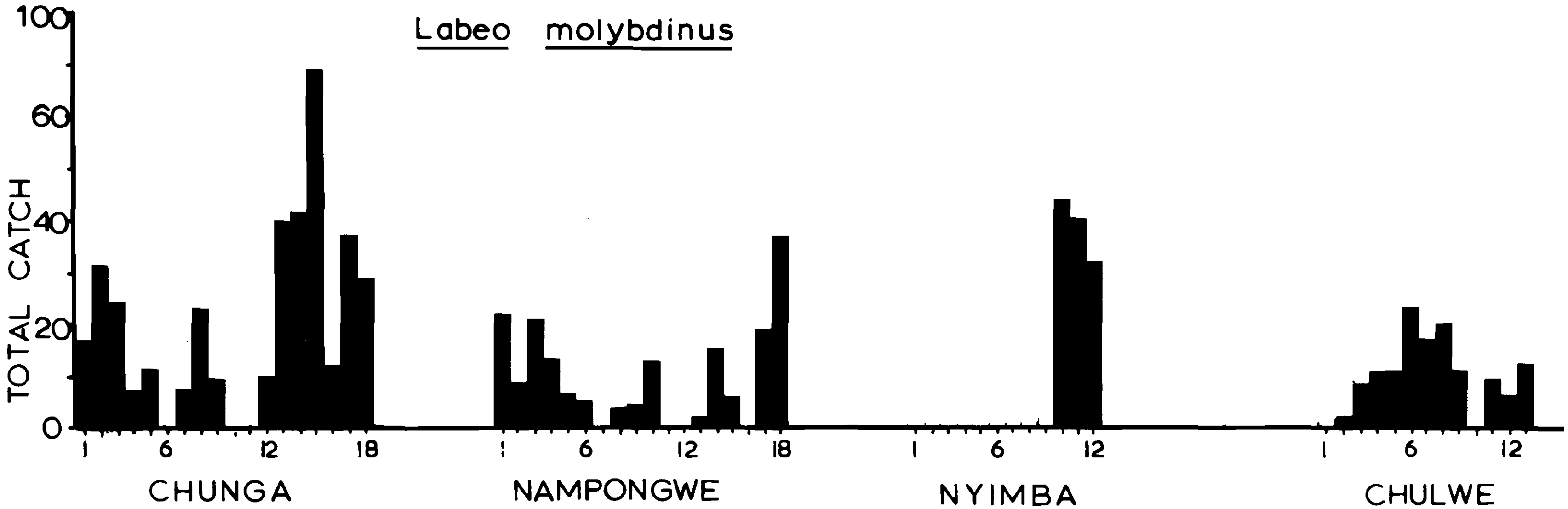


Figure 12. Total catch of _Labeo molybdinus_ by sampling period and location, Kafue River and floodplain, June 1968-May 1970.

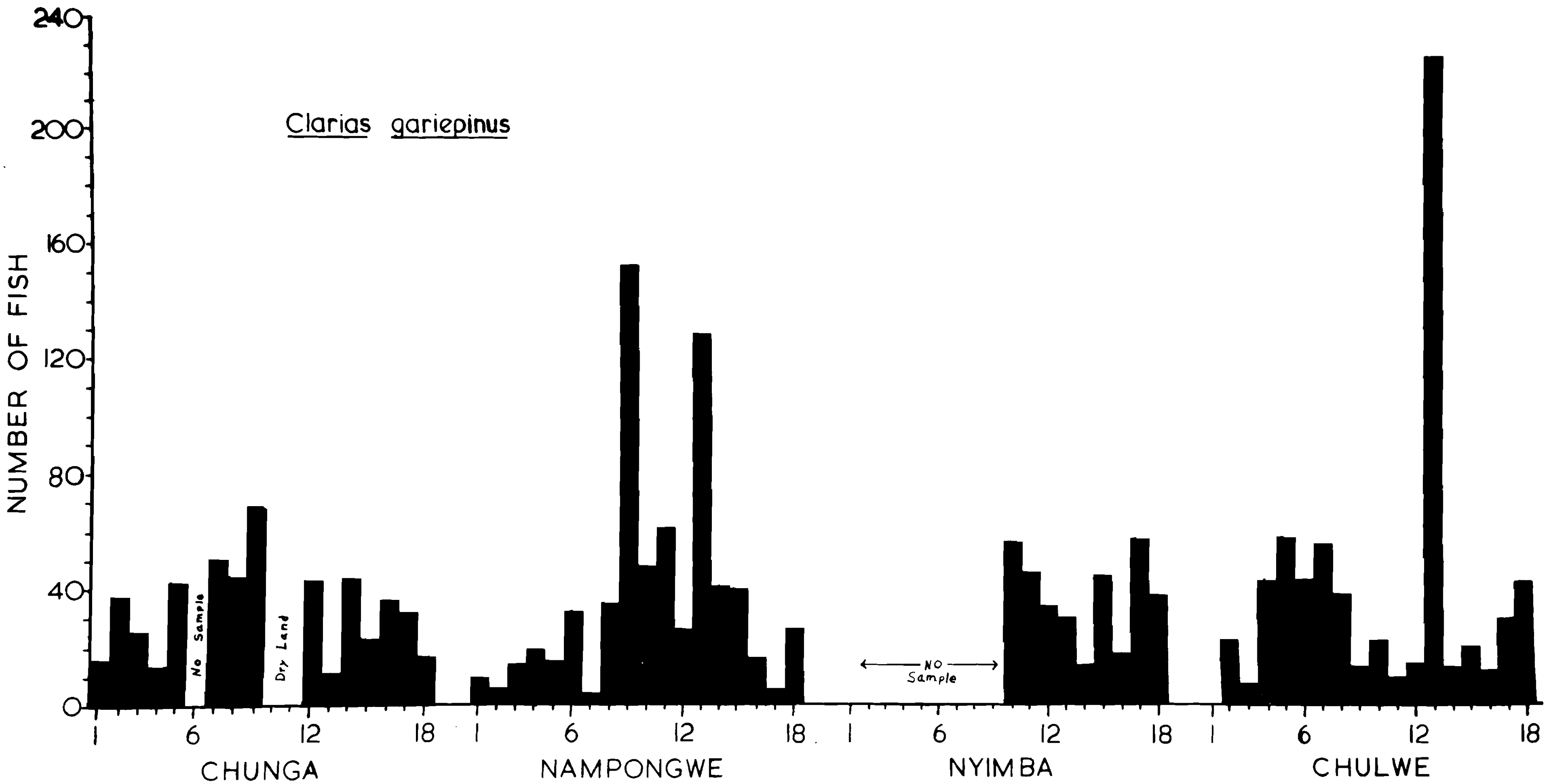


Figure 13. Total catch of Clarias gariepinus by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

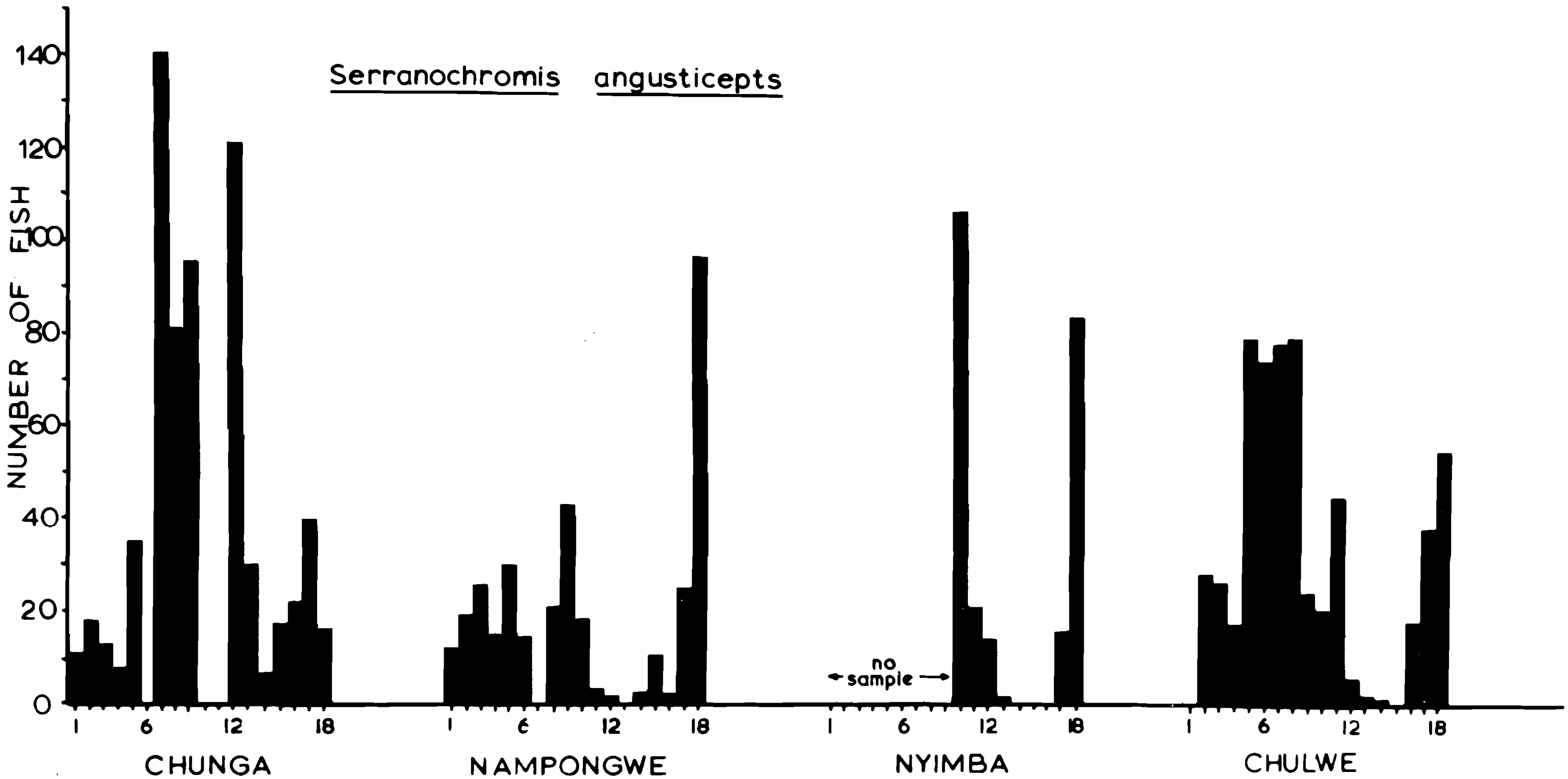


Figure 14. Total catch of Serranochromis angusticeps by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

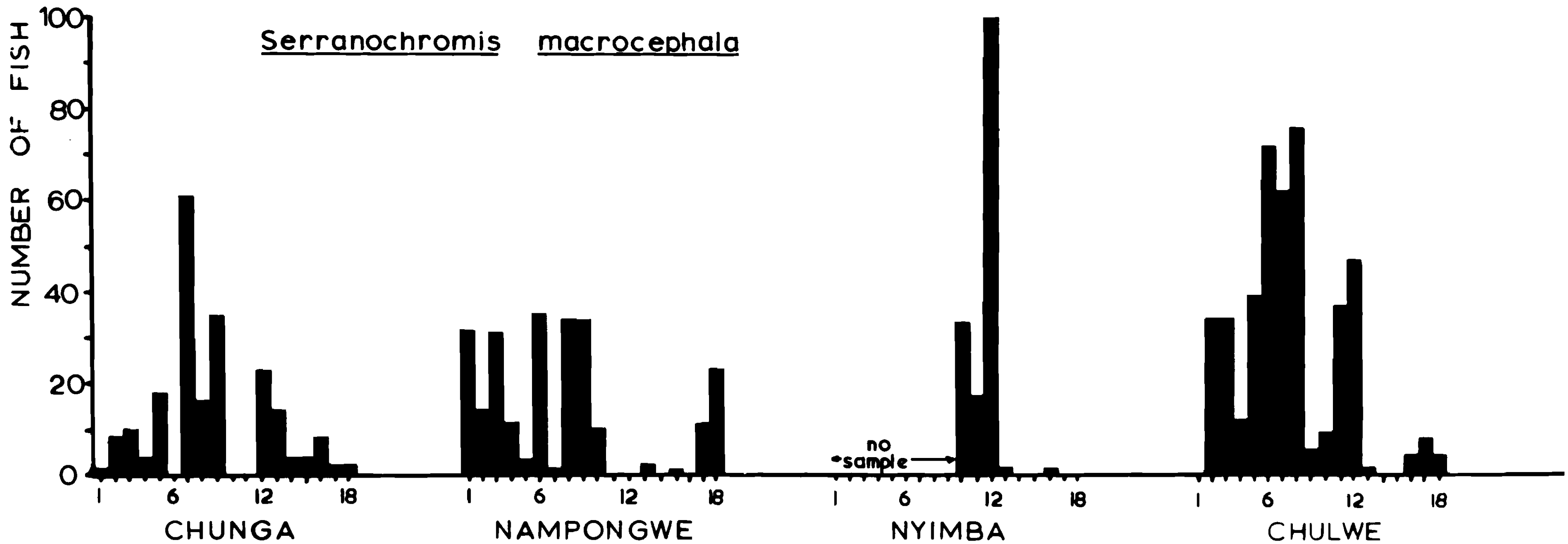


Figure 15. Total catch of Serranochromis macrocephala by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

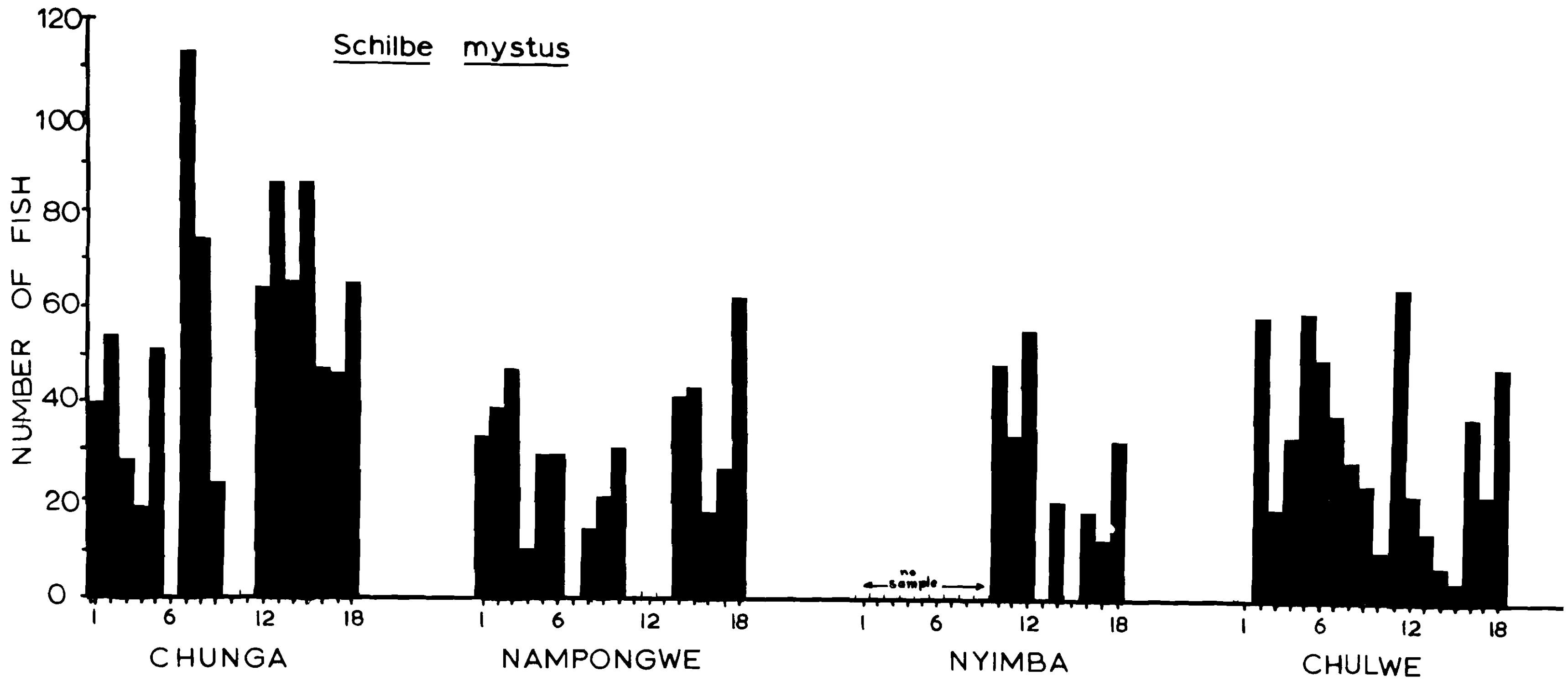


Figure 16. Total catch of Schilbe mystus by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

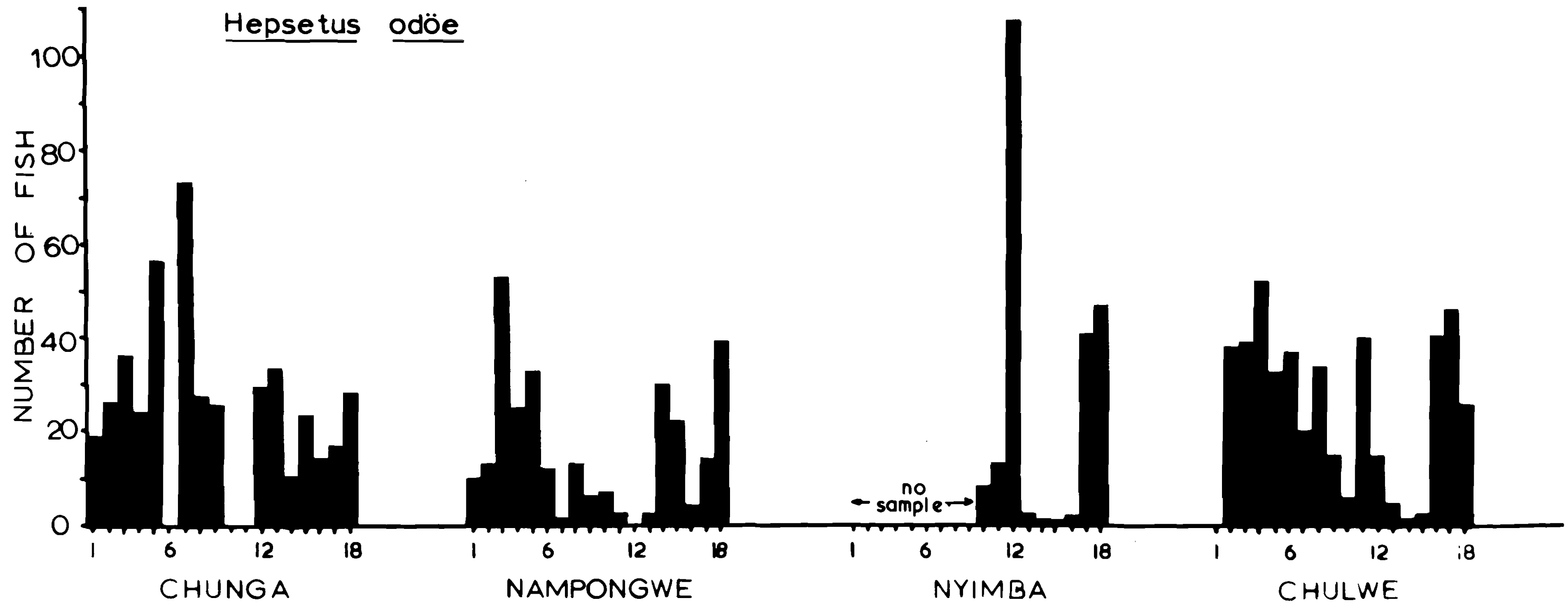


Figure 17. Total catch of Hepsetus odöe by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

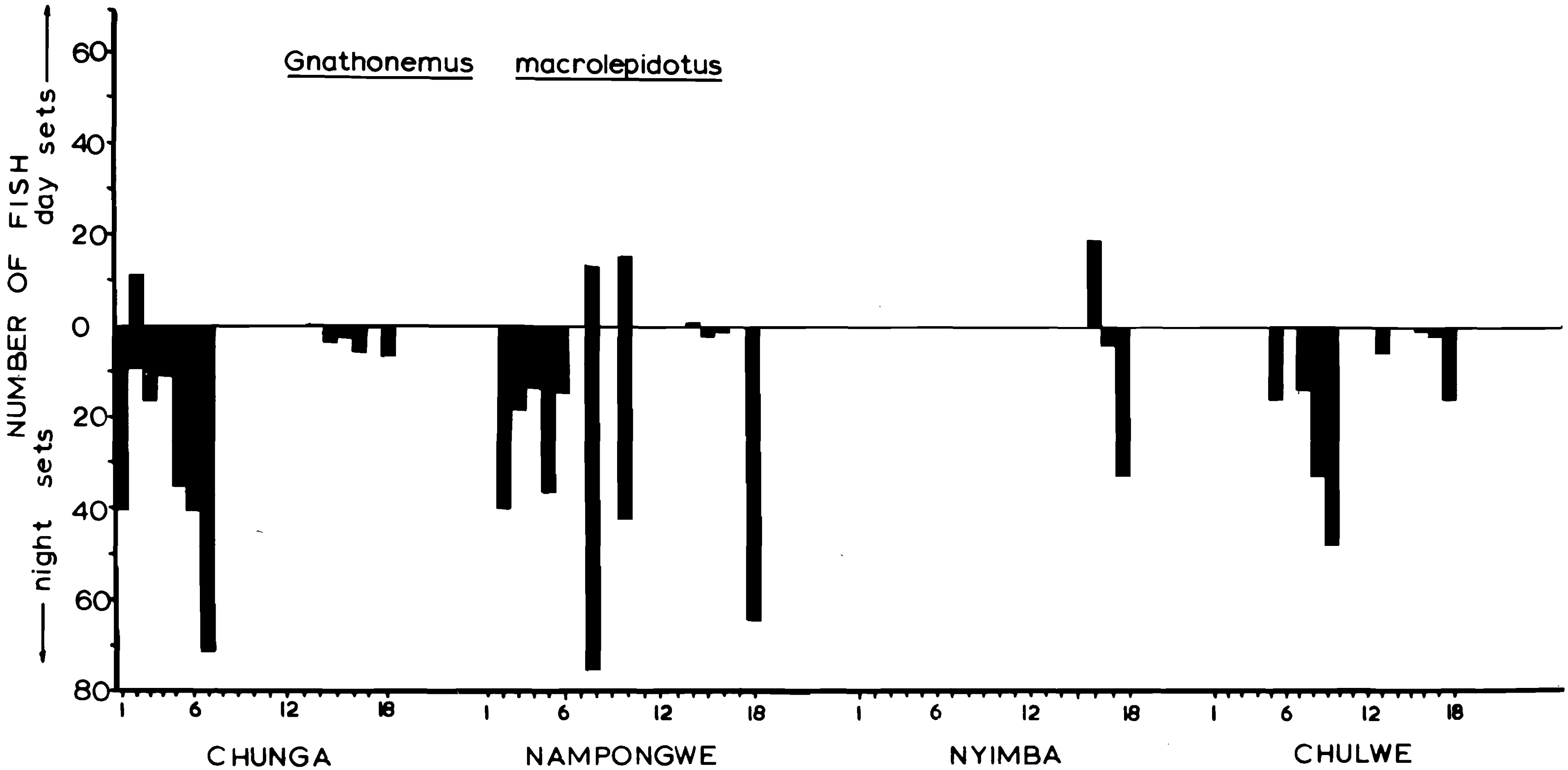


Figure 18. Day and night gill net catches of Gnathonemus macrolepidotus by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

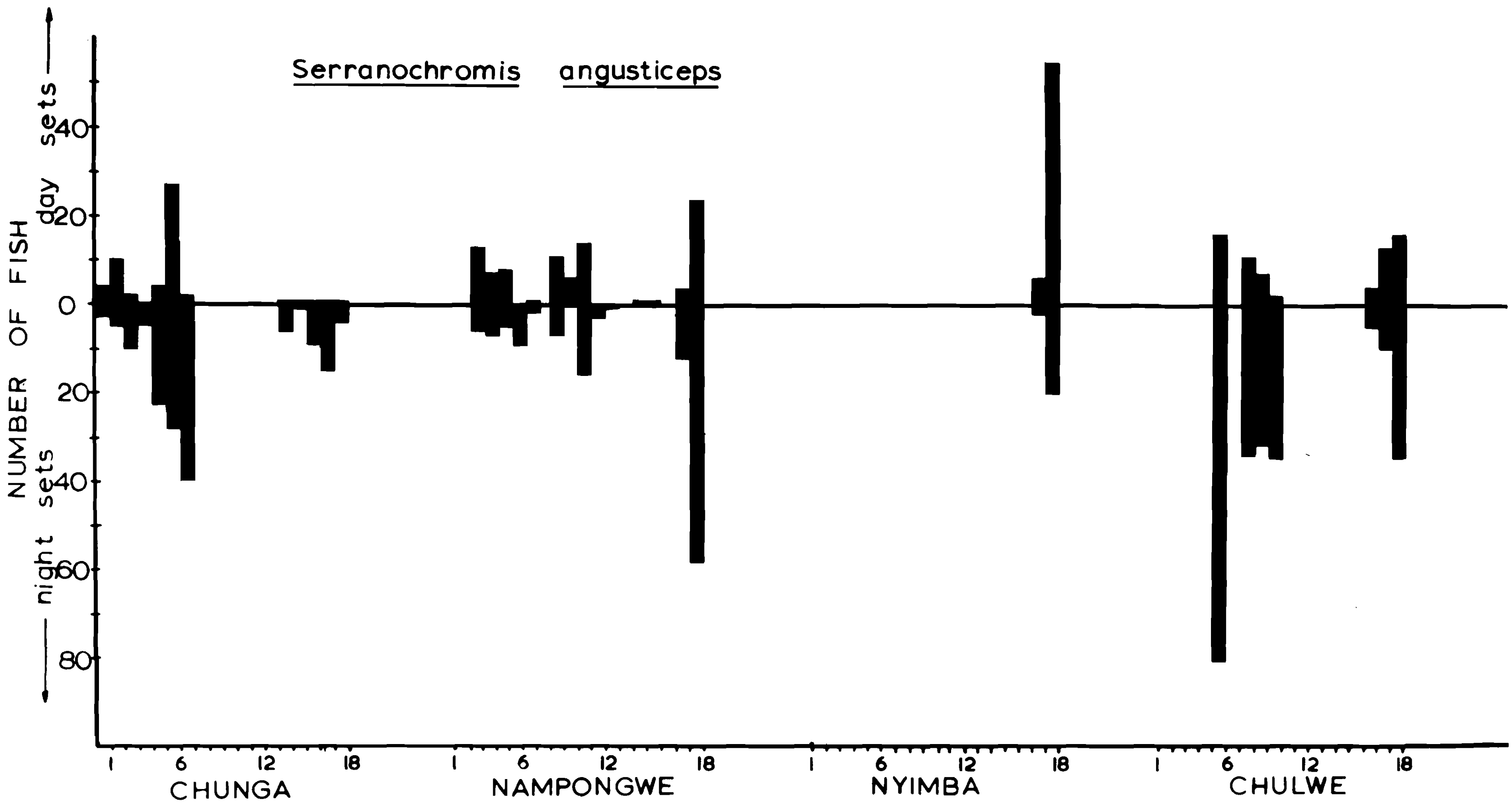


Figure 19. Day and night gill net catches of *Serranochromis angusticeps* by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

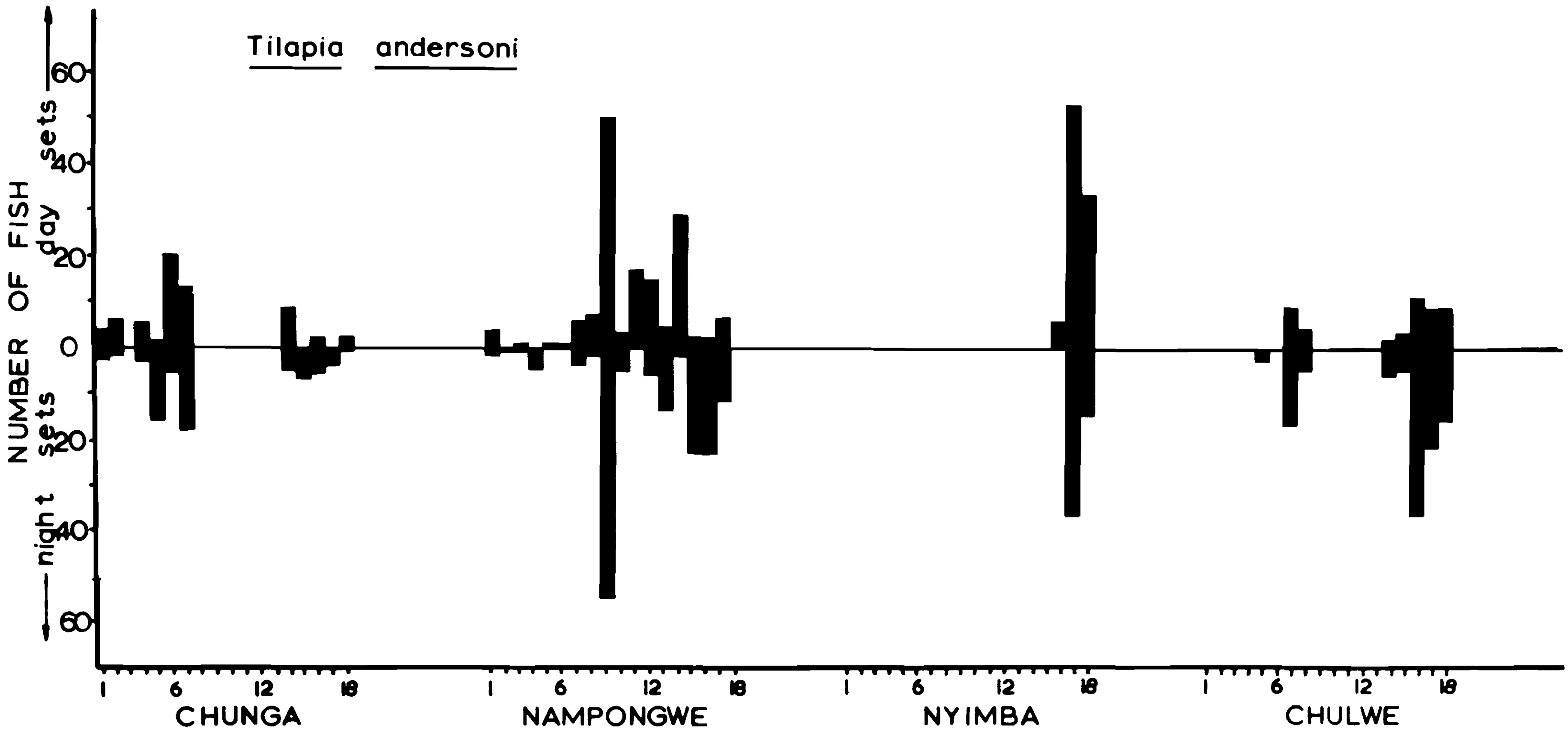


Figure 20. Day and night gill net catches of Tilapia andersoni by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

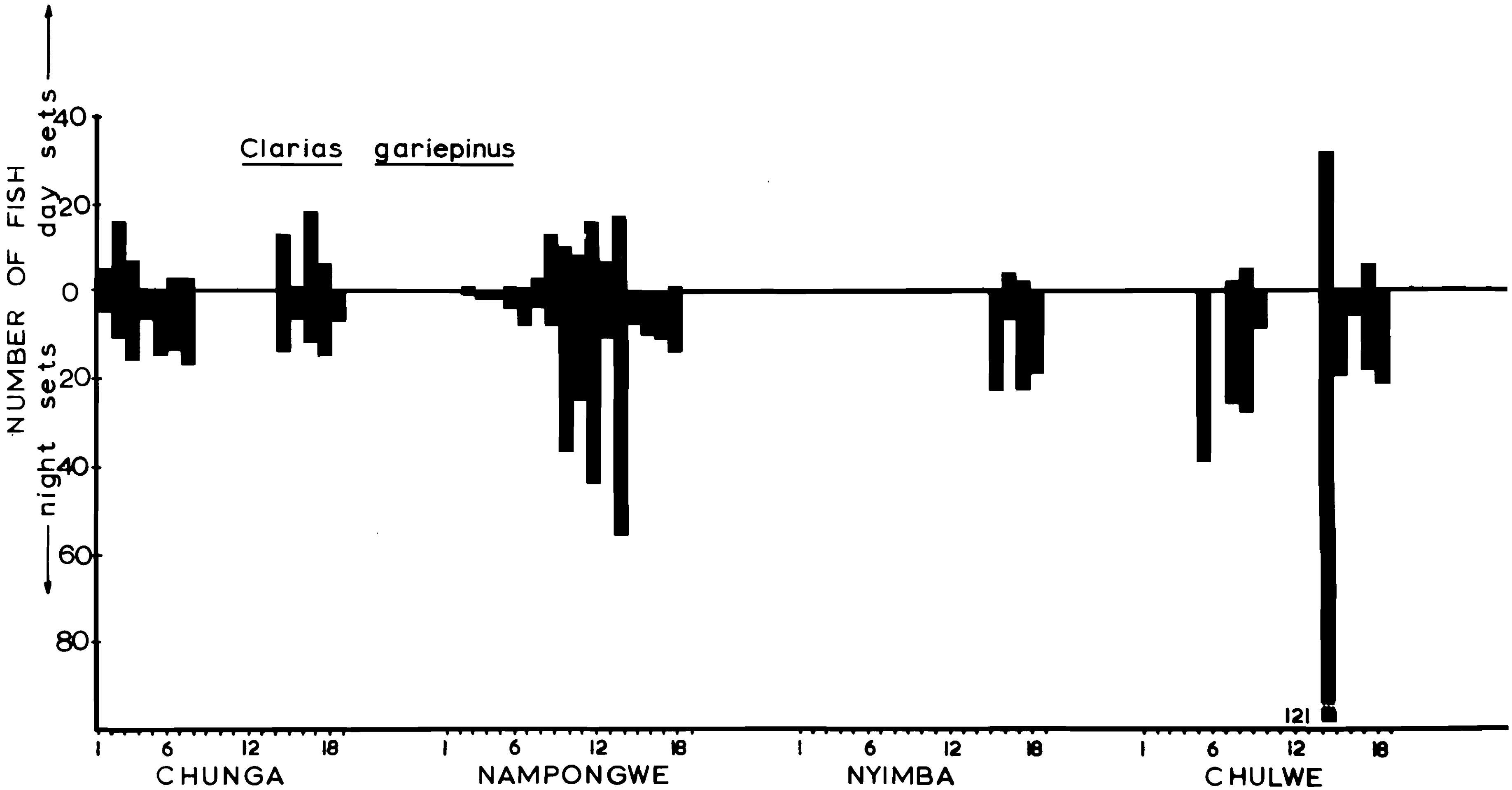


Figure 21. Day and night gill net catches of _Clarias gariepinus_ by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

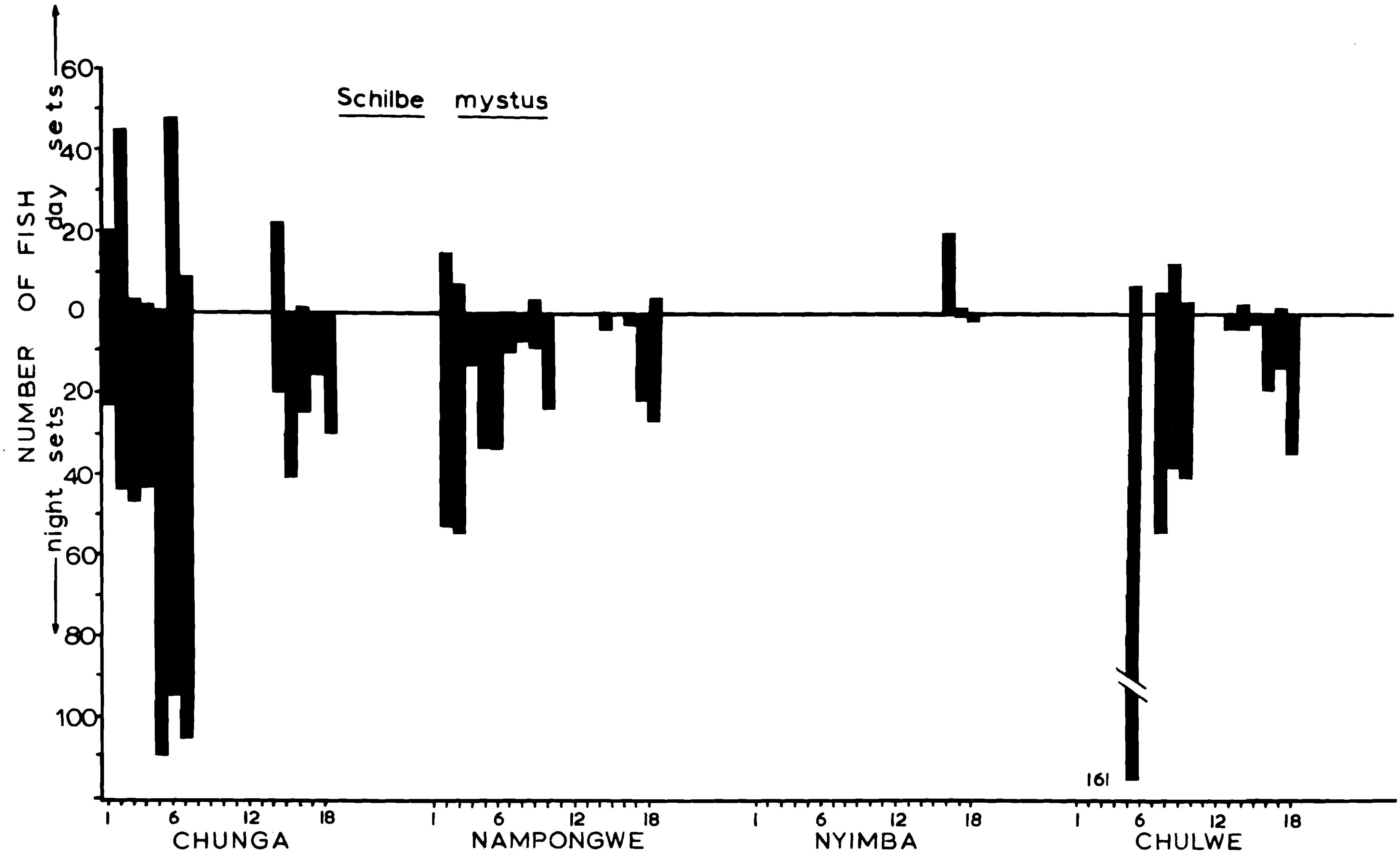


Figure 22. Day and night gill net catches of Schilbe mystus by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

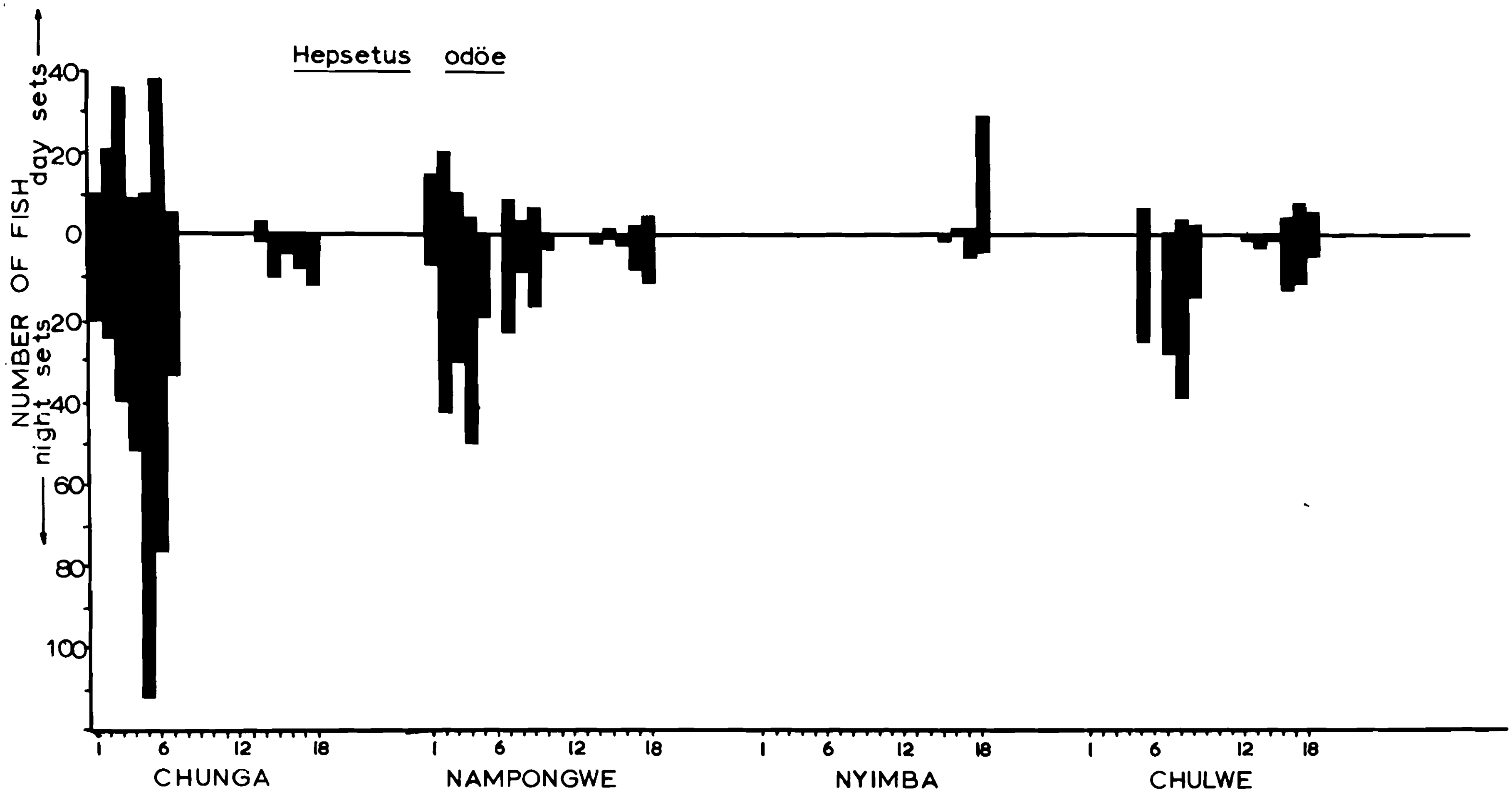


Figure 23. Day and night gill net catches of Hepsetus odöe by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

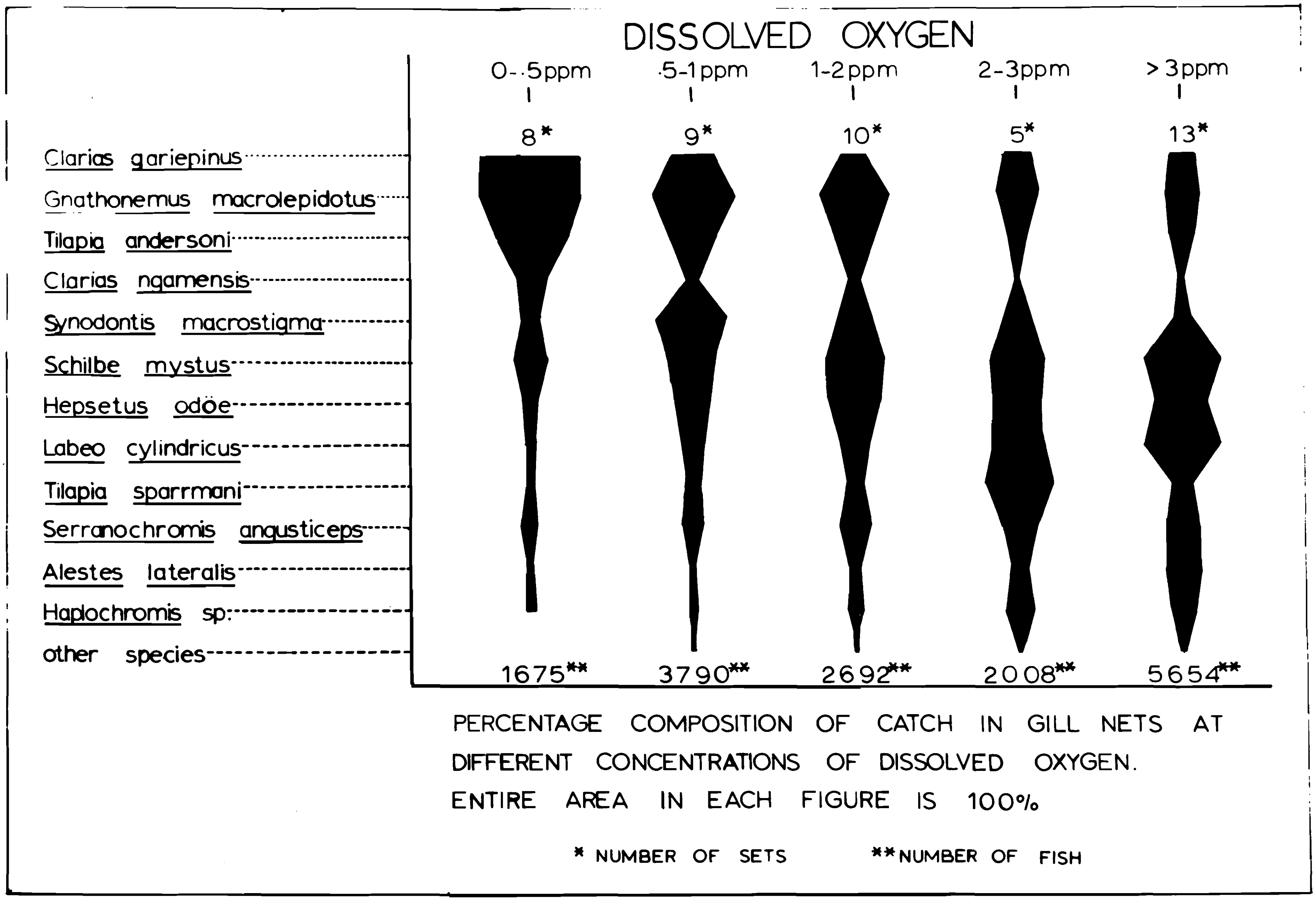
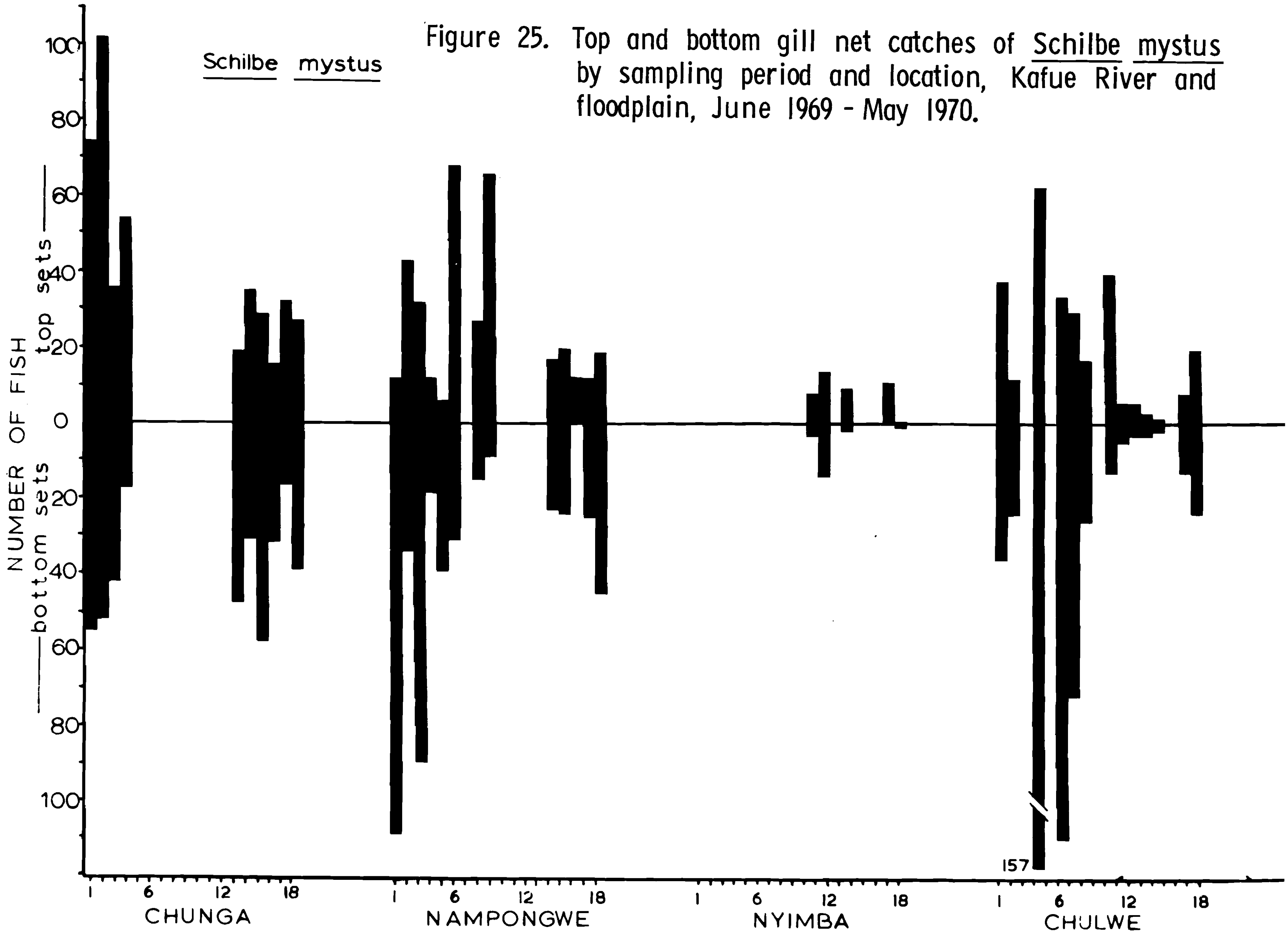


Figure 24. Percentage composition of catch in gill nets at different concentration of dissolved oxygen. Entire area in each figure is 100 percent.

Figure 25. Top and bottom gill net catches of Schilbe mystus by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.



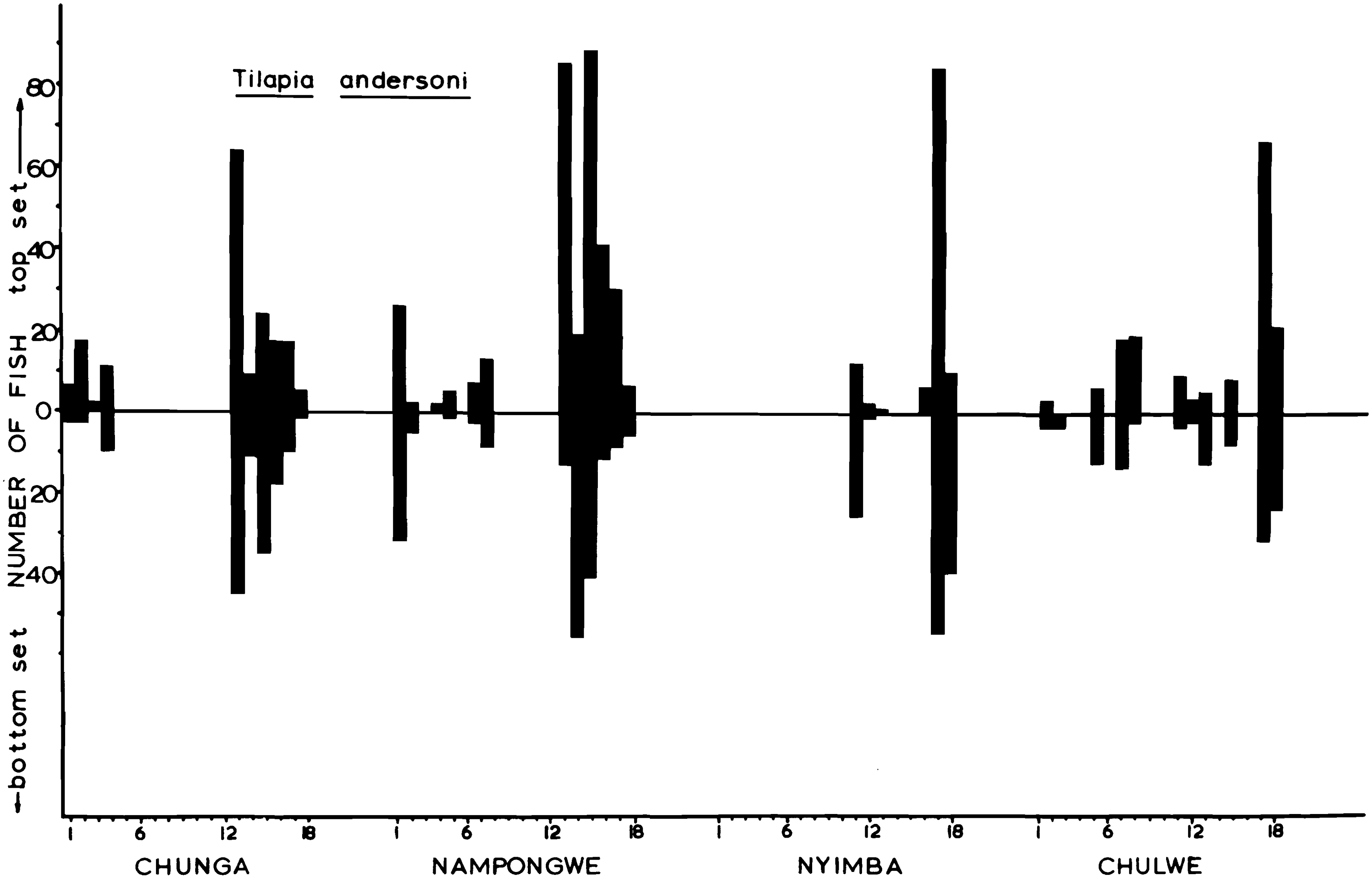


Figure 26. Top and bottom gill net catches of _Tilapia andersoni_ by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

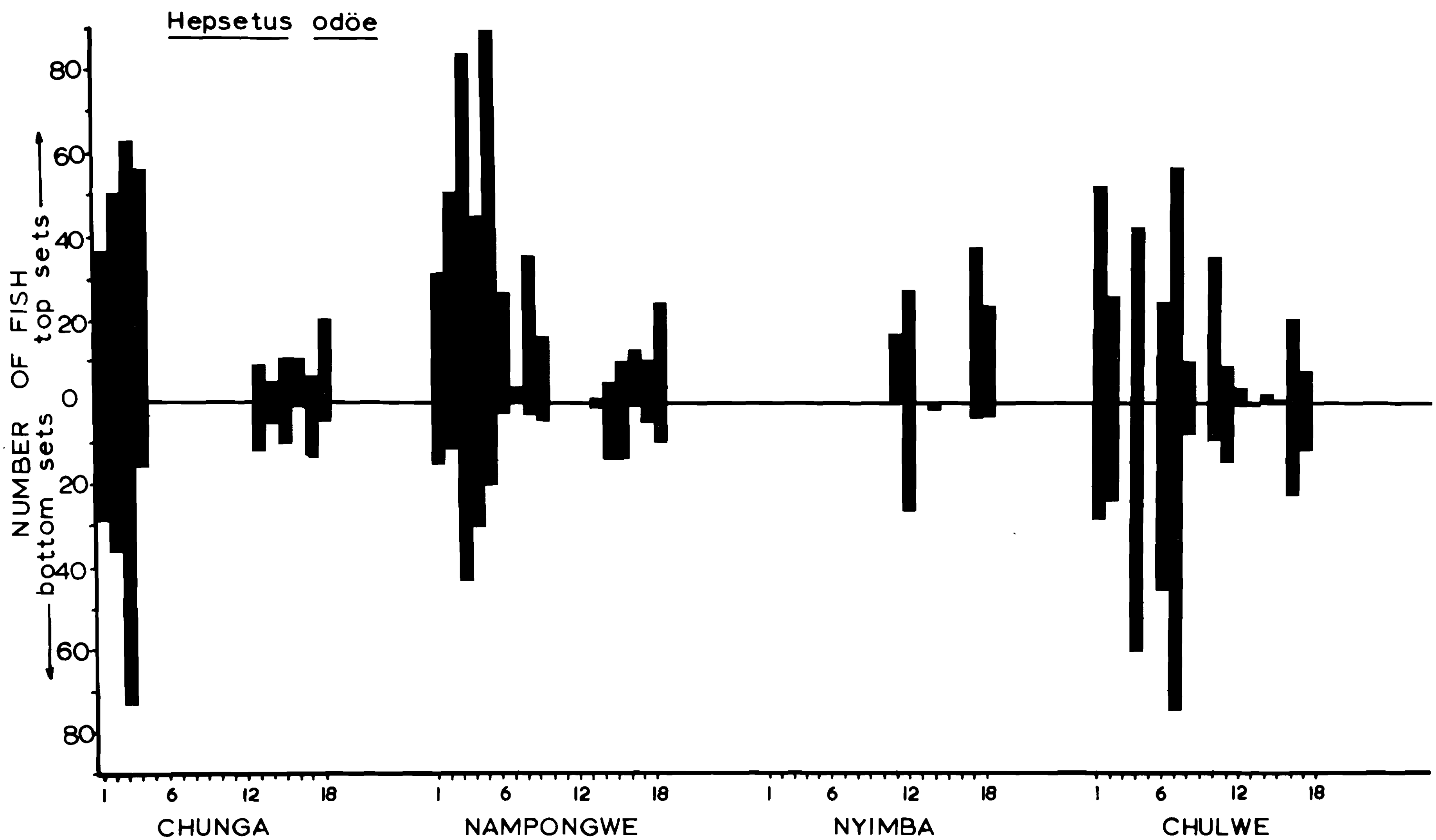


Figure 27. Top and bottom gill net catches of Hepsetus odöe by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

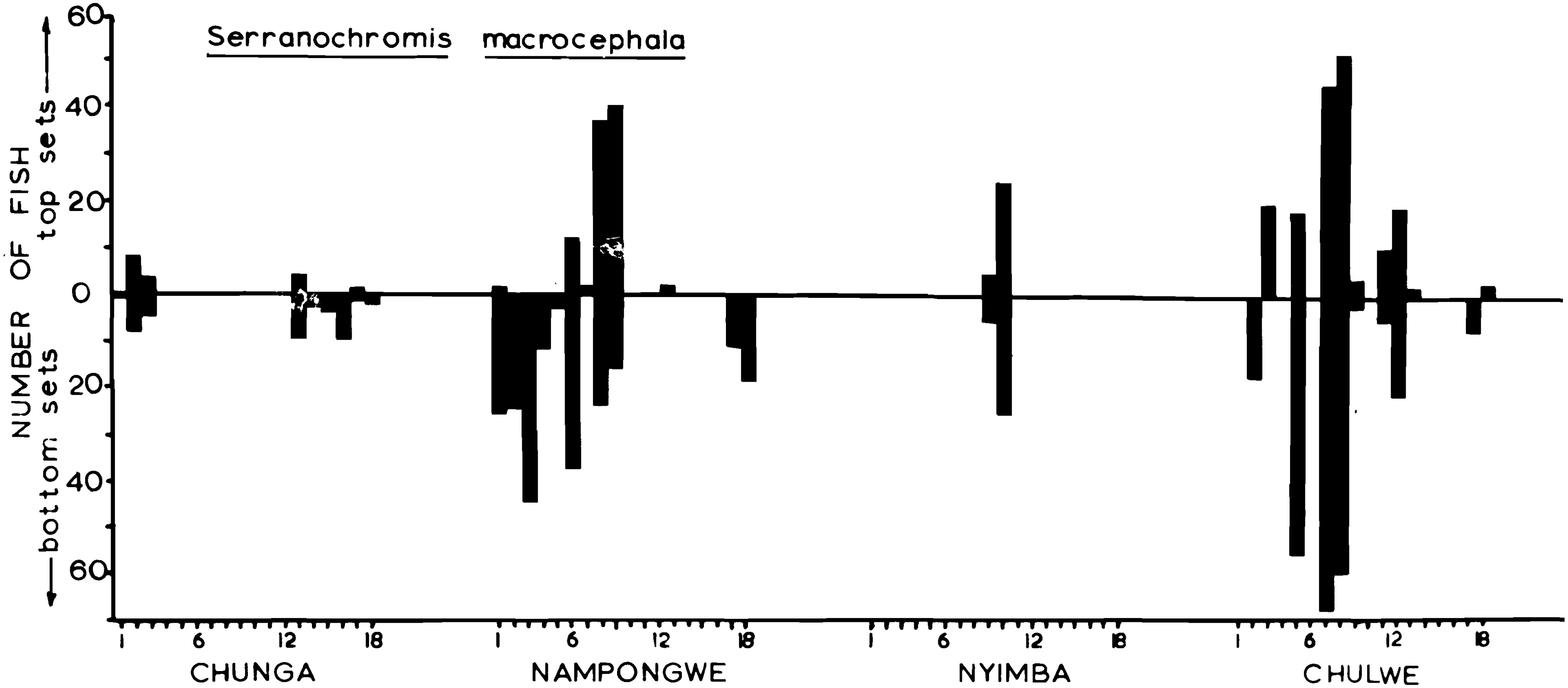


Figure 28. Top and bottom gill net catches of Serranochromis macrocephala by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

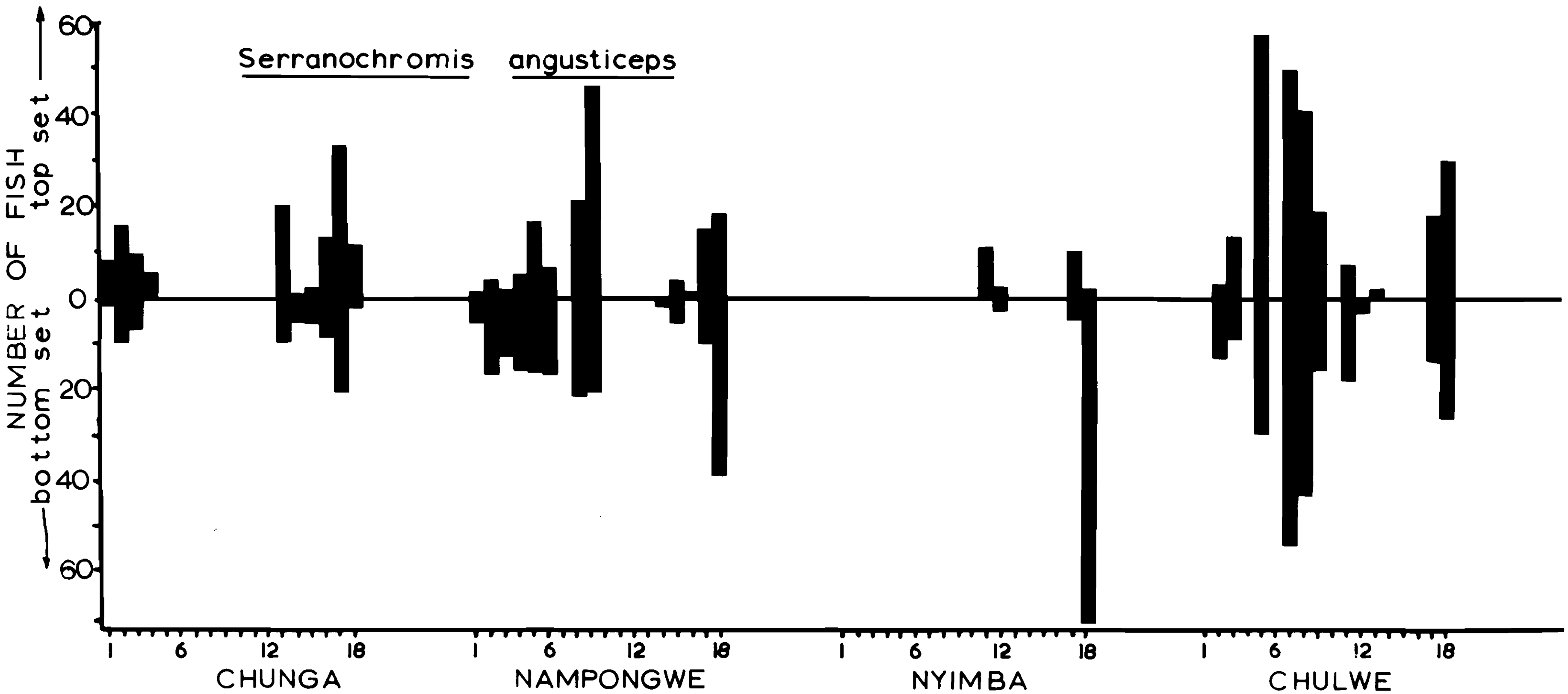


Figure 29. Top and bottom gill net catches of Serranchromis angusticeps by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

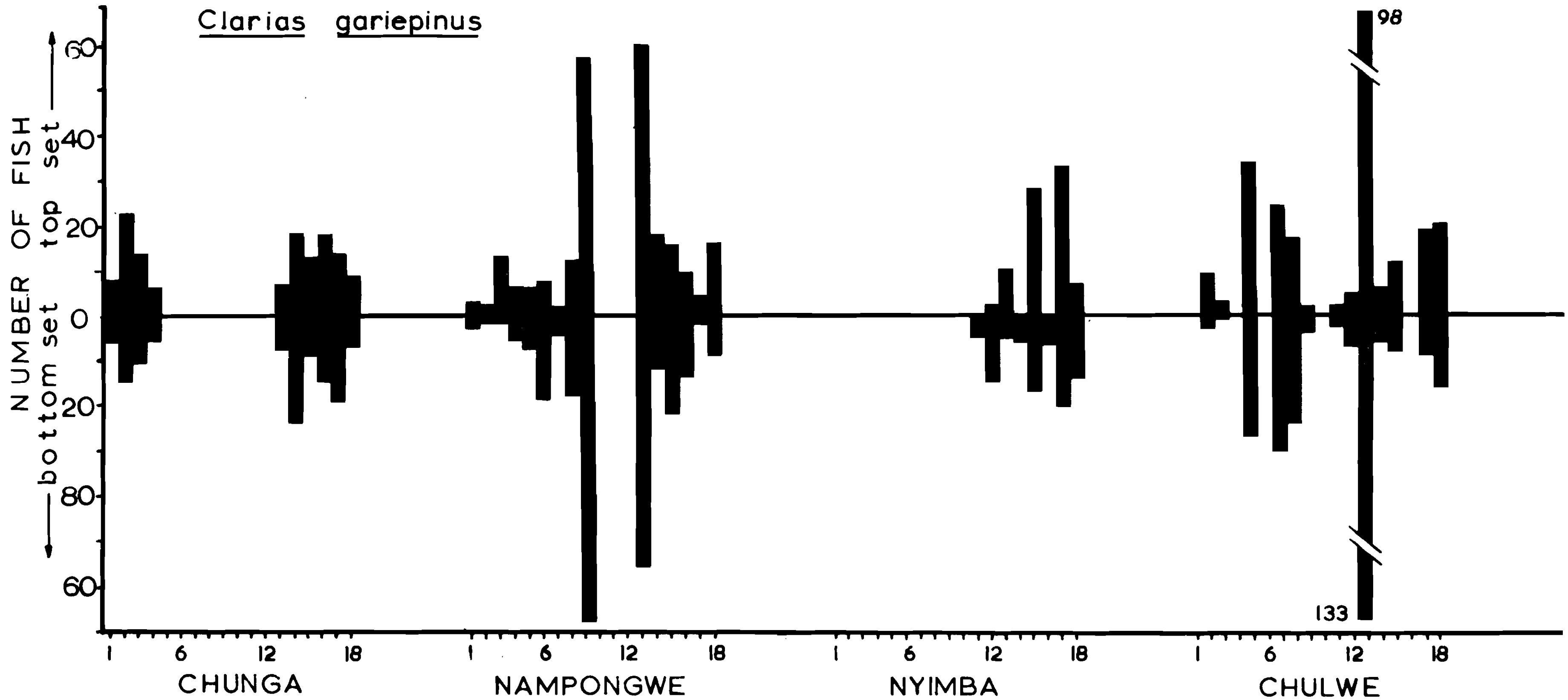


Figure 30. Top and bottom gill net catches of *Clarias gariepinus* by sampling period and location, Kafue River and floodplain, June 1969 - May 1970.

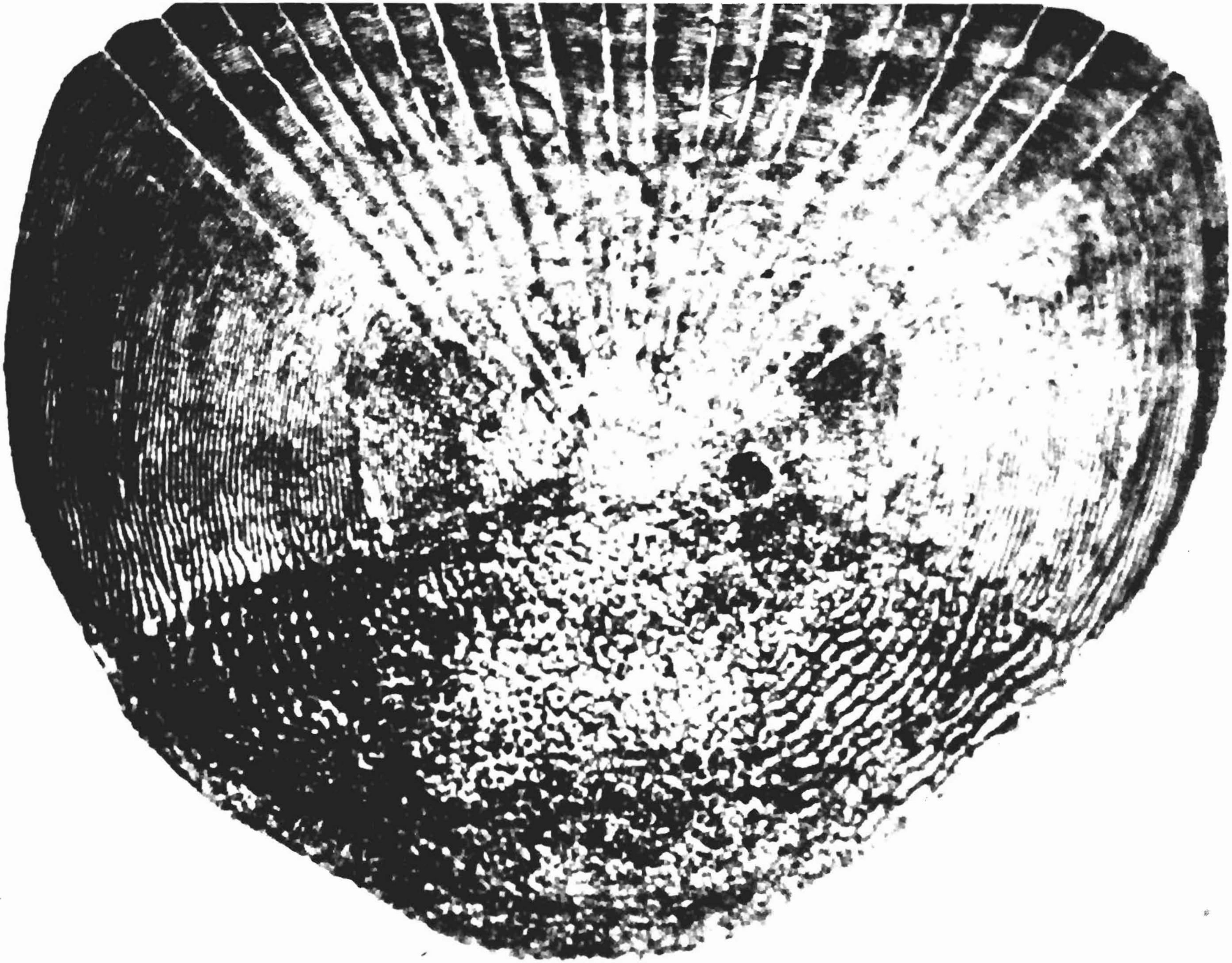


Figure 31. Picture of *Tilapia andersoni* scale on a scale projector.

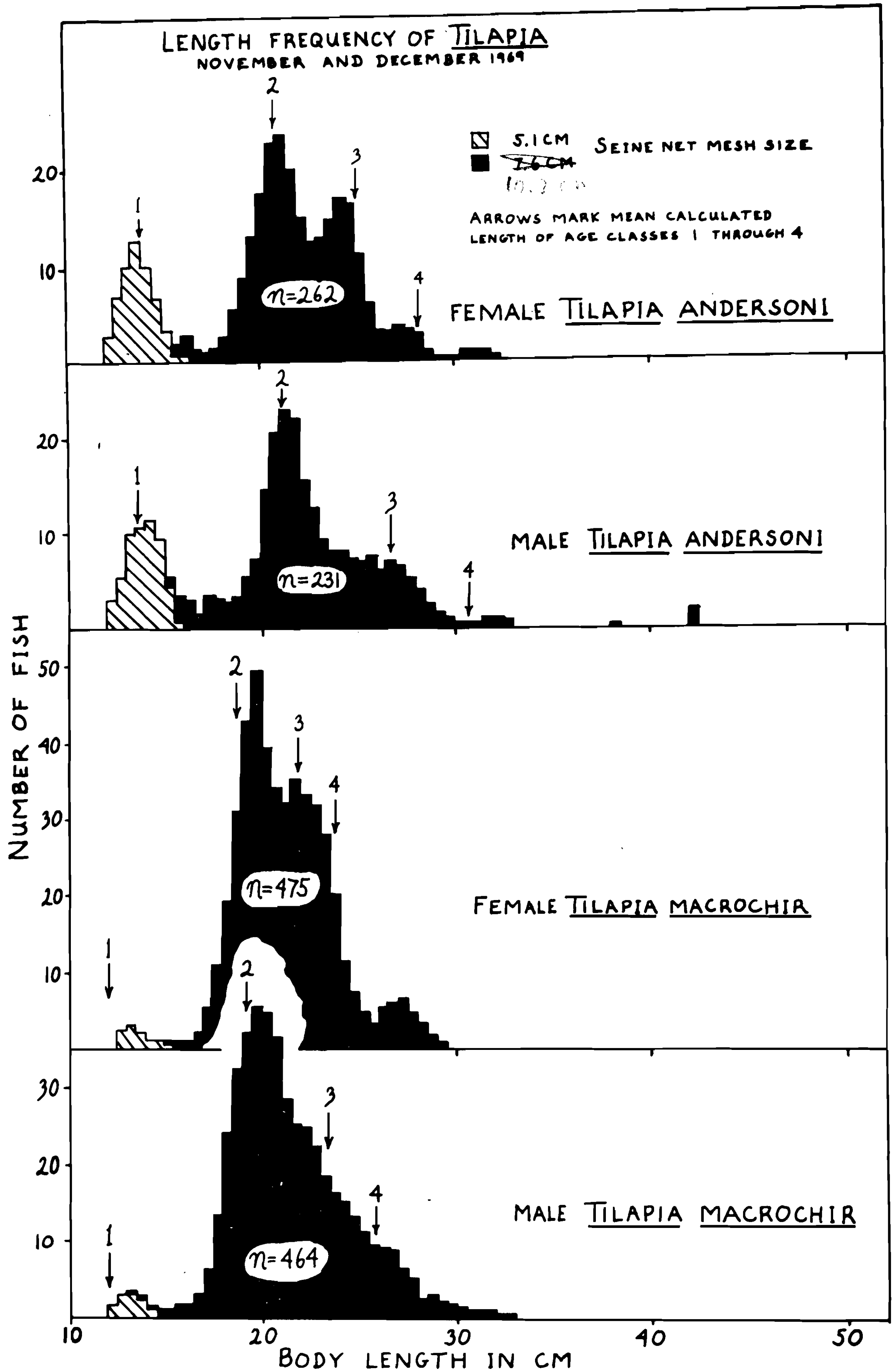


Figure 32. Length frequency of male and female Tilapia andersoni and T. macrochir, Kafue River, 1969.

Figure 33. Mean calculated growth of Tilapia andersoni.

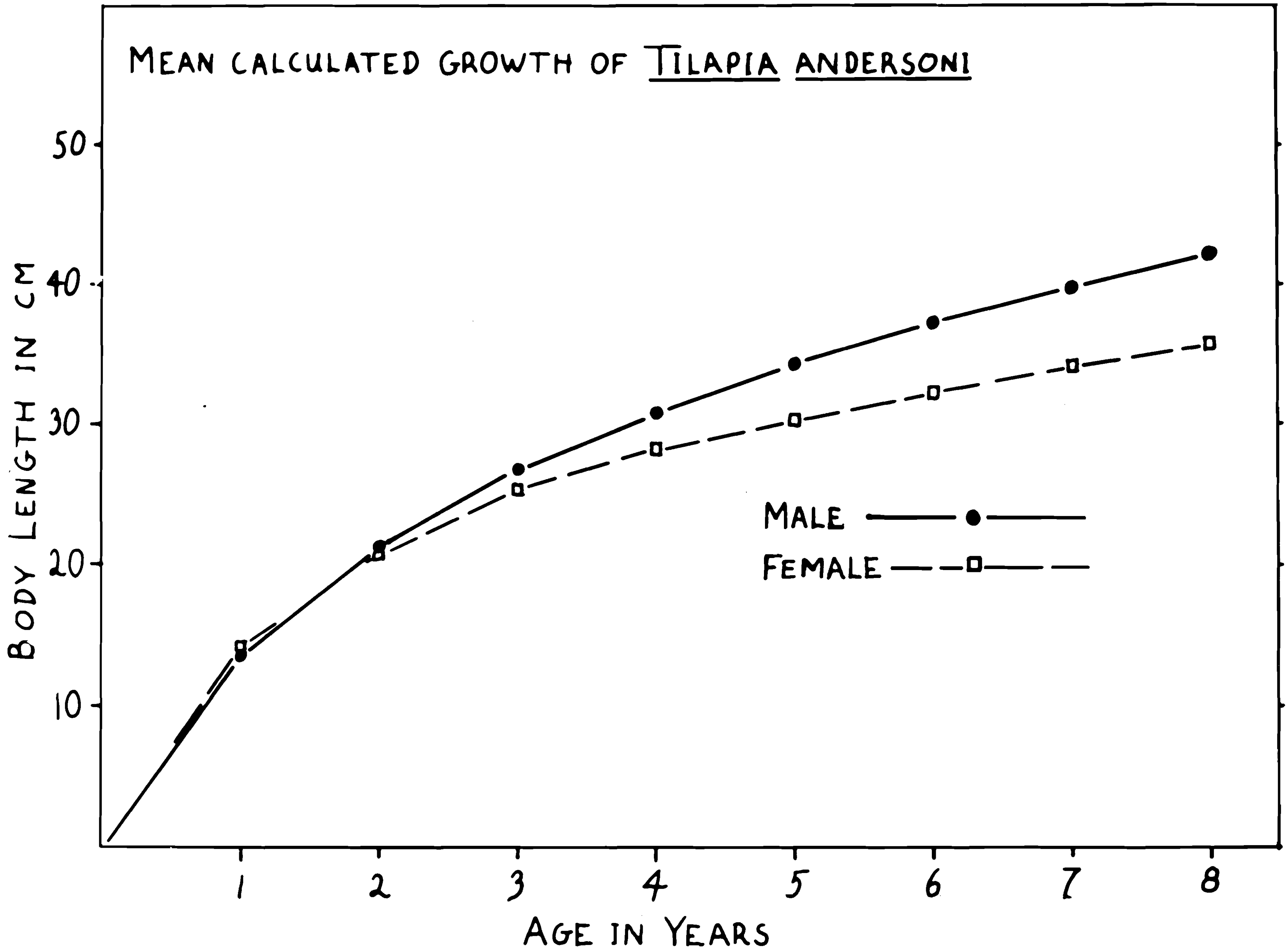


Figure 34. Mean calculated growth of Tilapia macrochir.

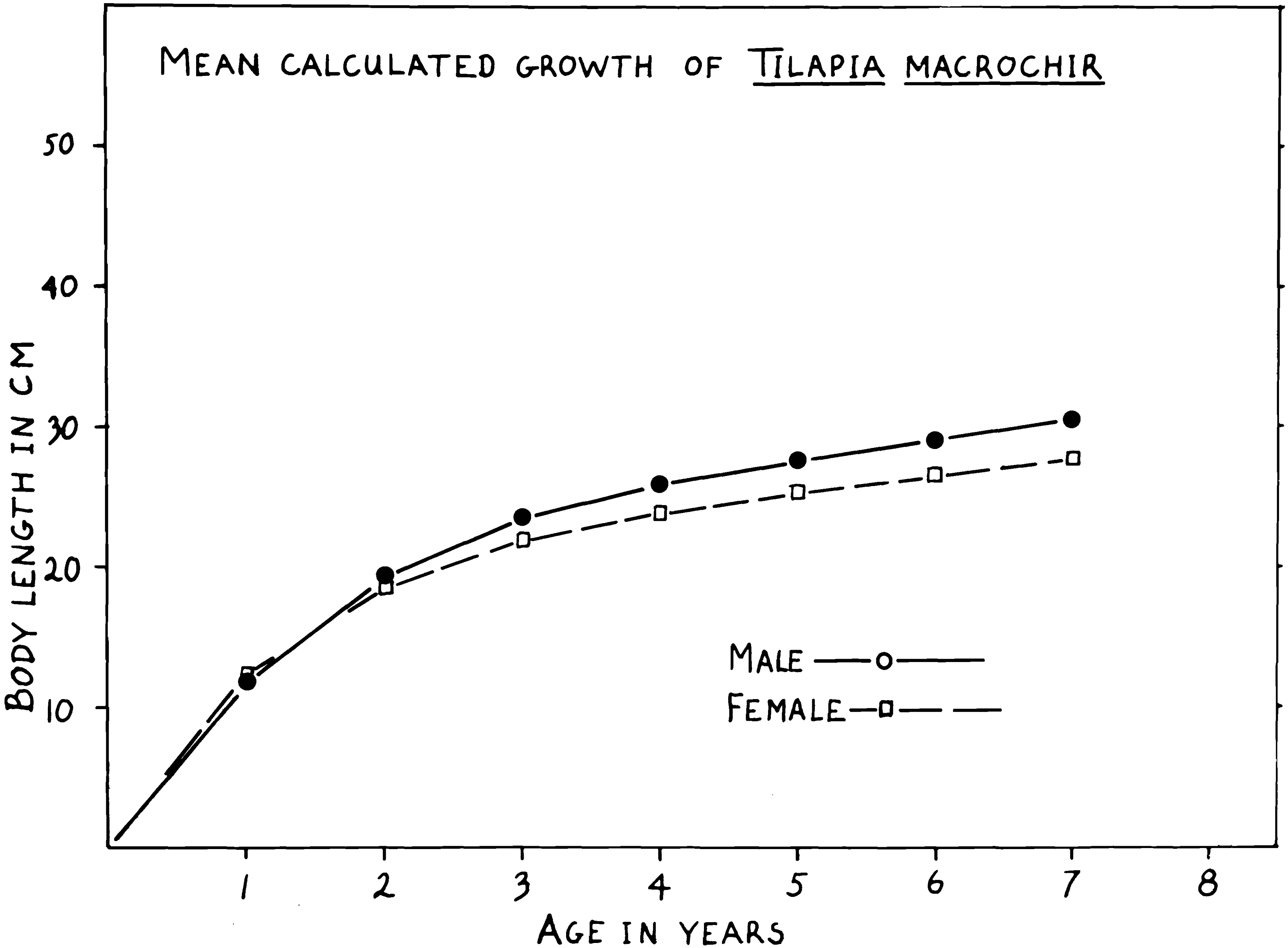
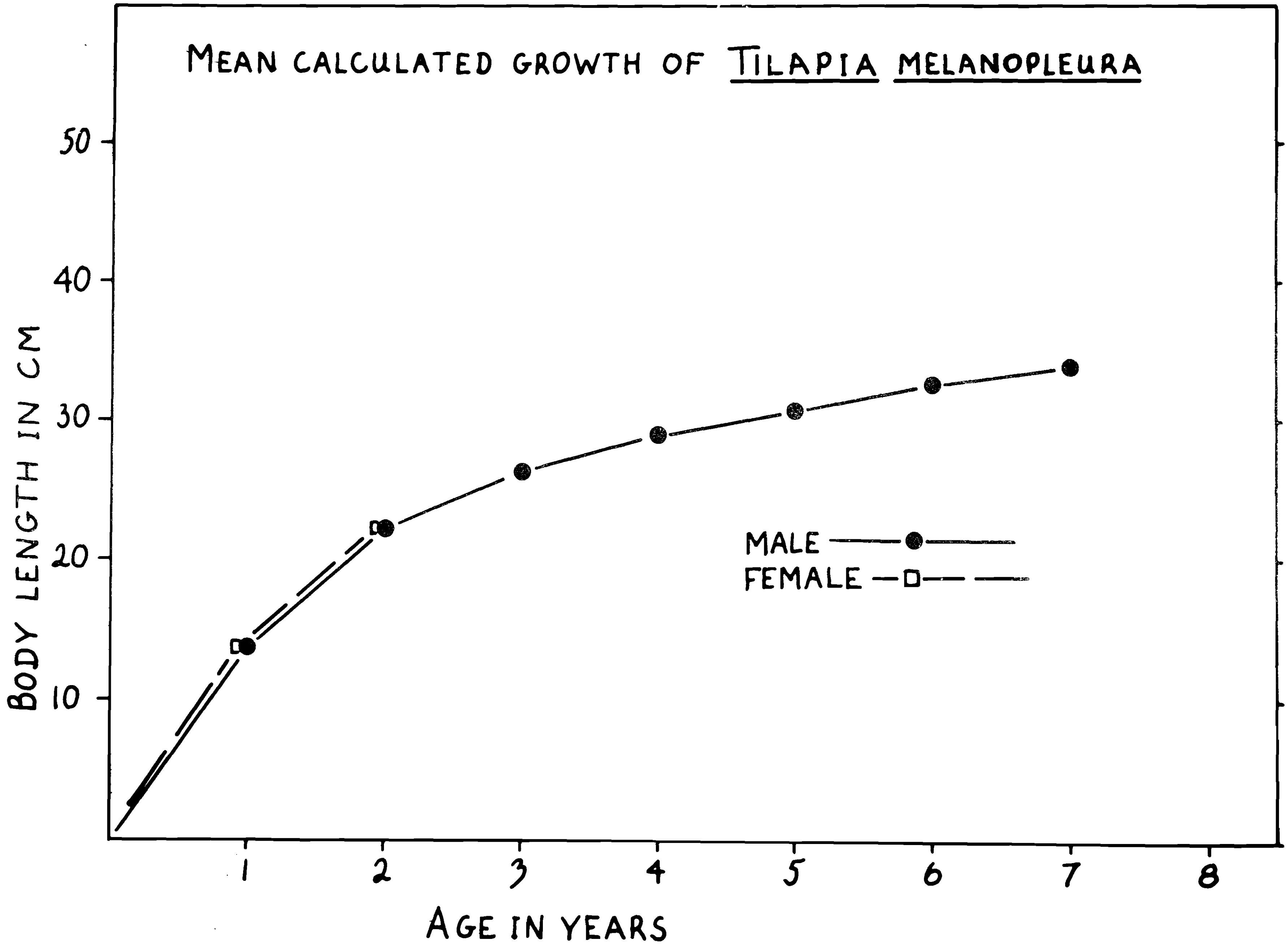


Figure 35. Mean calculated growth of Tilapia melanopleura.



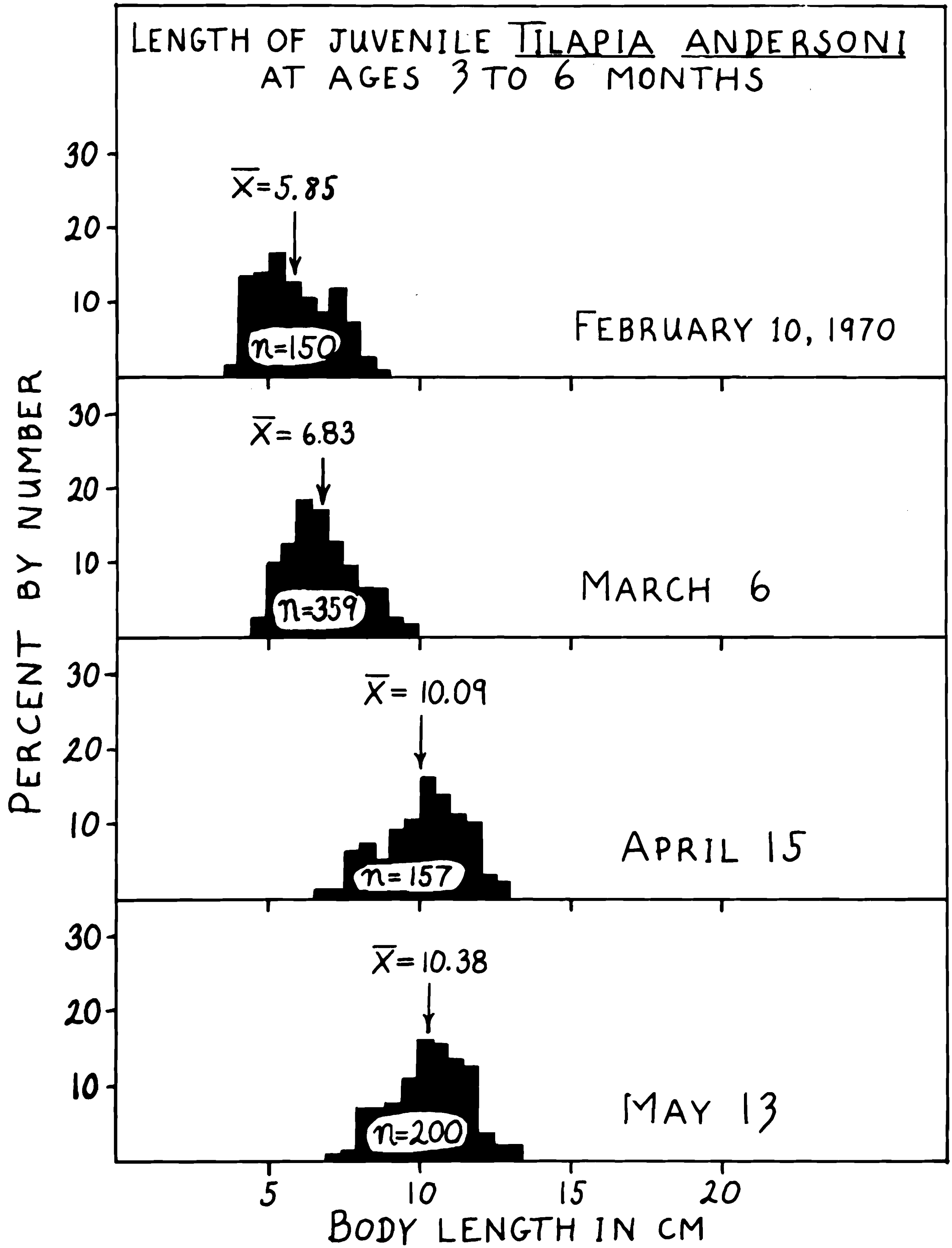


Figure 36. Length of juvenile Tilapia andersoni at ages 3 to 6 months. ($\bar{x}$ = mean).

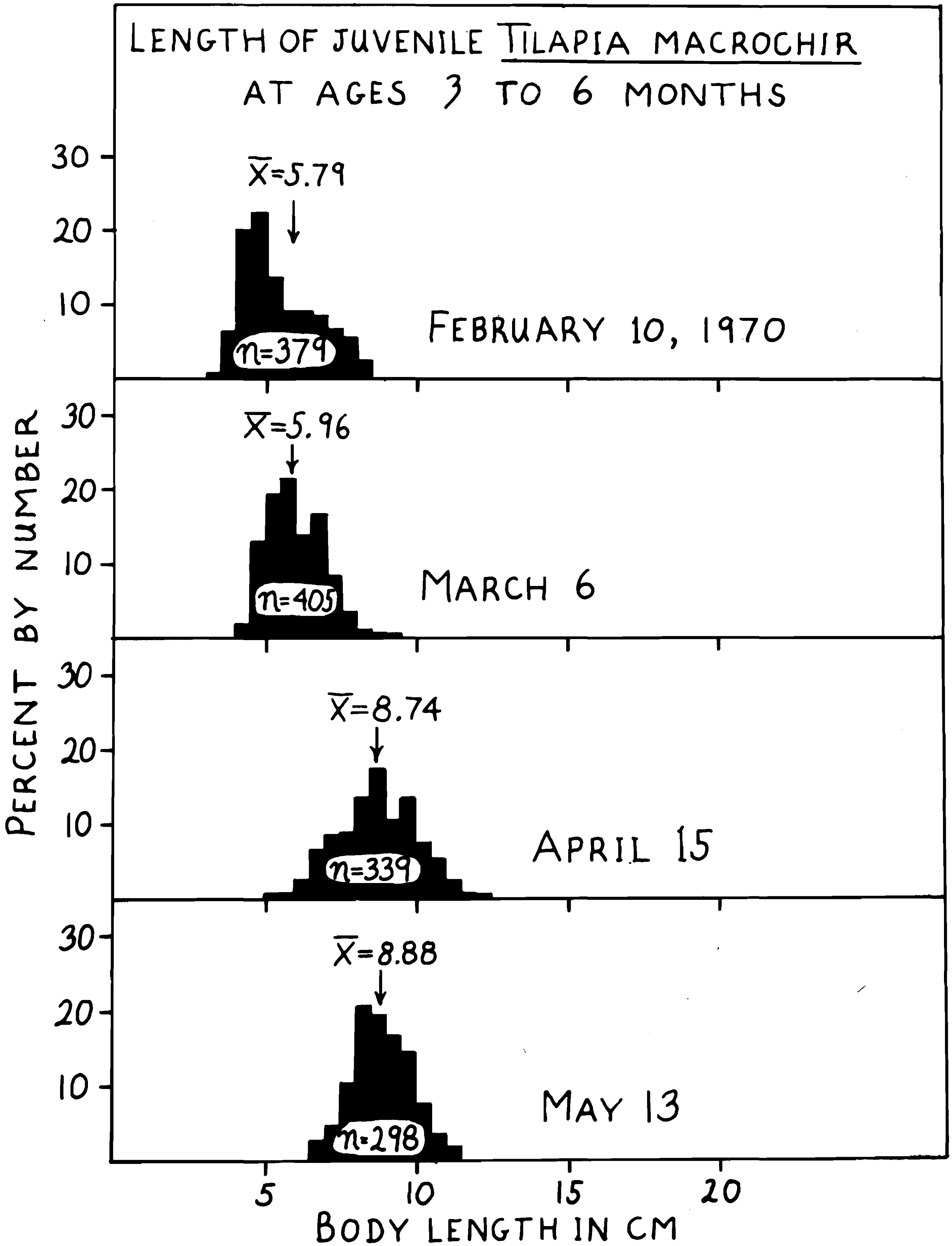


Figure 37. Length of juvenile <u>Tilapia</u> <u>macrochir</u> at ages 3 to 6 months. ($\bar{x}$ = mean).

Figure 38. Effect of flood size on the first year growth of male *Tilapia andersoni*.

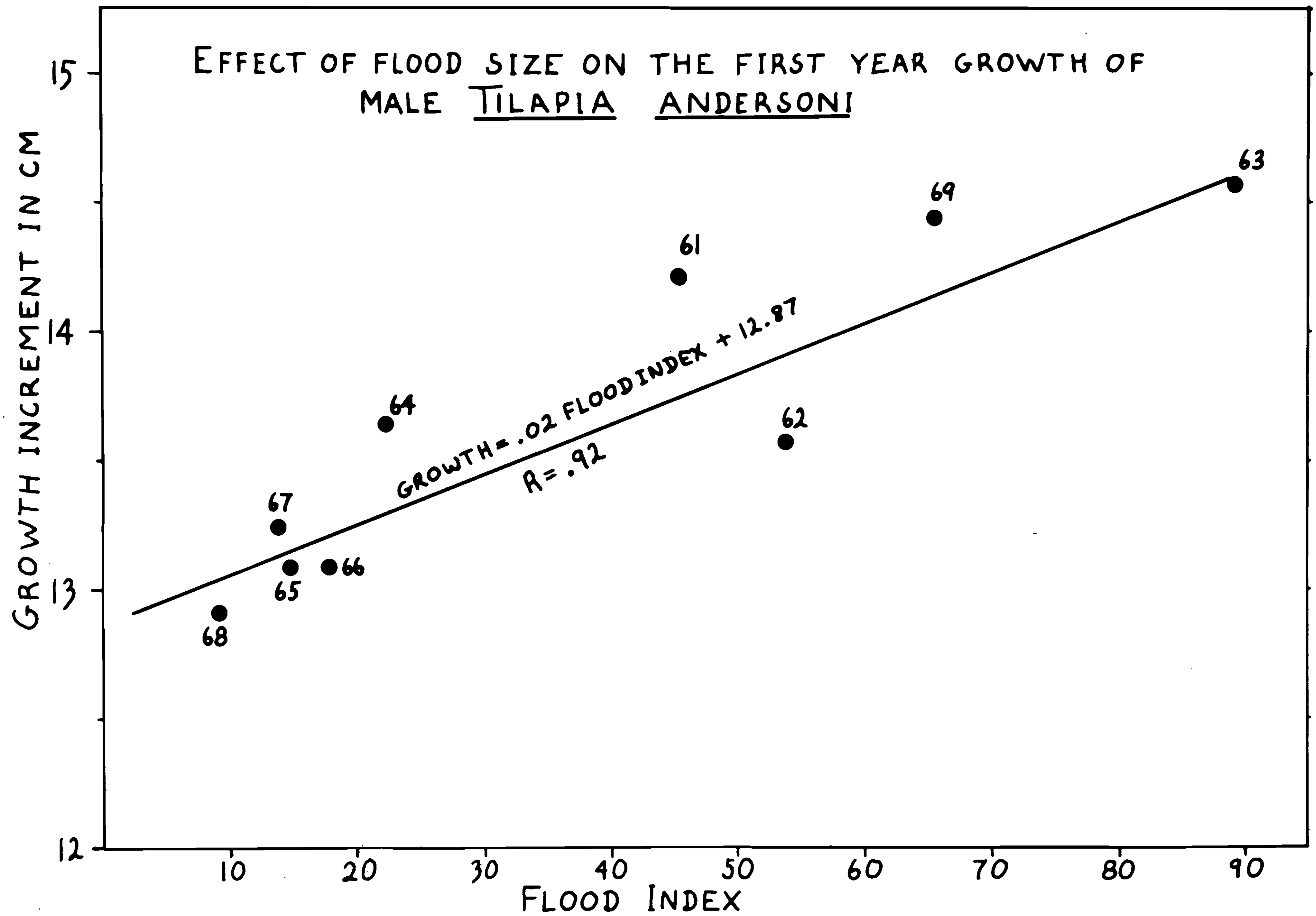


Figure 39. Effect of flood size on the first year growth of female *Tilapia andersoni*.

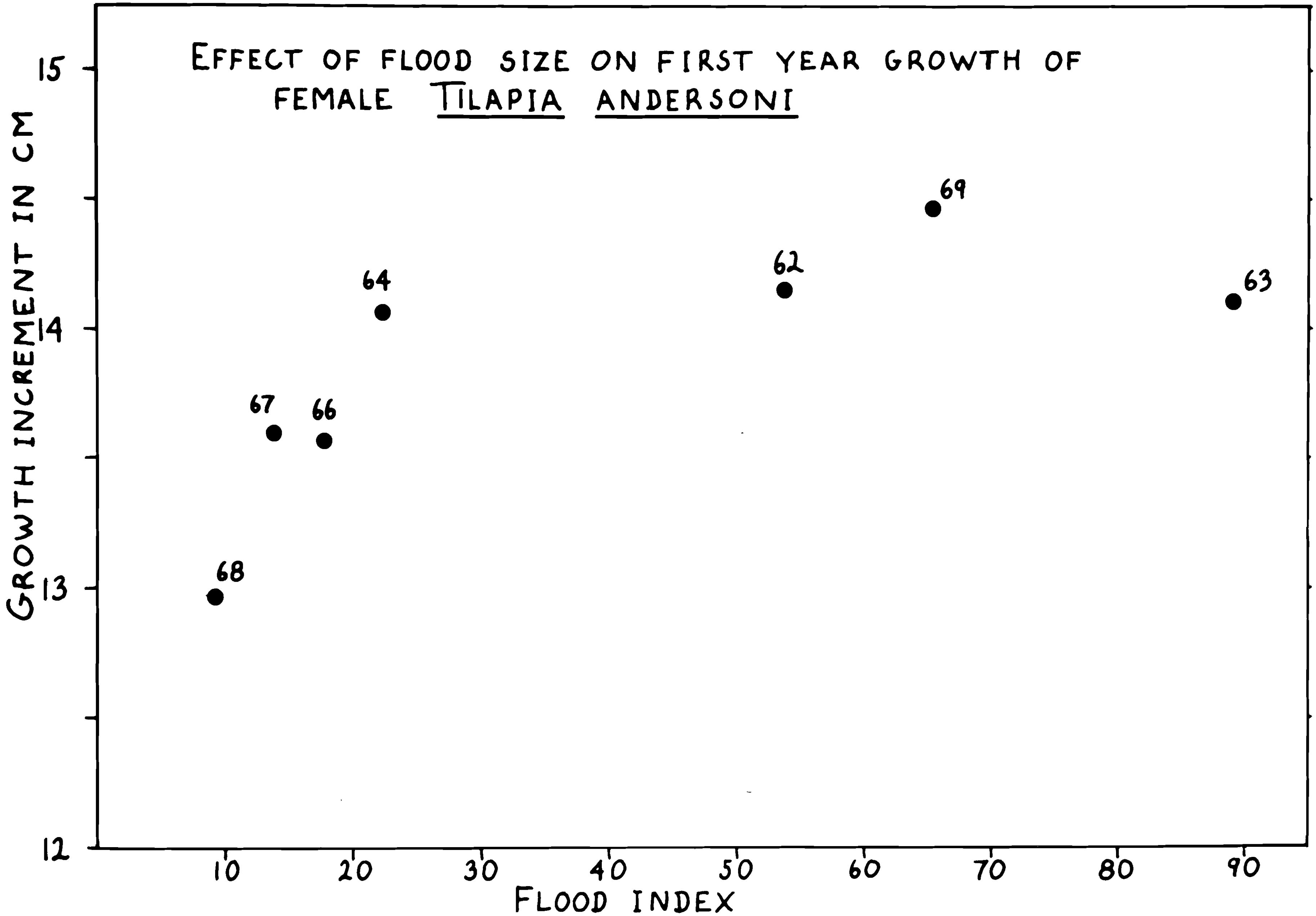
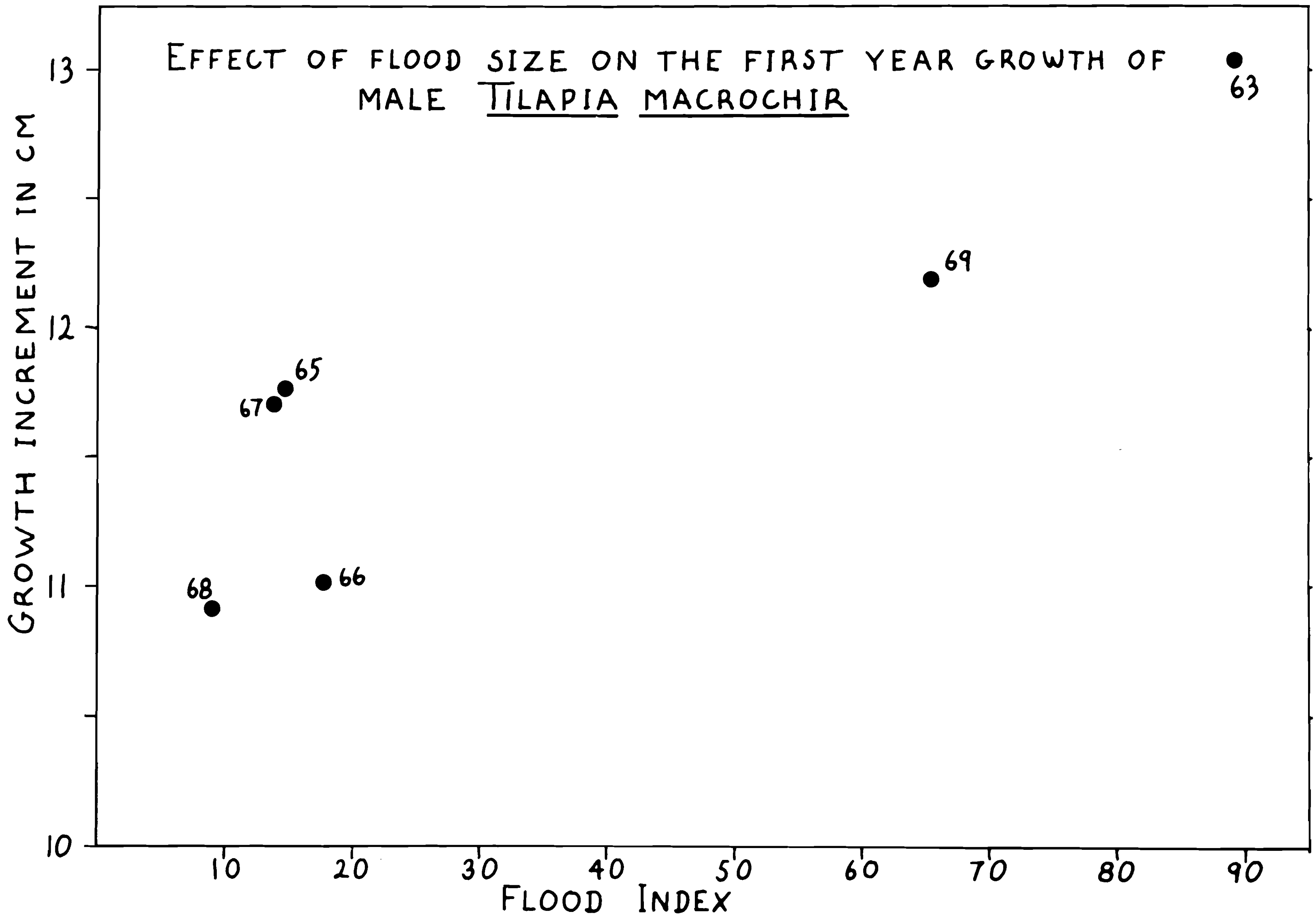


Figure 40. Effect of flood size on the first year growth of male Tilapia macrochir.



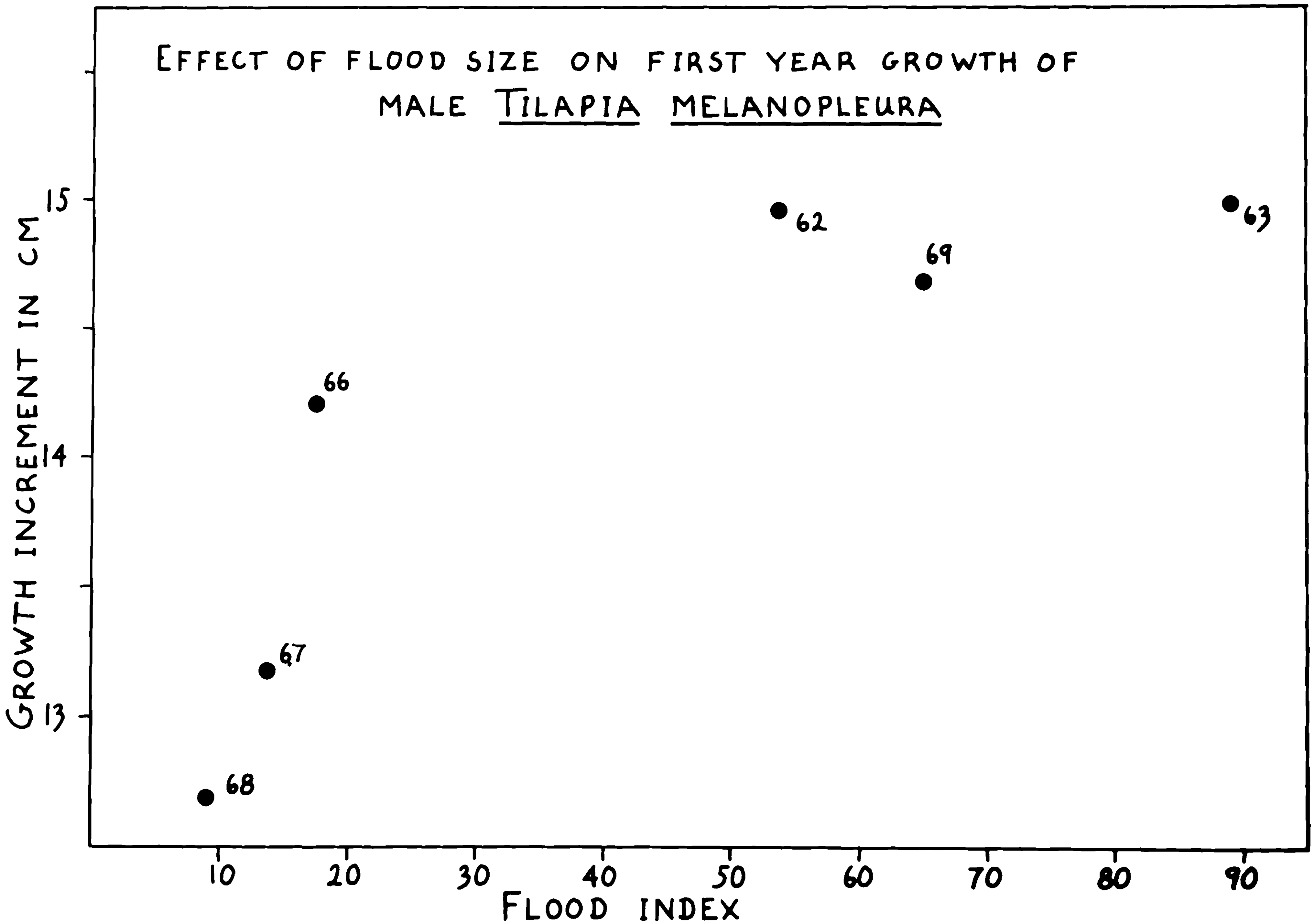


Figure 41. Effect of flood size on the first year growth of male *Tilapia melanopleura*.

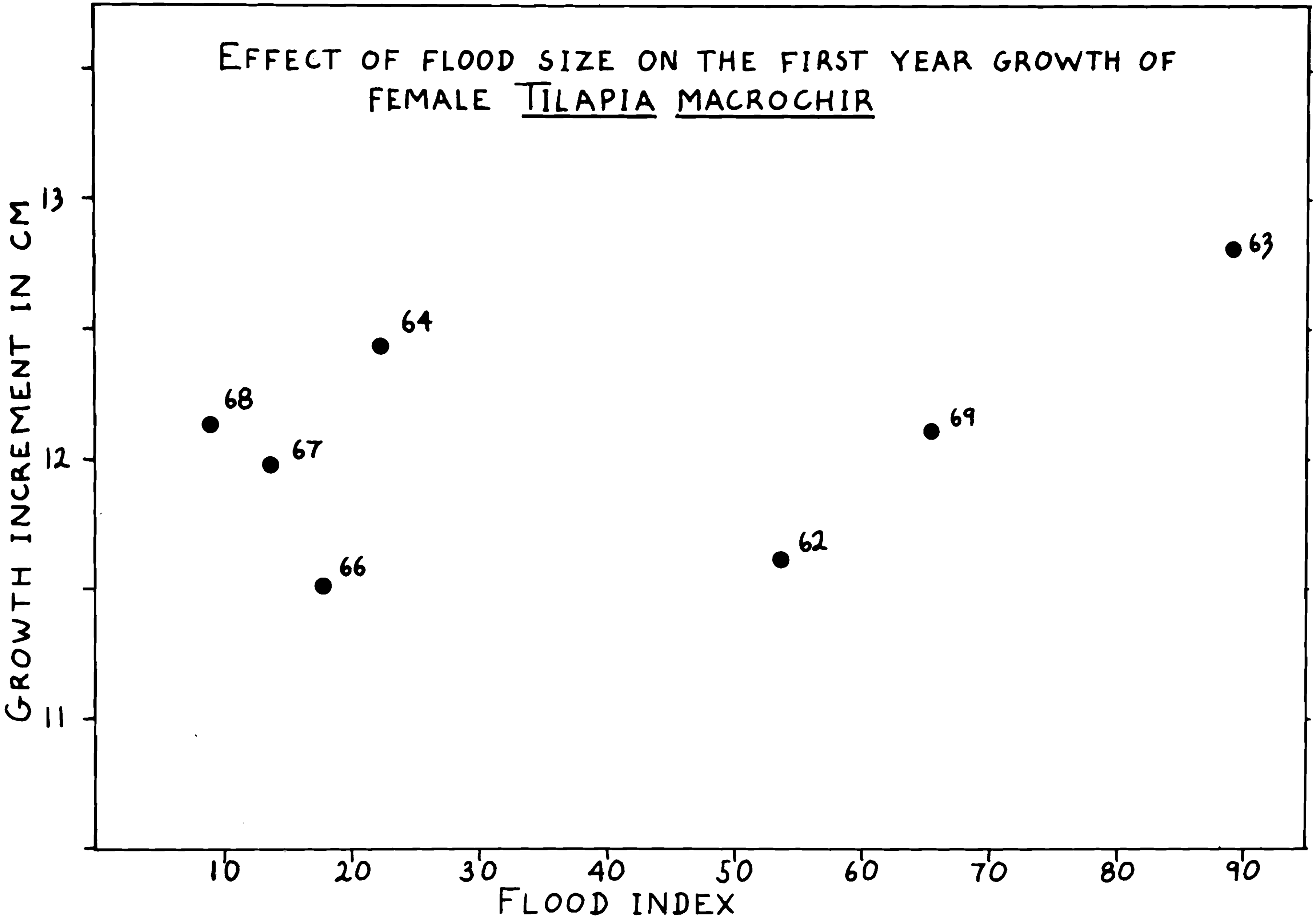


Figure 42. Effect of flood size on the first year growth of female *Tilapia macrochir*.

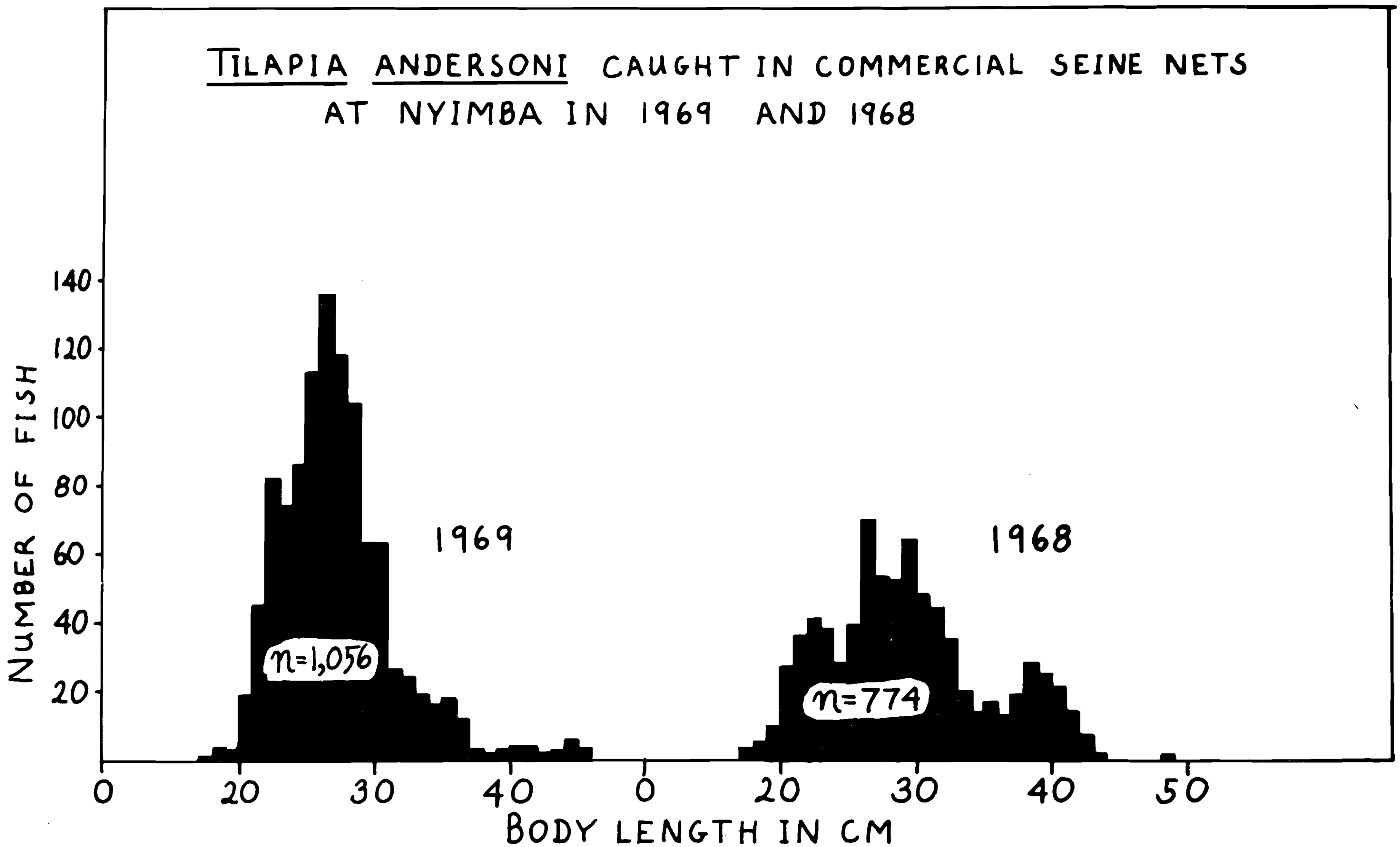


Figure 43. Tilapia andersoni caught by commercial seine net at Nyimba in 1968 and 1969 (data courtesy of G. V. Everett, Mansangu Fisheries Station).

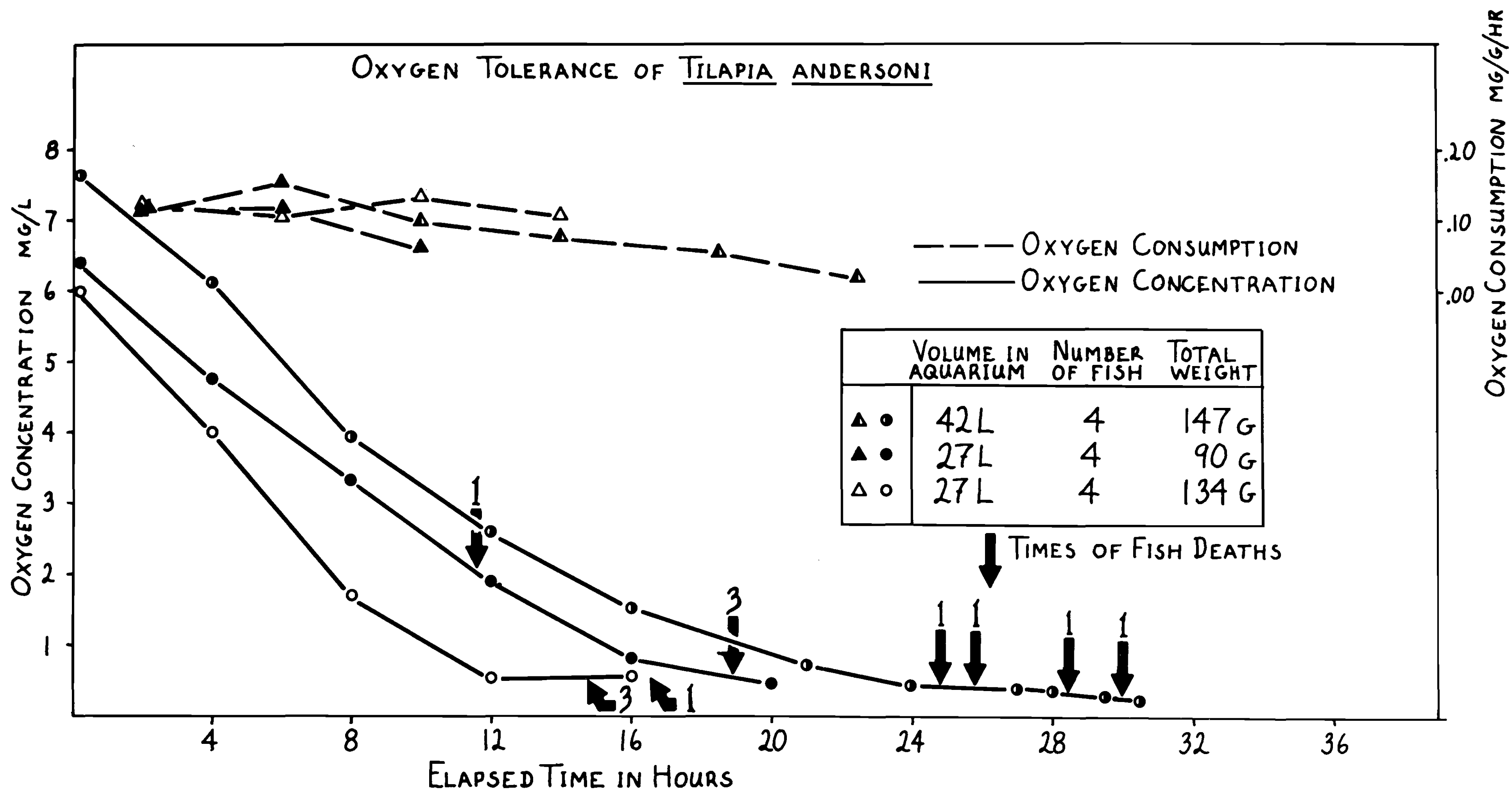


Figure 44. Oxygen tolerance of Tilapia andersoni (1 mg/l = 1 ppm)

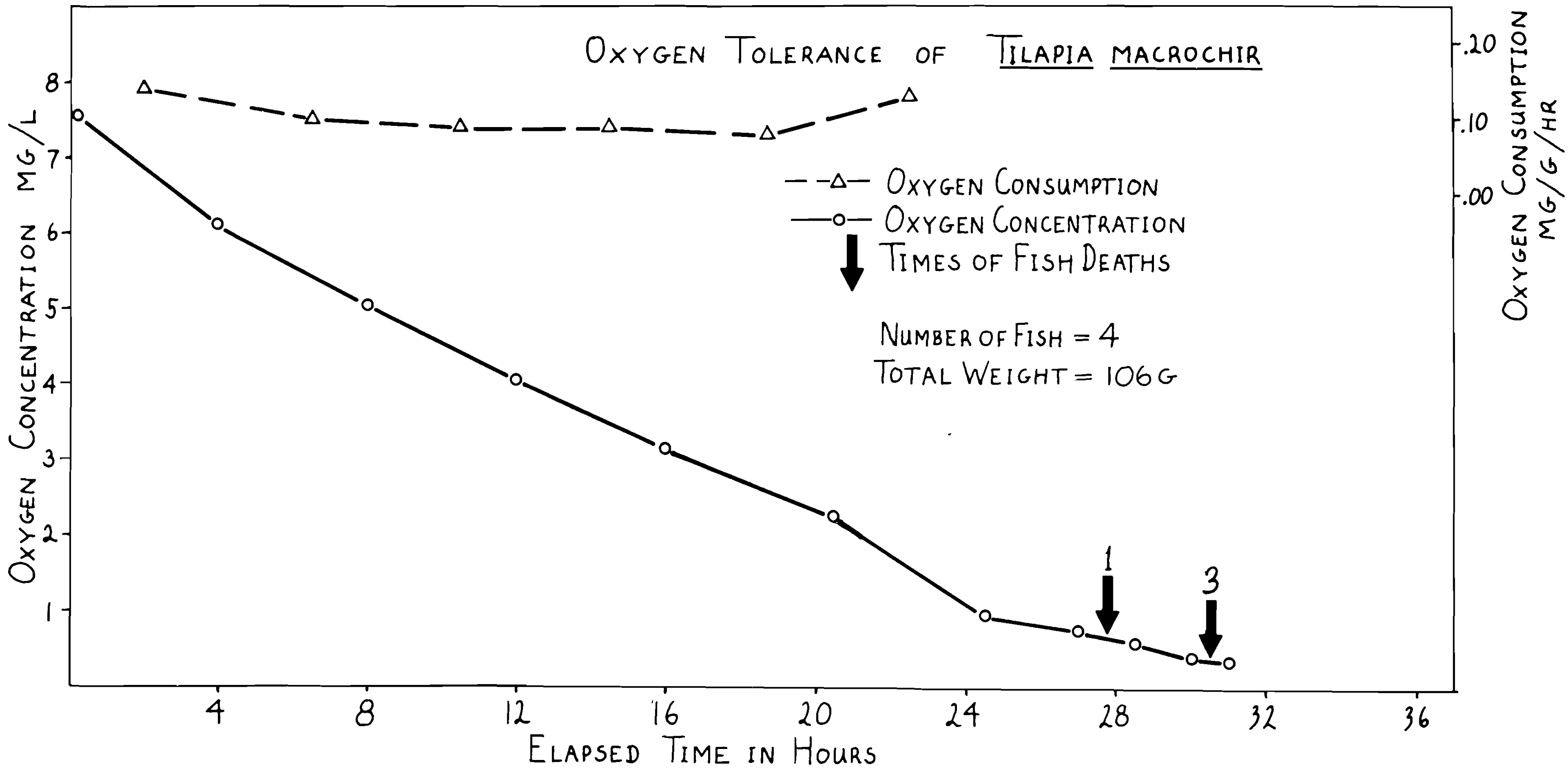


Figure 45. Oxygen tolerance of Tilapia macrochir (1 mg/l = 1 ppm)

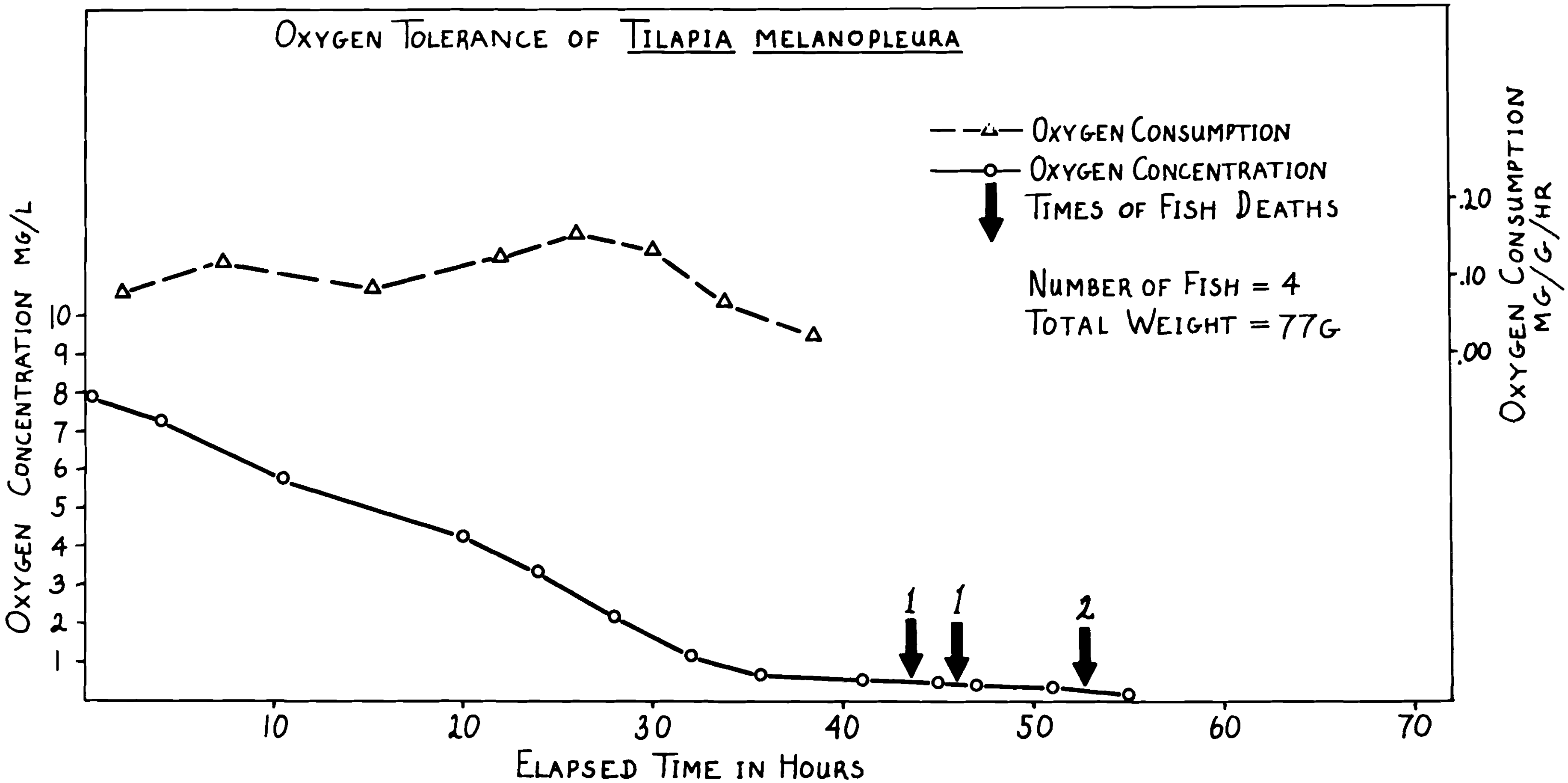


Figure 46. Oxygen tolerance of Tilapia melanopleura (1 mg/l = 1 ppm)

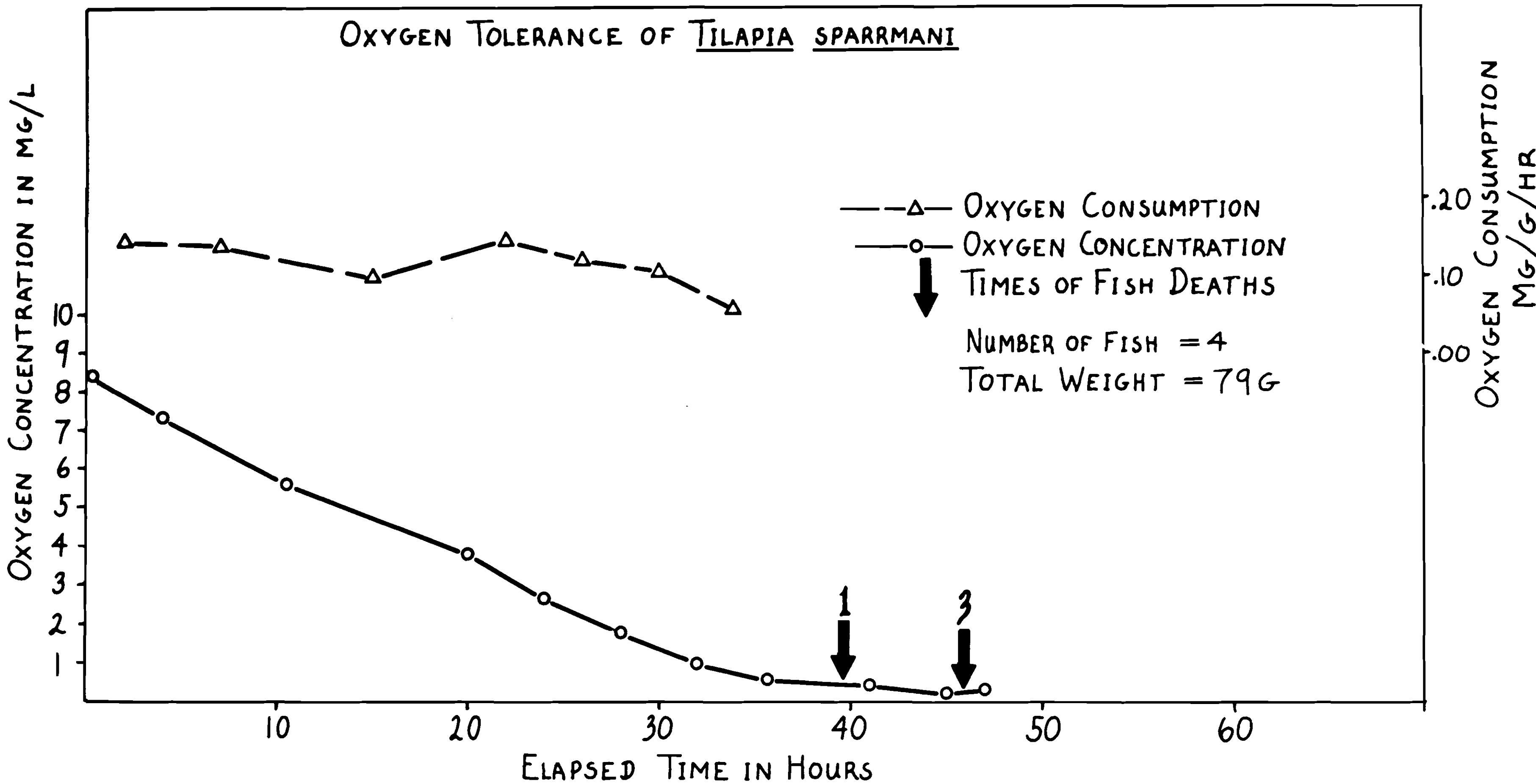


Figure 47. Oxygen tolerance of Tilapia sparrmani (1 mg/l = 1 ppm).

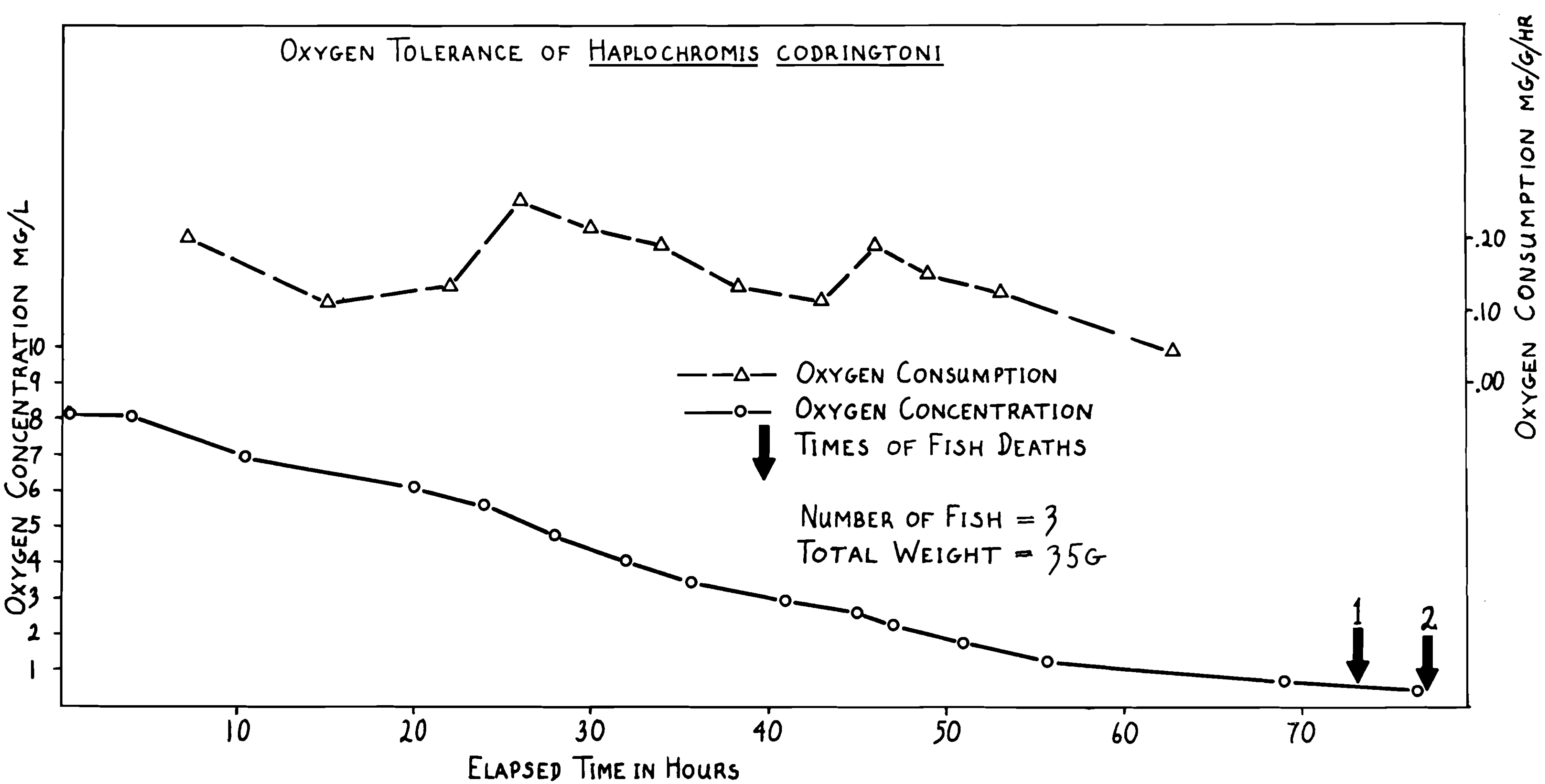


Figure 48. Oxygen tolerance of Haplochromis codringtoni (1 mg/l = 1 ppm).

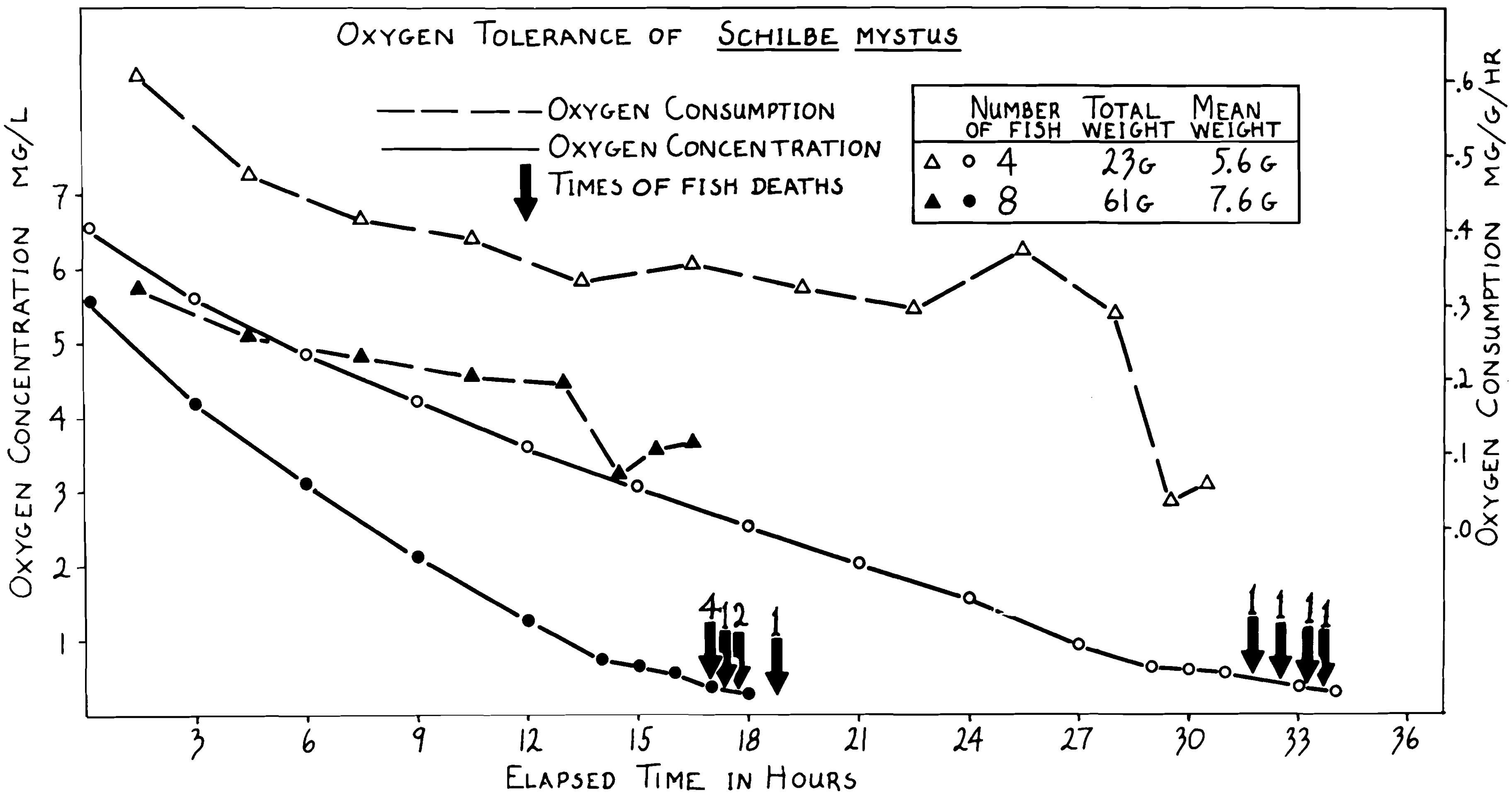


Figure 49. Oxygen tolerance of Schilbe mystus (1 mg/l = 1 ppm).

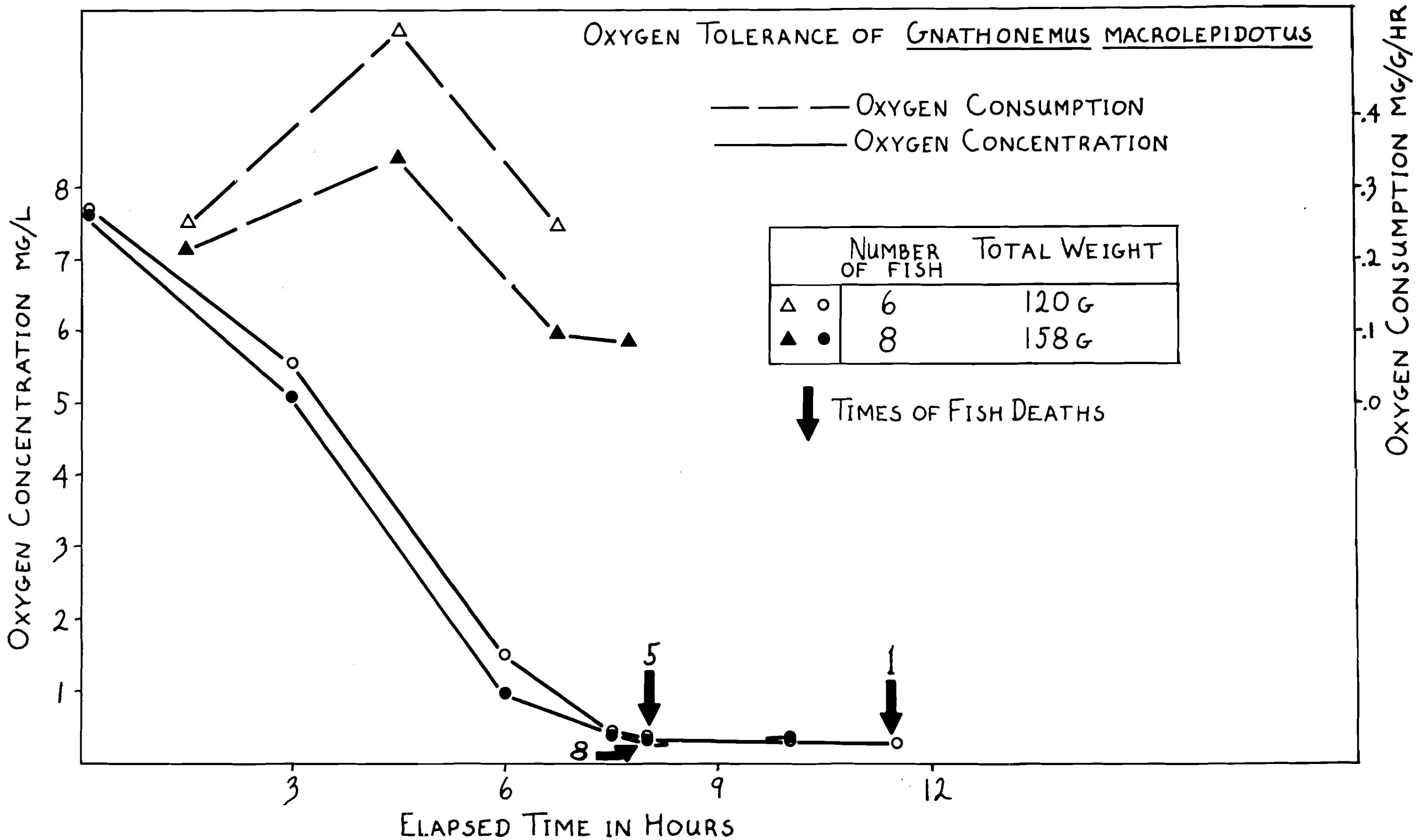
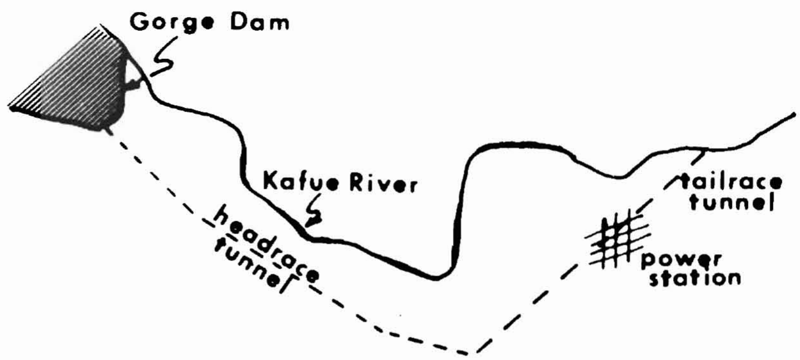


Figure 50. Oxygen tolerance of Gnathonemus macrolepidotus
(1 mg/l = 1 ppm).

A



B

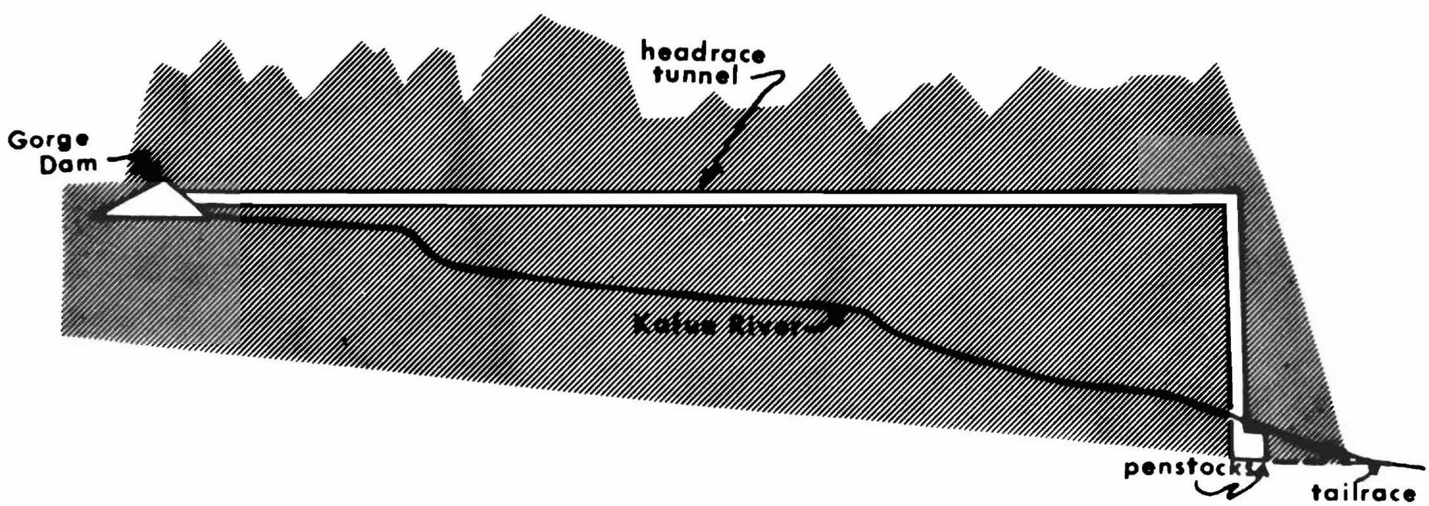


Figure 51. Drawing of Kafue Gorge Dam showing main Kafue River (A) and power installations (B).

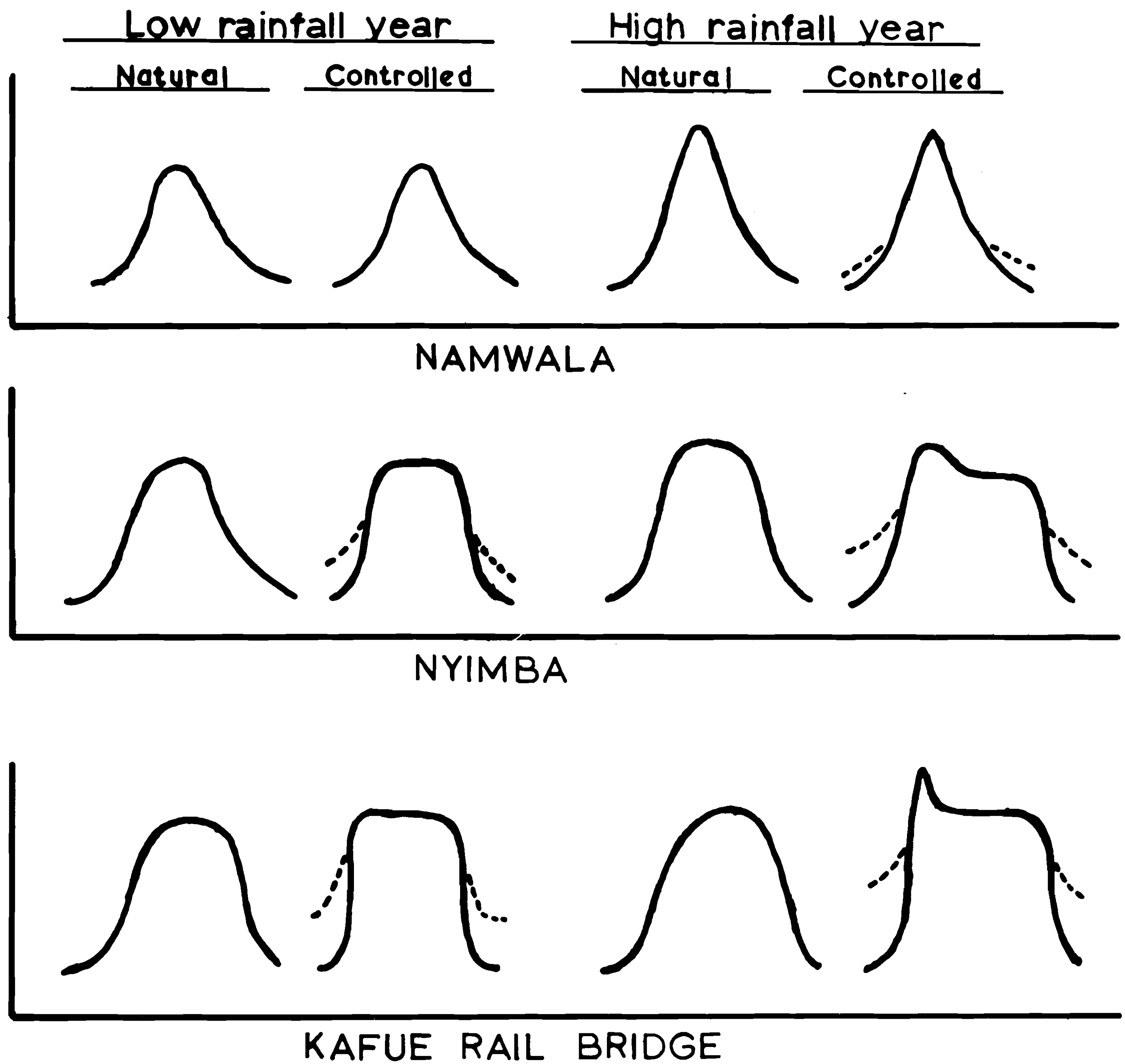


Figure 52. Effect of Kafue Gorge Dam on flood cycle at upper, middle and lower section of floodplain.

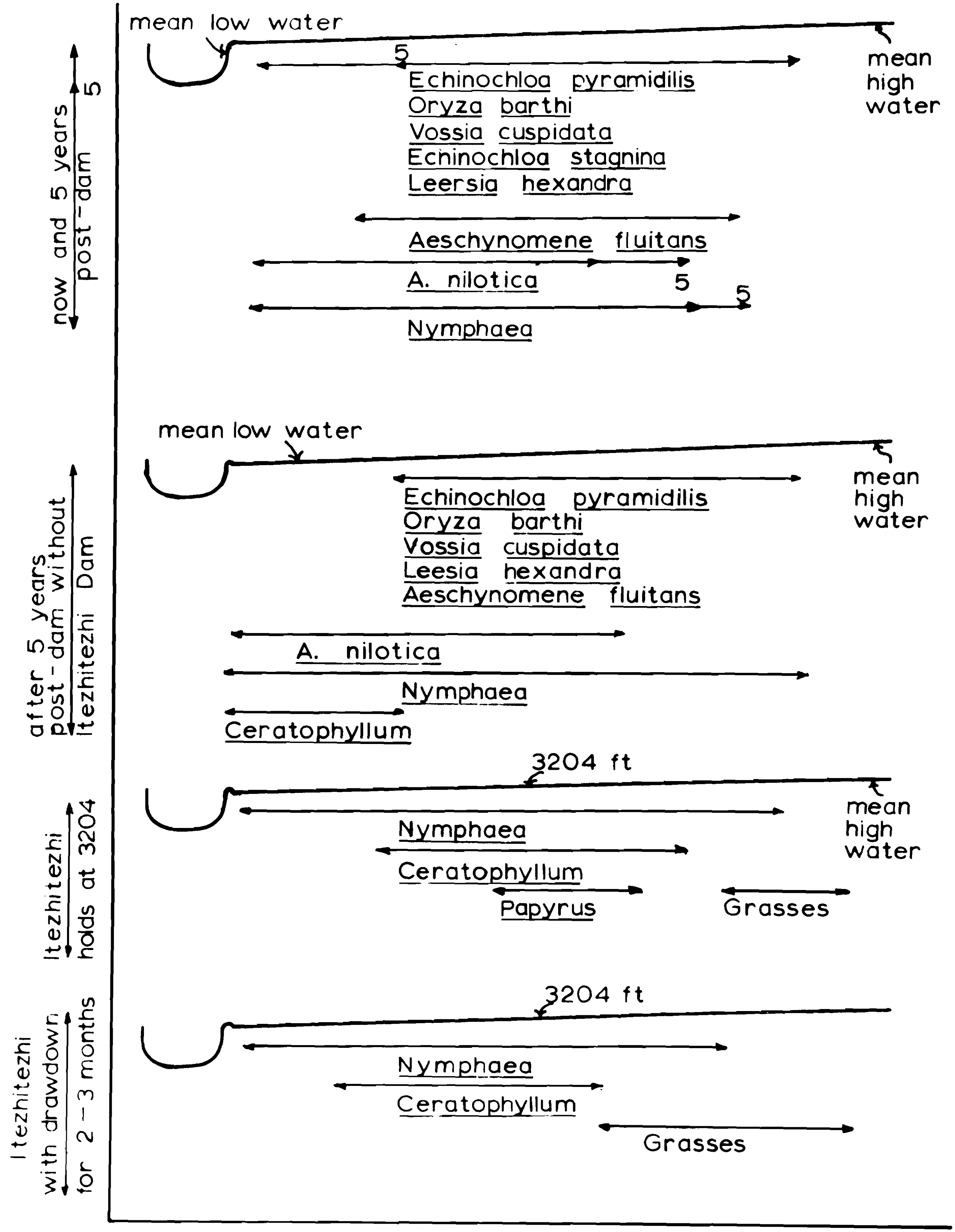


Figure 53. Schematic diagram of vegetation types in several hydrologic regimes.

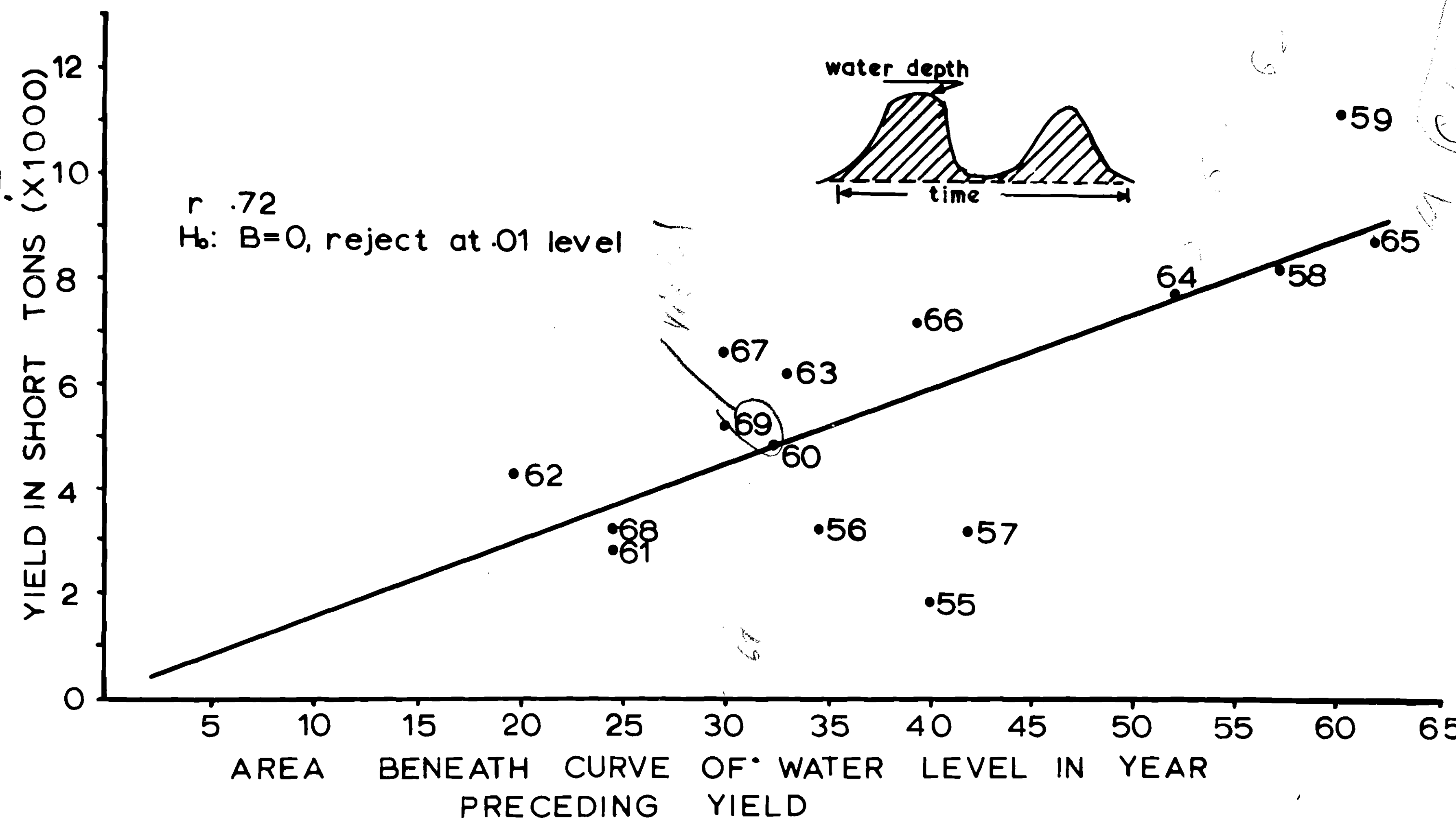
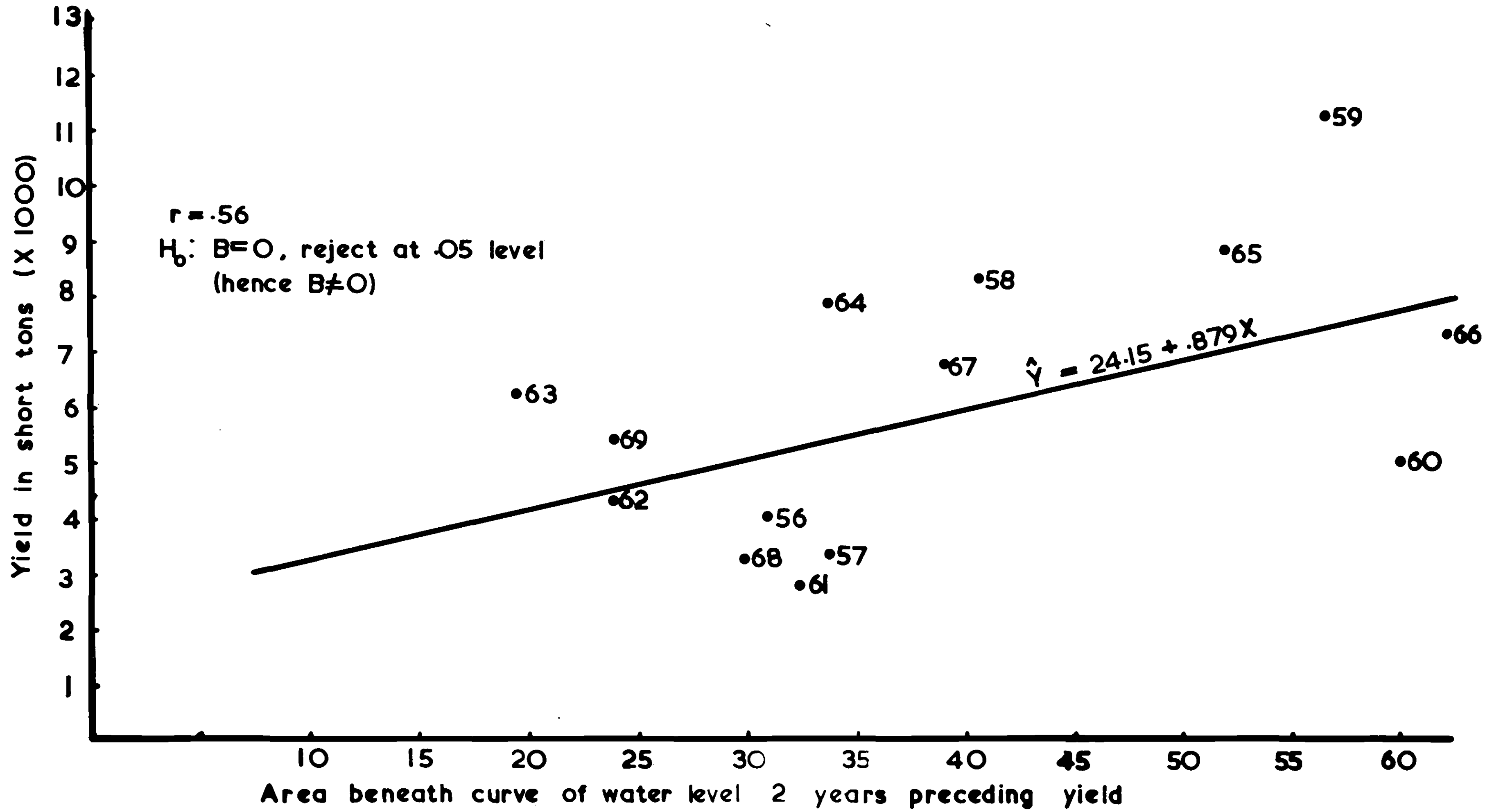


Figure 54. Correlation between length and magnitude of flood in preceding year and yield, Kafue River, 1954-69. Horizontal axis = area beneath curve of water depth at Kafue Rail Bridge; vertical axis = yield to fishery one year after flood.

Figure 55. Correlation between length and magnitude of flood 2 years prior to yield and yield, Kafue River, 1954-69. x = area beneath curve of water depth at Kafue Rail Bridge; y = yield to fishery 2 years after flood.



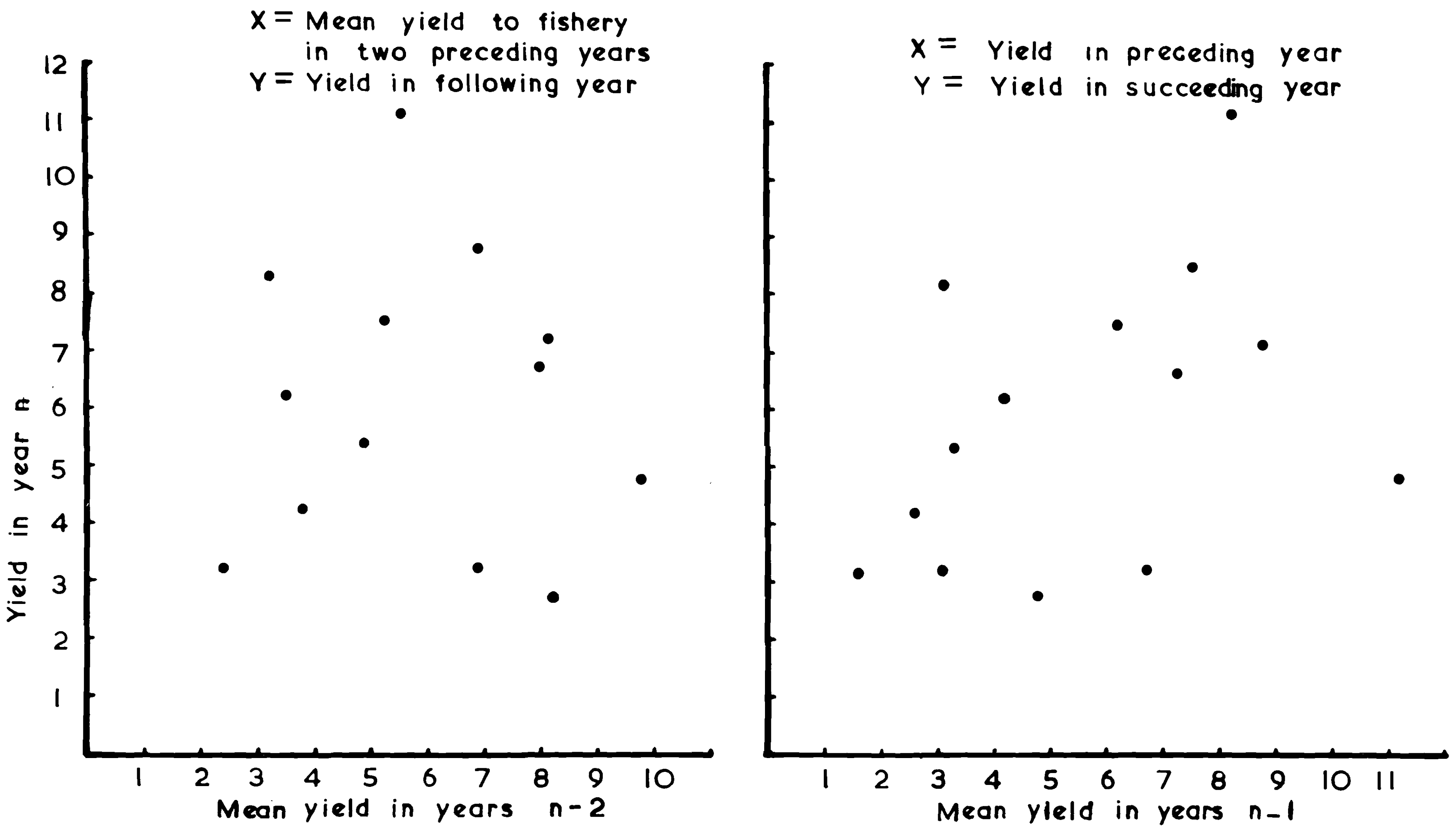


Figure 56. Yield in preceding two years plotted against subsequent yield.