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# POSSIBLE FISH STOCK SIZE ASSESSMENT AND AVAILABLE PRODUCTION SURVEY AS DEVELOPED ON LAKE KARIBA

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This paper is an outline of methods practically useful for the evaluation of ichthyomass, fish abundance, available production and yield in lakes and rivers. Terms and concepts are reviewed, and difficulties stemming from the use of "predetermined" mathematical models are discussed. Sampling with toxicants in blocked-off areas was found to be the most practical method and is described in detail. For the total estimation of ichthyomass the spatial ranges of fish distribution must be determined; the results of echo-sounding surveys for horizontal, vertical, topographical, seasonal and diel fish distribution are given.

Some of the most important methods for computing available production are listed and applied to Lake Kariba as an example. In particular, a method based on the balance between the main predator and prey species is reviewed. The ecological production survey concept is finally stressed as applied to multi-species fish stocks.

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"It cannot be over-emphasized that no matter how the data are tabulated (machine, desk calculator or by hand), the tabulations can be no more accurate than the original observations. Erroneously or sloppily collected data will always be erroneous and inaccurate no matter how refined the methods of tabulating or analyzing the data are. Statistical results can never be better than the data they are based on" (LAMBOU 1959).

There are different meanings for terms developed in fish population analysis (HOLT *et al.* 1959; HOLT 1960). A stock is part of a population and both terms have been clearly

defined in biology (e.g. MARR 1957; MAYR 1963). A stock is usually considered as a topographical part but not an isolated part of the population (the fish stock of a cove is part of the whole lake fish population). In an ecological sense stock may be equal to taxocene (CHODOROWSKI 1959; HUTCHINSON 1967; HANDLER 1970) in which case the stock includes members from a number of species. The terms spawning stock, usable stock, fishable stock, adult stock and unit stock (e.g. HOLT 1958; RICKER 1958b; GULLAND 1967, 1969) always refer to some definite part of all the fish inhabiting a certain area; they must be defined precisely

and differentiated by a special adjective. Stock or population sample is different from catch sample. Catch and landing are equal neither to ecological production nor to yield. They represent the part of production and yield which is caught and landed by fishermen. The quantitative values of stock or population represent abundance of fish and ichthyomass (if applied to all fish taxa present) or standing crop or standing stock. If applied to single species we may prefer the terms biomass or mass of species under study. The meaning of other terms will be clear from the following text (Fig. 1). We also simplify the terms applied in this fish production survey, as opposed to rather well-defined uses by some ecologists.

Parallel with the development of the fish production concept new terms were invented, defined and modified by various adjectives such as: actual, whole, gross, net, global, primary, potential, real, total, secondary, community, effective, etc. Such proliferation may finally lead to misunderstanding and misinterpretation of the production concept, if the latter is used without explanation.

Recently the most correct interpretation of fish production is that "Production is defined as the total elaboration of fish tissue during any time interval  $\Delta t$ , including what is formed by individuals that do not survive to the end of  $\Delta t$  (IVLEV 1945)" or "regardless of the ultimate fate of that tissue" (CHAPMAN 1967, 1968). It is formulated in simplified form by RICKER (1946):

$$P = G\bar{B} \quad (1)$$

Here  $P$  is production per unit time,  $G$  is a coefficient of biomass growth, and  $\bar{B}$  is the mean biomass during the unit time interval. Based on this formula the original numerical estimation of production proposed by Ricker was later developed into a simple graphical method by ALLEN (1951). Although many authors have used this method of estimating fish production, it is also subject to some criticism on the question of realism and

precision (CHAPMAN 1968; NIKOLSKIJ 1965). Nevertheless it is the simplest method so far available to estimate the production as meant by Ivlev's definition.

From the fishery management point of view we may consider the part of production represented by the total elaboration of fish tissue during any time interval  $\Delta t$  by fish surviving to the end of  $\Delta t$ . In case the ratio between the instantaneous growth and mortality rates ( $G/Z$ ) is constant and no immigration or emigration of fish occurs in the evaluated stock, this part also represents production in the sense of Ivlev (RICKER 1958a; NEESS and DUGDALE 1959). This production value can be estimated "by multiplying individual weight increases by the mean number of fish present in each interval of interest" (CHAPMAN 1967). It was used by BURMAKIN and ZHAKOV (1961), HOLCIK (1970a, 1970b) and by myself.

"Production" here is akin to the "net production" of some ecologists and would equal the "available production" of a population, untouched by death, predation or exploitation during the specified time interval. Normally it is a part of Ivlev's production. The latter incorporates also the various increments of the tissue of fish that have died from natural causes, or have been eaten by predators, or caught by fishermen at different times within the time interval of interest. The available production is that mass of fish which may be taken through increased exploitation in addition to existing levels. Thus yield can be interpreted as being a harvestable part of production.

More work has been done on ocean or anadromous fish population analysis with hypothetical mathematical models (BARANOV 1918; DERZHAVIN 1922; RICKER 1954, 1958a, BEVERTON and HOLT 1957; DOI 1959; HEMPEL and SAHRHAGE 1961; GULLAND 1962, 1965, 1968a, 1968b, 1969; IVANOV 1961; LARKIN and HOU-

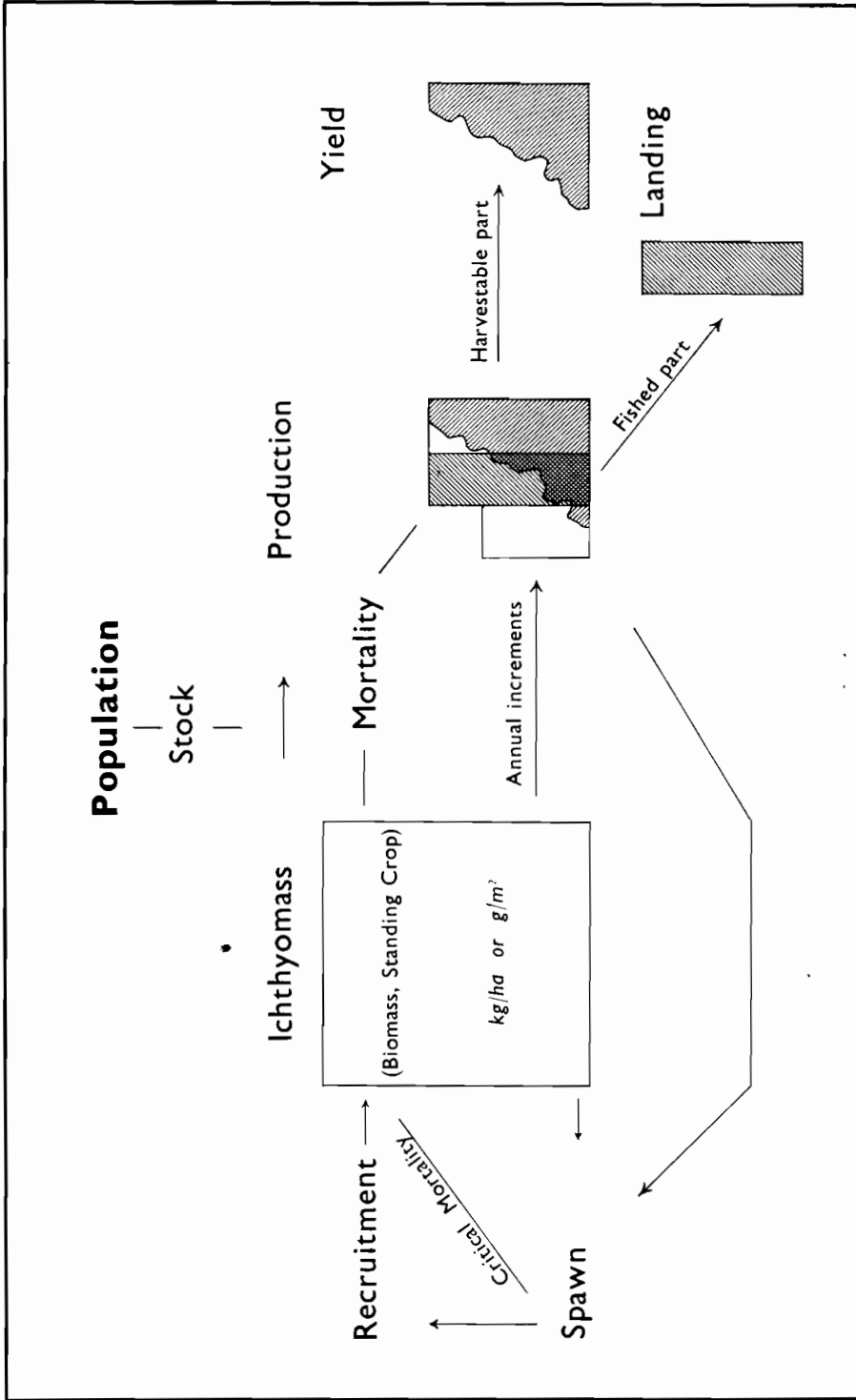


Fig 1. The simplified population analysis concept and terminology used.

TON 1964; PELLA and TOMLINSON 1969; FOX 1970) than has been done on fresh water fish populations. The reason for this is that the ocean environment is more difficult to sample than a smaller fresh water area (REGIER 1970a). The open water habitat of a large lake and that of an ocean are similar, however, and sampling methods for population analysis used in ocean fishery research are equally valid for shoaling open water fish without respect to salinity or the size of environment. Furthermore, methods of fresh water fish population analysis stressed here are fully applicable for lagoons, reefs, or inshore marine populations (BALON and SENES 1967; HOLCIK 1970b).

We may identify the role of models and distinguish between roles as follows. Methodological models are those which help to programme the research and state in advance the number of samples required for certain variability coefficients and confidence limits. These models are clearly useful. Models that seek to define the interrelationships of a series of variables rather precisely, as opposed to general semi-quantitative research concepts, should not be assumed uncritically (VARLEY'S comment, 1962), particularly in work which tries to generalize and predict theoretical conclusions. A model must not be accepted and applied before the collection of sufficient data to indicate its degree of realism. The steps might be formulated as follows:

1. Field data collection (measurements) on variables thought to be closely related to the question under consideration.
2. Summary calculations (perhaps with the help of computers, e.g. GERKING 1965; ALLEN 1966; SWINGLE and SWINGLE 1966; LEEPER, STERN and LAMBOU 1958; LAMBOU 1959, recognizing that computers cannot improve bad data or replace missing data).
3. Construction of working models.

4. Completion of field data collection.
5. Tests of models thought to be appropriate.
6. Formulation of theoretical generalization and construction of models that will yield predictions.

The rigorous purist would argue that a model is to be constructed separately for every case of data collection and in respect to the specific situation. If not, the influence of predetermined mathematical models on data collection and resulting calculation can lead to quite erroneous conclusions; empiric real data cannot be selected ultimately, but must be collected. Similar views have been expressed by VARLEY, PEARSALL, GRAHAM (1962), NIKOLSKIJ (1965), KNIGHT (1968) and others. Furthermore, no model constructed in advance is able to predict species inter-relationships and such model construction for a single or a few equalized species is the source of unrealistic results and erroneous conclusions (NIKOLSKIJ 1964; HOLCIK; 1970a).

Difficulties with overly simplified mathematical models may be illustrated by the trend in estimates of maximum sustained yield of the Peruvian anchoveta, *Cetengraulis mysticetus* as more data become available (SCHAEFER 1967, 1970). Alternative estimates could have been obtained employing simple calculations and evaluations of empiric variables from the fish biology, e.g. relation of mortality rates (man and birds) to fecundity and growth increases of the exploited anchoveta population. But this may mean more field data sampling. "It is clear that our mathematical models are not yet adequate for the complexity of natural systems" was the conclusion of a panel of ecologists under A. D. Hasler's chairmanship. It continued as follows: "Computer simulation is a promising technique for understanding such matters, but computer models need both adequate formulation, or programming, and higher quality data . . ." (HANDLER 1970).

The usual starting point in a quantitative

population analysis is to count or estimate the total stock or, more commonly, to obtain representative samples of it. If devices used to sample fish for such purpose are the same devices used to capture fish for food or sport, they are highly selective and the whole history of their use proves them to be unpractical if used uncritically. To estimate the gear's selectivity to limits of usable precision requires special studies, that have been undertaken for only a few species and gears. Some devices can be used successfully in specific cases without explicit selectivity estimates, e.g. use of the purse seine with single species stocks with schooling habits.

The capture-mark-recapture methods also are biased in that they evaluate only part of the stock (BASTL, HOLCIK and KRUPKA 1969) selected by gear in use. The Leslie-DeLury and other similar methods (CHAPMAN 1948) are applicable mainly for smaller stream habitats and are also affected by gear selectivity. In some cases where production by juveniles can be ignored, the latter method can yield sufficiently good data for practical management purposes (HOLCIK 1970a; MARTEN 1970). Combined with juvenile capture devices (BREder 1960) this method could in some cases replace chemical sampling.

The Lake Kariba programme has been based upon the above considerations. Furthermore, it has been assumed that the most important aspect of fishery research and development in early stages should be the evaluation of the protein reserves, employing a well planned study of the production and yield of fish (HOLT 1967). Otherwise there would be nothing to guide the gear and processing technologists in planning the size and composition of fish catches, the scope of the processing plants, marketing systems, etc. Data on fish catches or landings and fishing effort statistics cannot provide estimates related to ecological production nor its relationship to the magnitude of

potential catches early in the development process. Available mathematical models proposing to do so may yield only very approximate estimates applicably only to dominant species.

It was decided that the main data to be collected were: relative abundance of fish and relative biomass by species, relationships and balance between various species, age composition and mortality rates of various species, and annual weight growth increments.

One of the most adaptable survey methods for shallow waters is sampling by eradicants in blocked-off areas. Since TARZWELL'S (1940) first trials in 1939 in the Tennessee Valley, and ESCHMEYER'S (1943) programme, the method has been greatly improved and has been in general use in freshwater reservoir population studies (CARTER 1958; CHANCE 1958); and LAMBOU and STERN 1958; SWINGLE 1958; SURBER 1959). Some experiments have also been started in the sea (HIATT and STRASBURG 1960; RANDALL 1963). After this method was used for the first time in Africa on Lake Kariba, the results of an experiment on the Douglas Reservoir in the U.S.A. were published which discuss the significance of such sampling for an entire lake (HAYNE, HALL and NICHOLS 1967). The Lake Kariba work has utilized experience with different toxicants in population studies on the Elbe and Danube riverine lakes of Czechoslovakia (OLIVA 1955, 1960; BALON 1963, 1966a, 1966b, 1966c, 1967, 1968b); and this experience was adapted to African conditions.

The selection of the method of application depends upon the topography and maturity of the reservoir treated. If the lake is shallow and old with well developed open water ichthyofauna, the sampling area should be established away from the shore by blocking off square or circular areas. This should also be the case on most natural lakes, such

as Lake Mweru. Some deep lakes, however, have more or less separate inshore and open water fish fauna. This is the case of Lake Tanganyika, Lake Victoria, etc. Here blocked offshore areas as well as coves should be sampled. At Lake Kabira our original presumption was that the entire fish population was of riverine origin and that there had not yet been time to develop an open water fish fauna. After testing this by echo-sounding and gillnets set in different areas it became evident that cove and inshore sampling should be representative enough. Stream and river sampling is simpler between two blocking nets and the chemical can be neutralized downstream.

#### ECHO-SOUNDING SURVEY FOR RANGES OF FISH DISTRIBUTION

To test whether the fish fauna was essentially an inshore one, and to find ranges of fish distribution, a large scale echo-sounding survey was begun on Lake Kariba. With few exceptions, records from open water areas showed practically no fish. Closer to shore, in depths less than 30 m, the abundance of fish appeared to increase, the maximum being at 5 m during daytime and about 10 m at night. This generalization was equally valid for cleared bottom areas and for areas with submerged trees. Without exception the records showed that the main fish distribution was limited to shallow water close to shore and mainly to bays and coves.

Fish seemed to concentrate in the evening along the shoreline and especially in bays and coves, being distributed in remarkably high density from the surface to 15 m depth with maximum density at 6 to 7 m depth. Only at places shallower than 15 m was the evening concentration of fish distributed from the surface to the bottom. At dawn in the same places the major concentrations of fish had changed to a less dense distribution extending further offshore to a distance of

about 2 km. Around islands with steep shores fish were found only in coves or in strips a few meters wide close to shore. In areas of the lake shallower than 15 m but far away from shore, fish were recorded only occasionally, as was the case in the deeper open water areas. These observations are partly confirmed by COKE'S (1968) results with gillnets set in different depths.

It is estimated, therefore, that the main average area of Lake Kariba inhabited by fish in 1968 and 1969 was 33,422 ha, which corresponded to the 0-20 m depth area at a normal water level of 485 m (COCHE 1968, and personal communication). This represents 6.2% of the total lake surface, 5,364 km<sup>2</sup>.

#### SAMPLING METHOD

Lake Kariba, which has numerous bays and coves along the entire shoreline and which presents a fish distribution as mentioned above, is one of the best impoundments for cove and shore-line sampling. On the average this method should provide representative samples of the whole fish population. In a three year period several 0.5 to 5 ha coves, stream estuaries and three-sided blocked shore-line areas were selected and treated. The blocking nets of 8 mm mesh were set at different hours of the day (Fig. 2). This was done to avoid fencing off the same concentration of fish in the cove or along the shore-line and to avoid fencing off the highest evening concentration each time. The blocking nets should be, and usually were, checked by a diver, especially along the bottom leadrope.

Emulsifiable rotenone at 5% concentration, and 75% emulsifiable toxaphene sold locally as a cattle dip (firm name: Altik), were used (HEMPHILL 1954; HOOPER and GRZENDA 1957). The kind of eradicator used is, however, not important and availability (MALAISSE 1969) as well as effect-



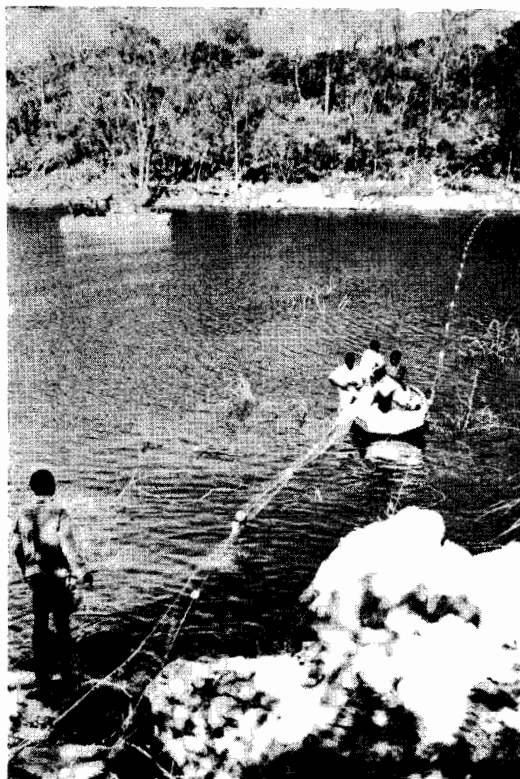


Fig 2. Setting of a double blocking net in the mouth of Chikanka Island cove at Lake Kariba.

iveness, harmlessness to environment, and cost may be taken into account (LENNON 1966; HERR, GRESELIN and CHAPPEL 1967; POWERS and BOWES 1967). The concentrated solution was distributed by boat through a 5 mm hole made in the original 5 gallon drum and was mixed by the outboard engine propeller or by motor pump through perforated hose—in a manner similar to that of CHANCE (1958). The water volume within the blocked area was estimated roughly in order to calculate the necessary amount of toxicant. The minimum lethal dose (HENEGAR 1966; MAHDI 1966) was exceeded because it was essential to kill all fish at once and get the residual fish on the bottom to surface not later than

the third or fourth day. In present temperature conditions, the fish which appeared later had become so rotten that it was difficult to lift and measure them. Fast killing was also essential in order to limit the bias created by scavenging by birds, mammals, and occasionally crocodiles and monitor lizards. An average of 200 litres of Altik was distributed per hectare or per 20,000 m<sup>3</sup> water which represented 7 ppm toxaphene. Even so, some *Clarias* were dying only the third day. The overdosing has a limited effect outside the cove. One month later the treated area was inhabited again and in one recorded case had a higher abundance and mass of fish (although by a smaller number of species) than it had prior to treatment.

Fish were collected in the deepest part by dip nets and along the shoreline by hand. All fishes including the smallest juveniles were collected. On some of the larger fish the necessary determinations and measurements were made on the spot. The majority were preserved in 4–10% formalin for later treatment in the laboratory.

Before the end of the sampling and the lifting of the blocking net, the entire cove was measured using plane table and soundings (first by lead-and-line, later by echosounding). A detailed bathymetric map was made. The area, length of shoreline, maximum and average depths and volume of water were then calculated exactly. Finally the blocked cove bottom was checked by a diver for residual fish which were counted for predetermined strips of bottom area.

#### PRIMARY LABORATORY PROCESSING OF FIELD SAMPLES

The majority of fish sampled, and particularly the smallest ones, were transported to the laboratory in formalin solution. Every specimen was identified and standard length recorded. The weight and the total

length were also recorded for the first few hundred fish of every species and correction factors for weight differences of fresh, rotten and preserved fish determined. Conversion diagrams and tables for total length and fresh weight were calculated which simplified processing of later experiments based on standard length measurements only (Table 1).

The symbols used are those suggested in the IBP Handbook No. 3 (RICKER 1968). The standard length (l) and the total length (L) were measured with an accuracy of 1 mm; the weight (w) of fresh fish or of fish fixed in formalin was obtained to the nearest 0.1 g (small) or 1 g (large fish). The entire material was put into groups of 10 mm length intervals. The basic table of abundance and biomass was then constructed and the length-frequency distributions were calculated. Then from each "10-mm-length-group" a maximum of 10 specimens (5 females and 5 males) were selected, their sex was determined and key scales or vertebrae removed.

In this paper there will not be a list of all processes and methods used but only those of special importance for the main outline of the fish population production study. Concrete cases have been published (BALON 1971c, 1971d), and will be described in the future. Here, a single example will be used throughout to illustrate the problems being discussed.

## STOCK COMPOSITIONS, ABUNDANCE AND ICHTHYOMASS

The composition of the samples was listed by species, with the numbers and weights of specimens in each 10 mm length-group. Relating the results to the area treated it was possible to calculate the abundance (relative number of fish per hectare) and the biomass (relative weight of fish per hectare) for every species and for the entire stock sampled (Table 2).

To estimate how close these values repre-

sented the whole lake fish population, corrections had to be applied for all possible sampling biases. Most of them were usually difficult to perform and have not been presented in detail here. HAYNE et al. (1967) proposed a simple ratio called "bias in cove samples". It is the "quotient when the sample mean value is divided by the population mean. If this ratio is 1.0, then the cove samples are a good representation of the whole arm. If this measure of bias exceeds 1.0, then the use of cove samples will overestimate the true value, and when the bias is less than 1.0, then cove samples produce an underestimate". But because of topographical, seasonal and diel variances even an unbiased cove will vary and such a ratio cannot be considered as a precise measure of this bias. The only important "bias" within *single* locality treated by piscicide and blocking net is due to bird and mammal pick-up of the dead fish. We expect therefore that the bias should generally be one of underestimation.

Ignoring the question of bias, LAMBOU and STERN (1958) and HAYNE et al. (1967) estimated the number of coves to be sampled to give abundance and biomass estimates of required precisions (Table 3). Recalculated on the basis of local samples, such a table would help in planning and evaluating a particular sampling scheme. Bearing the above considerations in mind, the total average of stock abundance and ichthyomass sample data thus yield corrected estimates of the population abundance and ichthyomass for each species. Separate estimates can be made in respect of topographical, seasonal and diel strata.<sup>1</sup>

From the present data we may calculate

1. LOUBENS (1969) made different sample comparisons with the rank correlation coefficient of Kendall. He also discussed the different bias involved in piscicide sampling in the Lake Tchad basin.

Table 1. Conversion table of *Hydrocynus vittatus* observed mean standard length, calculated total length and geometric intercepted mean weights.

Standard length in mm	Total length in mm	Weight in g	Standard length in mm	Total length in mm	Weight in g	Standard length in mm	Total length in mm	Weight in g	Standard length in mm	Total length in mm	Weight in g	Standard length in mm	Total length in mm	Weight in g
15	18	0.045	155	195	74	295	377	530	435	548	1900	575	724	4600
20	24	0.11	160	202	80	300	378	555	440	554	1950	580	731	4800
25	30	0.23	165	208	86	305	384	580	445	561	2050	585	737	4850
30	36	0.40	170	214	94	310	390	620	450	567	2100	590	743	5000
35	42	0.66	175	221	105	315	397	650	455	573	2200	595	750	5200
40	48	1.0	180	227	110	320	403	675	460	579	2300	600	756	5400
45	54	1.3	185	233	125	325	409	730	465	586	2350	605	762	5500
50	60	2.0	190	239	130	330	416	740	470	592	2400	610	768	5600
55	66	2.6	195	246	142	335	422	790	475	598	2500	615	775	5700
60	72	3.5	200	252	155	340	428	820	480	605	2600	620	781	5800
65	78	4.5	205	258	172	345	435	850	485	611	2700	625	787	6000
70	84	5.6	210	265	180	350	441	900	490	617	2800	630	794	6200
75	91	7.2	215	272	198	355	447	950	495	624	2850	635	800	6350
80	97	8.8	220	278	210	360	453	1030	500	630	2950	640	806	6500
85	103	10.2	225	285	228	365	460	1080	505	636	3100	645	813	6600
90	109	12.5	230	291	240	370	466	1120	510	642	3200	650	819	6800
95	121	14.6	235	297	260	375	472	1170	515	649	3250	655	825	7000
100	128	17.5	240	304	280	380	479	1220	520	655	3400	660	831	7200
105	134	21.0	245	310	298	385	485	1270	525	661	3500	665	838	7400
110	140	24.0	250	316	310	390	491	1330	530	668	3600	670	844	7600
115	147	28.5	255	321	335	395	498	1400	535	674	3650	675	850	7700
120	153	30	260	327	350	400	504	1440	540	680	3800	680	857	7800
125	160	36	265	334	370	405	510	1500	545	687	3900	685	863	7900
130	166	40	270	340	400	410	516	1550	550	693	4000	690	869	8000
135	170	44	275	346	425	415	523	1650	555	699	4100	695	876	8200
140	176	52	280	353	450	420	529	1700	560	705	4250	700	882	8500
145	183	56	285	359	475	425	535	1760	565	712	4400	705	888	8800
150	189	62	290	365	500	430	542	1830	570	718	4500	710	894	9000

Table 2. Abundance of fish stock and ichthyomass in cove of Lake Kariba Chikanka Island (No. 16—surface 12100 m<sup>2</sup>, shore line 680m) on 21 June 1968

28 Species	Standard length ranges in mm	Average length of 1 sp. in mm	Number of specimens	Relative			Total weight in g	Relative	
				Number of fish per 1 ha	Number of fish per 100m shore line	Average weight of 1 sp. in g		Weights in kg per ha	Weights in kg per 100m shore line
				ABUNDANCE				ICHTHYOMASS	
<i>Tilapia rendalli gefuensis</i> Thys, 1964	37–425	126	582	481	85	177	103281	85.35	15.19
<i>Clarias gariepinus</i> (Burchell, 1822)	30–710	334	89	73	13	812	72246	59.70	10.62
<i>Tilapia mossambica mortimeri</i> Trewavas, 1966	35–299	101	479	396	70	78	37350	30.86	5.49
<i>Hydrocynus vittatus</i> Castelnau, 1861	48–420	131	296	245	43	126	37264	30.79	5.48
<i>Marcusenius discorhynchus</i> (Peters, 1852)	33–185	125	329	272	48	42	13706	11.32	2.01
<i>Heterobranchus longifilis</i> Val, 1840	103–963	400	7	6	1	1927	13487	11.14	1.98
<i>Sargochromis codringtoni</i> (Boulenger, 1908)	72–270	157	45	37	7	205	9247	7.64	1.36
<i>Synodontis zambezensis</i> Peters, 1852	26–278	158	60	49	9	129	7721	6.38	1.13
<i>Distichodus schenga</i> Peters, 1852	63–230	191	28	23	4	227	6367	5.26	0.94
<i>Labeo altivelis</i> Peters, 1852	57–315	210	10	8	1	569	5690	4.70	0.84
<i>Alestes lateralis</i> (Boulenger, 1900)	22–60	40	1759	1454	259	1.3	2271	1.87	0.33
<i>Haplochromis carlottae</i> (Boulenger, 1905)	200–250	225	4	3	0.5	542	2167	1.78	0.32
<i>Malapterurus electricus</i> (Gmelin, 1789)	380	380	1	0.8	0.1	1272	1272	1.05	0.19
<i>Serranochromis macrocephalus</i> (Boulenger, 1899)	162–225	189	4	3	0.5	260	1039	0.85	0.15
<i>Synodontis nebulosus</i> Peters, 1852	34–121	94	34	28	5	21	711	0.58	0.10
<i>Brachyalestes imberi imberi</i> (Peters, 1852)	60–150	103	11	9	2	45	495	0.40	0.07
<i>Eutropius depressirostris</i> (Peters, 1852)	18–179	74	30	25	4	13	391	0.32	0.06
<i>Haplochromis darlingi</i> (Boulenger, 1911)	24–88	42	165	136	24	2.3	386	0.31	0.06
<i>Barbus unitaeniatus</i> Günther, 1866	35–58	47	79	65	12	2.5	199	0.16	0.03
<i>Hippopotamyrus macrolepidotus</i> (Peters, 1852)	165–191	178	2	2	0.3	100	201	0.16	0.03
<i>Schilbe mystus</i> (Linnaeus, 1762)	75–139	100	13	11	2	15	190	0.15	0.03
<i>Micralestes acutidens</i> (Peters, 1852)	36–53	44	44	36	6	1.9	83	0.07	0.01
<i>Hemihaplochromis philander</i> (Weber, 1897)	24–58	42	22	18	3	2.8	61	0.05	0.01
<i>Sargochromis giardi</i> (Pellegrin, 1904)	109	109	1	0.8	0.1	64	64	0.05	0.009
<i>Barbus fasciolatus</i> Günther, 1868	28–35	31	52	43	8	0.7	38	0.03	0.005
<i>Labeo lunatus</i> Jubb, 1963	92	92	1	0.8	0.1	20	20	0.02	0.003
<i>Labeo congoro</i> Peters, 1852	70	70	1	0.8	0.1	9.5	9.5	0.008	0.001
<i>Barbus poechii</i> Steindachner, 1911	53	53	1	0.8	0.1	3.4	3.4	0.003	0.0005
Total			4149	3427	609		315963	261	46

Table 3. Number of cove samples necessary to produce confidence limits  $\pm 20\%$  of the mean with given values of coefficient of variability

Coefficient of variability	Statistical confidence level used		
	80%	95%	99%
0.20	3	7	11
0.55	14	32	55
1.00	42	100	169

various relationships and "balance" between the various species, e.g. by applying the ratios  $F/C$ ,  $Y/C$ ,  $A_T$  and the values  $A_F$ ,  $I_F$ ,  $S_F$  and  $E$  as proposed by SWINGLE (1950). Together with echo-sounding records showing vertical and horizontal fish distribution, they can lead directly to conclusions valuable for fishery management and direct attention to locations and species sizes to be fished. SWINGLE (1961) has proposed the equation  $\hat{Y} = 151.1 + 0.638A_T + 6.212F/C + 2.79S_F$  (2) for the estimation of ichthyomass (standing crop) in some reservoirs of the U.S.A. The value  $\hat{Y}$  expresses pounds per acre,  $A_T$  the percentage of the total weight of a fish stock composed of fish of harvestable size,  $F/C$  is the ratio of the total weight of all forage fishes to the total weight of all piscivorous fishes in a stock, and  $S_F$  the percentage of total weight of forage species composed of fish available to the average-size piscivorous fish. So far the estimates of ichthyomass derived from the mentioned equation have been in reasonably good agreement with the sampling averages found by SWINGLE and SWINGLE (1968). But more data and tests are needed to estimate a corresponding equation for Zambia or other waters. Further elaboration of the concepts involved (SWINGLE 1968) would appear to be useful.

Further tests of the general validity of our direct estimates can be sought by applying RYDER's (1965) morpho-edaphic index or similar approaches which may be elaborated later (JENKINS 1968). If the relationship between direct estimates of ichthyomass,

production and yield and these indices become well established, much labour can be eliminated and the data needed for initial research and development obtained and applied more rapidly and less expensively.

#### AGE COMPOSITION, GROWTH AND MORTALITY RATES

For estimating age composition, growth and mortality rates, it is necessary to know the correct time of the annulus appearance (BERG and GRIMALDI 1967). In north temperate regions many authors find the annulus to be formed in April to July, less often in March to August. Findings in subtropical regions to date have pointed to a time of annulus formation between December and April (EL ZARKA 1961; VAN RENSBURG 1966a; BALON 1971c), after the rainy season had gotten well under way and when the main spawning period of many species was observed (JOHNELS 1952). In tropical regions with two rainy seasons and repeated spawning in the same year the situation seems to be more complicated. I suspect that there will be one main rainy season and one main spawning period, to which the annulus appearance can be related (VAN SOMEREN 1950, 1952). Repeated spawning is also known in fish of temperate regions. The time of annulus formation in all regions seems to be connected with the main spawning period and with the main vegetation growth period.

Many authors have found that the annulus appearance is delayed as age increases

Table 4. Age group nomenclature related to seasonal appearance of annuli

Age groups		0	I	II	III
Number of annuli and occurrence of additional sklerites after last one (+)		0	0, 1, 1+	1+, 2, 2+	2+, 3, 3+
Name of age groups			yearling	2-year-old	3-year-old
Number of annuli		—	0, 1, 1+	1+, 2, 2+	2+, 3, 3+
Name of age groups		young-of-year	2-summer-old	3-summer-old	4-summer-old
Number of annuli		0	1+	2+	3+

(ZAWISZA 1951; BALON 1955). In most cases, therefore, the growing seasons of fish are not related in the most simple manner to the calendar year. To bring the growth nomenclature of fish under the calendar year, it is always necessary to check carefully the time of capture with annulus appearance (Table 4). The age groups should agree with calendar years; for example Group O normally includes fish within the year of hatching. For late-spawning fish of the temperate zone this means only half a year, for brown trout and tropical late spawners an entire year, and for some early spawners of the tropical region it may only mean a few weeks. The next age-groups I, II, III, IV, etc., always include a full calendar year. To avoid the O age-group paradox when fish juveniles from a December spawn are graduated a few weeks later from O to the I age-group, some authors prefer to use the symbols 0+, 1+, 2+, 3+, 4+ etc. in age-group designation, according to the number of annuli present.

For the time being no unbiased evidence is available to oppose the objections made by DE BONT (1967) on the validity of the annuli, especially with tropical fish, so it is necessary to rely on experience with the aging of fish in temperate zones (BALON 1953, 1955, 1957, 1962a, 1962b, 1965). Moreover, it is necessary to differentiate the real tropical areas where the formation of annuli is still questionable (BERTRAM, BORLEY and TREWAVAS 1942; DE BONT 1950; JOHNELS 1952; HOLDEN 1955; GARROD 1959; FRYER 1961; OKEDI 1969) from the sub-tropical areas with more pronounced seasons where evidently annuli are formed (LOWE 1952; JENSEN 1957; KOURA and EL BOLOCK 1958; EL BOLOCK and KOURA 1960, 1961; EL-ZARKA 1961; VAN RENSBURG 1966b) as in temperate regions. Consequently, I can only repeat with DE BONT (1967)

that "There is first of all the presence of different kinds of marks which are not necessarily present on all scales of the same fish, nor on all scales of the same species. Secondly, the time of the year that the marks are laid down may be different from one species to another, from region to region for the same species, and variable from one year to another. There are nearly as many explanations proposed as cases studied. The main factor involved may be one or a combination of the following: drop in temperature, decrease in available food, photoperiod, reproduction, migration, internal physiological rhythm, etc." But still I have the impression that all this is valid for both cold and warm regions. We encounter the problem of false annuli in the American or European pikes as well as in the sub-tropical tiger-fish. They are, however, always differentiable by their singular appearance and especially by their incomplete course as described in details elsewhere (CHUGUNOVA 1952, 1959; BALON 1963).

Therefore, I believe it more reasonable to consider the marks observed on tropical fish scales as similar to the annuli of temperate fish and of possible use as year marks if there is no strong evidence to the contrary. In order to speculate about the intervals in organism development (BALON 1960, 1971a) it can be assumed that the combination of the quoted factors in tropical regions also affects the intervals of seasonal development and that also here the "planetary yearly system" is recorded on the structure of the scales. As it was correctly remarked by DE BONT (1967) not even in temperate regions do we yet know which of the factors or which combination of them causes the phenomenon of the annulus formation. It is obvious that the "complete cessation of growth during winter" cannot be generalized as the only reason of annulus formation (BERG and GRIMALDI 1967).

In the Lake Kariba studies, the key scales

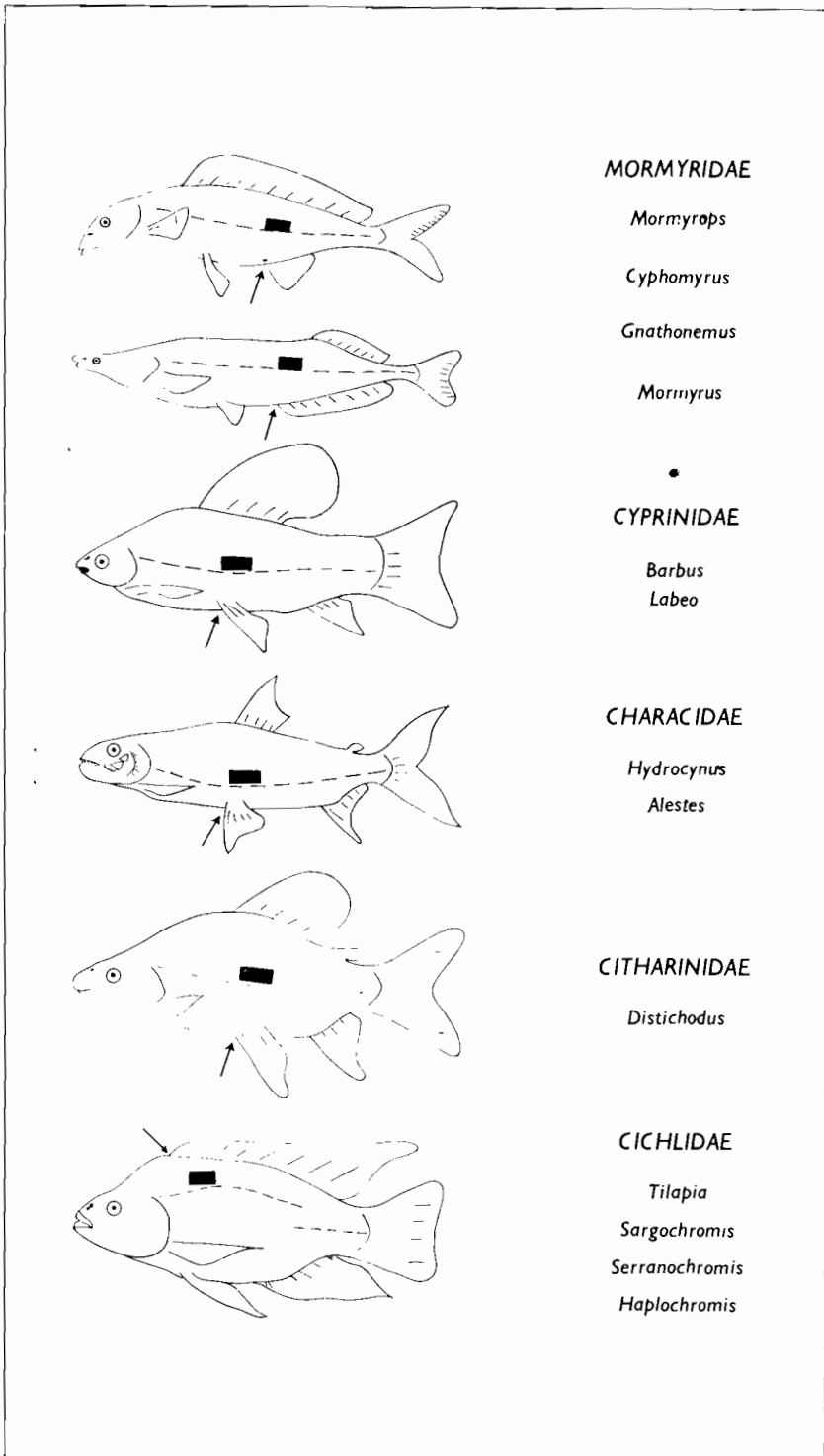


Fig 3. Key scales sampling scheme of Lake Kariba fishes.



(Fig. 3) or vertebrae sampled following the length-frequency distribution were used for age determination. The latter, after having been adjusted to the total number of specimens present in the sample of each species (Table 5) were used for calculating mortality

rates. The instantaneous rate of total mortality ( $Z$ ) can be calculated according to RICKER 1958a); the seasonal total mortality rate ( $A$ ) and the survival rate ( $S$ ) have to be determined for the given  $Z$  ( $i$  for RICKER) from his tables of exponential

Table 5. Age composition of *Hydrocynus vittatus*, Chikanka Cove sampled stock. Calculated from the same relation by age determined part (n = 160)

Standard length groups in mm	O		I		II		III		IV		VI		Σn
	n	%	n	%	n	%	n	%	n	%	n	%	
41- 50	3	1.0											3
51- 60	26	8.6											26
61- 70	30	10.0											30
71- 80	23	7.6											23
81- 90	27	9.0											27
91-100	18	6.0											18
101-110	23	7.6											23
111-120	24	8.0											24
121-130	17	5.6											17
131-140	7	2.3											7
141-150	2	0.7											2
151-160	5	1.6											5
161-170	6	2.0											6
171-180	2	0.7											2
181-190	1	0.3											1
191-200	4	1.3											4
201-210	3	1.0											3
211-220	1	0.3	4	1.3									5
221-230			11	3.6									11
231-240	3	1.0	7	2.3									10
241-250			4	1.3									4
251-260			4	1.3	5	1.6							9
261-270			2	0.7	3	1.0							5
271-280			2	0.7	3	1.0	2	0.7					7
281-290					3	1.0	3	1.0					6
291-300					5	1.6							5
301-310					2	0.7							2
311-320					1	0.3							1
321-330					2	0.7							2
331-340							3	1.0					3
341-350					1	0.3	1	0.3	1	0.3			3
351-360							2	0.7					2
381-390			1	0.3									1
411-420							1	0.3					1
501-510							1	0.3			1	0.3	2
511-520											1	0.3	1
Totals	225	75	35	12	25	8	13	4	1	0.3	2	0.6	301

functions and derivatives. The estimate of mean seasonal survival rate ( $\hat{S}$ ) should be calculated according to

$$\hat{S} = \frac{n_2 + n_3 + n_4 + n_5 + \dots + n_i}{n_1 + n_2 + n_3 + n_4 + \dots + n_{i-1}} \quad (3)$$

where there are  $i$  age groups and  $n_i$  fish in the  $i$ th group. The estimate of mean seasonal total mortality ( $A$ ) can be derived from Ricker's table and the mean daily rate of mortality is  $\frac{Z}{365}$  (HOLCIK 1966). (4)

$S$  and  $A$ , however, can be directly read from the semilogarithmic diagram of the stock curves (BALON 1971c, Fig. 9, BALON 1971d, Fig. 14) and estimated by some kind of mechanical means from the resulting slope if a certain relationship of units on ordinate and abscissa is maintained. This approach is arithmetically well elaborated by REGIER's (1962) models of mortality coefficients under various fishing pressures. However, empirical data so far obtained for different population curves present a proportional distribution of mortality in annual intervals. It can be inferred that the coefficient of natural mortality is not constant, as assumed by REGIER (1962) but changing with every change of fishing mortality as some kind of density dependant, etc. feedback. It explains the proportional total mortality rates within successive years in a "stable" population, in spite of varying actual catch (ROBSON and CHAPMAN 1961).

Concerning the methods of back calculation of growth of fish from annuli measurements on scale and bones it can be repeated that "Each method is accurate which calculates corrections based on one of the objectively determined relations of body length to the observed scale-radius measurement. It is impossible to make methods more exact because the chief cause of error, as indicated previously, lies in the subjective inaccuracy of measurements. There is, hence, only a single further course to follow; the

seasonal and yearly rhythm of scale growth in relation to the body growth of fish must be empirically determined" (BALON 1963). Any method which follows this view is, therefore, correct (e.g. MONASTYRSKY 1926; SEGERSTRÅLE 1933; HILE 1941, 1970; RICKER and LAGLER 1942; VOVK 1956). However, the effect of size selective mortality bias has to be taken into account (RICKER 1969).

For the calculation of production we need to know the annual increment of growth for all species. As the determination of age is part of the growth study it can be used to establish the age composition and the mortality rates of each studied taxa stock (Table 6). This has provided some very interesting results. The mean seasonal total mortality rate for tiger-fish was calculated as 71% and the mean seasonal survival rate as 29%. Using rough mortality values it was calculated that in order to produce one 6-year-old tiger-fish weighing more than 2 kg, 4,000 specimens were required in the first growth season, weighing 640 kg total (Table 7). In the same way it was determined how many juveniles were necessary to produce one first mature female, or male, etc. There seems to be no need to use mortality rates for correction of production *sensu lato*. It was proved that in normal conditions the recruitment and mortality are in balance (OLIVA 1960; ROBSON and REGIER 1968; HOLCIK 1970a); and we meant by 'normal' when the population's adaptive mechanisms are not yet "pushed beyond the range of their effectiveness and systems will become unstable and will begin to transform" (REGIER 1970a). The calculation of production dates, however, should take into consideration the time difference between the annulus formation and sampling date (HOLCIK personal communication February 18, 1971). We cannot use the increments from back calculated growth rates which are related to

Table 6. Age compositions, seasonal total mortality rates (A), survival rates (S) and instantaneous rates of total mortality (Z) for *H. vittatus*

Age Groups		O	I	II	III	IV	V	VI	VII	Σ
Aged part Chikanka Island stock	n	114	23	11	9	1		2		160
	%n	71.2	14.4	6.9	5.6	0.6		1.2		100
	A	0.7981	0.5229	0.1813	0.8892	0.4984			0.711	
	S	0.2019	0.4771	0.8187	0.1108	0.5016			0.289	
Z	1.60	0.74	0.20	2.20	0.69				1.24	
Total stock Chikanka Island	n	225	35	25	13	1		2		301
	%n	74.7	11.6	8.3	4.3	0.3		0.7		100
	A	0.8443	0.2882	0.4780	0.9227	0.4984			0.747	
	S	0.1557	0.7118	0.5220	0.0773	0.5016			0.253	
Z	1.86	0.34	0.65	2.56	0.69				1.37	
All studied samples Sinazongwe area	n	114	23	15	21	14	9	7	1	204
	%n	55.9	11.3	7.3	10.3	6.9	4.4	3.4	0.5	100
	A	0.7981	0.3495	0.2882	0.3297	0.3560		0.2212		0.8577
	S	0.2019	0.6505	0.7118	0.6703	0.6440		0.7788		0.1423
Z	1.60	0.43	0.34	0.40	0.44		0.25		1.95	0.59

Table 7. Relative mass of *Hydrocynus vittatus* after mean seasonal total mortality rate ( $\hat{A}$ ) and mean seasonal survival rate ( $\hat{S}$ )

Growth seasons	Number of specimens dead after $\hat{A} = 75\%$	Number of surviving specimens $\hat{S} = 25\%$	Standard length in cm of one specimen		Weight in g of one specimen		Mass of survivals Weight of growth season kg	
			mean	range	mean	range	mean	minimum—maximum
1	3000	1000	18	9.3–29	160	14–460	160	14–460
2	750	250	28	15–39	420	60–1150	105	15–287
3	188	62	35	22–45	800	193–1800	50	12–112
4	46	15	39	34–48	1150	750–2100	17	11–31
5	11	4	48	47–50	2110	2050–2480	8	8–10
6	3	1	49		2300		2	

the time of annulus formation and multiply it simply by the assessed abundance, which is related to the time of sampling. We have to adjust the abundance at time of capture ( $N$ ) to the time of the annulus formation ( $N^!$ ) according to the mean daily rate of mortality (instantaneous rate of total mortality) as

$$N^! = N \left( 1 + \frac{Zt}{365} \right) \quad (5)$$

where  $t$  expresses the number of days elapsed from the time of annulus formation to the date of sampling of the given locality,  $Z$  is the mean instantaneous mortality rate for the species in a particular locality and  $N$  is the number of fish in an age-group. Furthermore, some corrections should be made for the same time differences in fish weight and to young-of-year fish, which exist at time of the sample but not in the time of annulus formation (HOLCIK 1971).

In a study of fish production it is useful to calculate relative values of growth (BALON 1968a). For example, we may calculate the *absolute increment*

$$h_i = l_i - l_{i-1} \quad (6)$$

and the *index of the species average size*

$$\bar{H} = \sum_{i=1}^{j+a} h_i \quad (7)$$

in order to separate the fish into classes of *economically preferred species* ( $\bar{H} > 5$ ), partly exploited *secondary species* ( $5 > \bar{H} > 2$ ), and unexploited *accompanying species* ( $\bar{H} < 2$ ). In these formulae  $l$  is the fish length during various  $i$ th years of growth,  $j$  for juvenile and  $a$  for adult period (BALON 1971a). Weight indices are obtained by replacing the symbol  $l$  by  $w$ .

To compare the growth rates of different species or the same species in different lakes it is best to calculate the *specific weight rate of growth*

$$CW = \frac{w_i - w_{i-1}}{w_{i-1}} \cdot 100 \quad (8)$$

and the *index of population weight growth intensity*

$$\bar{C}_w = \frac{\sum_{i=1}^{j+a} cw_i}{w = 1} \quad (9)$$

From the relative indices of growth mentioned it is possible to determine the mean age of first maturity of the species stock or population (BALON 1964, 1968a). But for the evaluation of the seasonal changes in species stock it is more useful to calculate the relative condition index (LE CREN 1951).

## PRODUCTION AND YIELD

For illustrating the results we have selected here one of the main predator species (*Hydrocynus vittatus*) and one main prey species (*Alestes lateralis*) living in Lake Kariba. The calculations are based on the methods previously mentioned. The calculated lengths for previous years of life are used to estimate mean lengths and increments (BALON 1971c, Fig. 10, Table 8). The minimum harvestable size in relation to the first spawning and especially to economical increments can be established from the crossing point of length increment in percent of length of the first growth season curve and length in percent of length of the final growth season curve (BALON 1971c). HOLCIK (1970 a) assumed furthermore that from "the relation of production to ichthyomass it is possible to compute the best minimum size if we subtract the amount equal to the total production from the total ichthyomass by age groups". In our case both methods gave similar results.

According to the population estimated and the growth analysis the yearly available production<sup>2</sup> of tiger-fish in Lake Kariba

2. The production values are given the simplest way. No corrections on annulus formation and sampling time differences were made. As already stated all our production values express the annual biomass increments of surviving fish only—the available production.

Table 8. Available production computation of *Hydrocynus vittatus* in Lake Kariba

Age groups	Number of fish n/ha	Sample curve intercepted $\hat{n}$ /ha	Mean weight in g of one specimen $\bar{w}$	Mean weight increments in g of one specimen h	Total increments of age group per year in kg h $\hat{n}$ /ha
O	186	116	140	140	16.2
I	29	55	590	450	24.7
II	21	27	1050	460	12.4
III	11	12	1530	480	5.3
IV	1	6	2000	470	2.8
V	—	2	2400	400	0.8
VI	2	2	3000	600	1.2
Relative production in kg/ha/yr				P <sub>A</sub>	63.9
Relative production in percent of biomass (30.8 kg)				P <sub>A</sub> /B	207.5
Relative production for 33,422 of fish inhabited lake area				$\hat{P}_A$	2119 metric tons

equals at the time recorded 12% of the ichthyomass and 207.5% of the tiger-fish biomass (Table 8). If we consider that the tiger-fish habitat corresponds with general fish distribution recorded (33,422 ha or 6.2% of the lake surface) its yearly production for the lake would be 2,119 metric tons. From this estimated production the yield or quantity of tiger-fish which can be removed yearly by fishing in the most economical size and without deleterious effect on the present stock, can be calculated. If we determine the harvestable size to belong in average to the II-age group (mean weight about 1 kg or 1.3 kg and 38 cm according to HOLCIK's method), the yield or annual production of harvestable size would be 22.5 kg/ha. It is possible, therefore, to crop annually a total of 742 metric tons of tiger-fish more. This tonnage represents already 70% of the present annual harvest of all fish from the Zambian part of Lake Kariba.

*Alestes lateralis* is the most abundant fish: 59% of the total. Because of its small size its share in the ichthyomass is low, only a little over 0.7%. Its annual available production has been calculated for the same 6.2% inhabited area of Lake Kariba as 169 metric tons (Table 9). As we later found

that this species is the first to colonize the free open lake area, this production value might be underestimated. From the analysis of the length frequency, the largest specimens of *A. lateralis* are small enough to be eaten by tiger-fish in the most numerous size range. *A. lateralis* will obviously also be eaten by other predators, but on this issue there is no knowledge up to now. As we have been treating only the data for *A. lateralis* and tiger-fish, let us consider the interrelation of these fish as an example of yield estimates for prey species.

How is the calculated annual production of *A. lateralis* related to the food ration of the main predator? In a paper on tiger-fish (BALON 1971c) attention was drawn to the similarity in many aspects of the biology of the tiger-fish and the European pike. Here—because of shortage of values for the tiger-fish we shall try to use the values found for the annual food ration of the pike in the Volga Delta mentioned by POPOVA (1967); an average value of 3 kg per kilogram of body weight. This lies roughly between POPOVA's (1967) and MUNRO's (1967) "daily ration" 5 ml of food per kg of tiger-fish (calculated as "annual ration" it is  $5 \times 365 = 1,825$  ml/kg). The mass of tiger-fish per

Table 9. Available production computation of Lake Kariba *Alestes lateralis*

Age groups	Absolute mass per 1 ha			Relative mass per survival			Total increment of age group per year in kg	Production		
	Number of specimens per 1 ha	Standard length in cm of 1 specimen	Mean weight in g of 1 specimen	Mass (weight of age group in kg)	Number of specimens after 85% after 15% after 15%	Mass in kg		Mean weight increment in g of 1 specimen	absolute in kg	in % ichthyomass
O	1232	4.6	2	2.46	850	150	0.30	2	2.46	
I	206	7.7	12	2.47	128	22	0.26	10	2.06	4.90
II	16	10.6	36	0.58	19	3	0.11	24	0.38	169 metric tons

inhabited 6.2% area of Lake Kariba was calculated as 1,056,000 kg. This quantity of tigerfish requires 3,168,000 kg of food, so the annual production of 169 tons of *A. lateralis* covers 5.3% of the annual food requirement of the Kariba tiger-fish population. MATTHES (1968) found that 5.3% of the stomach contents of the tiger-fish was *A. lateralis*, which is a very striking agreement for such speculative calculations. At the same time it probably proves that in this case available production estimation is equal to the total production in Ivlev's meaning (see p. 44).

To calculate uniform data for every species living in the studied impoundment (Lake Kariba with 40 species) is a very long lasting project indeed. It could only be effectively accomplished by the cooperation of several institutions working on individual species production and yield to obtain the total annual fish production and yield.

If the maximum sustainable yield is obtained from the natural balanced fish population the fishery management should then look for ways to increase the production and yield by changing the species composition, their relationship, and balance following SWINGLE's (1950) or others criteria, according to the carrying capacity of the lake. In Lake Kariba the Tanganyika sardine *Limnothrissa miodon* was successfully introduced (BELL-CROSS and BELL-CROSS 1971; BALON 1971e) to utilize the uninhabited open lake area, and a large eel stock inhabiting the 20-45 m depth area was later discovered (BALON 1971b). Assessment of these stocks is done with different methods. The sardine is studied using a combination of determined echo-traces, ring-net hauls and underwater photography, the eels with capture-mark-recapture method. Both will add to the already estimated ichthyomass and production of the shore-line fish population, though the addition may not be so simple

in view of the newly developed interactions in relation to the available nutrients.

If there is a shortage of time the production evaluation of the economically preferred species and of the secondary species should be sufficient (Table 10); often the accompanying species do not represent an appreciable part of the ichthyomass and production.

The fish population is a complicated community. Different species are not equal. Their inter-and intra-relationships are as different as those taxonomical characters from one species to another. Furthermore, every species is related in various ways to the environmental factors. We are able to recognize several types of single species stock, eg.:

$$\begin{array}{l}
 \text{I. } A : X = a : y \\
 \text{II. } A : Y = a : x \\
 \text{III. } B : X = b : y \\
 \text{IV. } B : Y = b : x
 \end{array} \quad (11)$$

where *A* is a high and *B* a low amount of food within easy reach, *X* is the high and *Y* the low stock density, *a* is the fast and *b* the slow growth rate, *x* is the early and *y* the late sexual maturity (BALON 1963). By changing the above mentioned relationship (e.g. by fishing or dam building), one species stock change over to another species stock type. Not always does fishing result in a reduction of the abundance or the ichthyomass. KESTEVEN (1962) was not precise on this point even when he later described the situation very well: "The reduction is not equal to the catch, since part of what is caught would have died from natural causes. The reduction of community biomass may be even less than catch-minus-some-proportion-of-it that would have gone to natural mortality, since removal of the catch means presumably greater survival of the organisms on which the caught fish had fed, except that the surviving members of the exploited population may each eat slightly more

Table 10. Recent (1968–1971) list of Lake Kariba fish species in economical order according to the species average size, abundance, topographical frequency of occurrence and mean percentage of total number of specimens.

Order number	ECONOMICALLY PREFERRED SPECIES	Frequency of occurrence	Mean percentage of total number
1	<i>Tilapia mossambica mortimeri</i> Trewavas, 1966	8	10.00
2	<i>Tilapia rendalli gefuensis</i> Thys, 1964	8	3.62
3	<i>Hydrocynus vittatus</i> Castelnau, 1861	8	2.48
4	<i>Clarias gariepinus</i> (Burchell, 1822)	6	2.00
5	<i>Sargochromis codringtoni</i> (Boulenger, 1908)	6	1.10
6	<i>Heterobranchus longifilis</i> Val., 1840	6	0.09
7	<i>Mormyrops deliciosus</i> (Leach, 1818)	5	0.47
8	<i>Labeo altivelis</i> Peters, 1852	5	0.18
9	<i>Mormyrus longirostris</i> Peters 1852	4	0.05
10	<i>Distichodus schenga</i> Peters, 1852	3	0.28
11	<i>Labeo congoro</i> Peters, 1852	3	0.02
12	<i>Tilapia andersonii</i> (Castelnau, 1861)	2	0.85
13	<i>Sargochromis giardi</i> (Pellegrin, 1904)	2	0.16
14	<i>Haplochromis carlottae</i> (Boulenger, 1905)	1	0.10
15	<i>Serranochromis robustus jallae</i> (Boulenger, 1896)	1	0.04
16	<i>Serranochromis macrocephalus</i> (Boulenger, 1899)	1	0.04
17	<i>Distichodus mossambicus</i> Peters, 1852	1	0.03
SECONDARY SPECIES			21.51
18	<i>Alestes lateralis</i> (Boulenger, 1900)	8	58.78
19	<i>Hippopotamyrus discorhynchus</i> (Peters, 1852)	6	7.94
20	<i>Eutropius depressirostris</i> (Peters, 1852)	5	0.74
21	<i>Marcusenius macrolepidotus</i> (Peters, 1852)	5	0.12
22	<i>Malapterurus electricus</i> (Gmelin, 1789)	5	0.07
23	<i>Schilbe mystus</i> (Linnaeus, 1762)	3	0.13
24	<i>Anguilla nebulosa labiata</i> Peters, 1852	—	—
25	<i>Limnothrissa miodon</i> (Boulenger, 1906)	—	—
ACCOMPANYING SPECIES			67.78
26	<i>Haplochromis darlingi</i> (Boulenger, 1911)	8	5.20
27	<i>Barbus fasciolatus</i> Günther, 1868	5	4.64
28	<i>Barbus unitaeniatus</i> Günther, 1866	8	1.80
29	<i>Hemihaplochromis philander</i> (Weber, 1897)	7	1.28
30	<i>Synodontis zambezensis</i> Peters, 1852	6	1.02
31	<i>Micralestes acutidens</i> (Peters, 1852)	6	0.41
32	<i>Synodontis nebulosus</i> Peters, 1852	5	0.33
33	<i>Brachyalestes imberi imberi</i> (Peters, 1852)	5	0.28
34	<i>Aplocheilichthys johnstonii</i> (Günther, 1893)	5	0.04
35	<i>Labeo cylindricus</i> Peters, 1852	3	0.01
36	<i>Barbus lineomaculatus</i> Boulenger, 1903	2	0.02
37	<i>Barbus poechii</i> Steindachner, 1911	2	0.02
38	<i>Labeo lunatus</i> Jubb, 1963	1	0.02
39	<i>Barbus paludinosus</i> Peters, 1852	—	—
40	<i>Barilius zambezensis</i> (Peters, 1852)	—	—
			15.07



and take up the spare food left by those that have been caught. By eating more, the surviving fish could grow more, and further offset the removal by the catch. Again, if the fishing removes older fish, the growing potential and efficiency of food utilization of the population can increase". A reduction of the ichthyomass is then usually not the immediate result of fishing (if this does not extend beyond "normal" population adaptability). Even reduction of economically preferred species does not necessarily mean a reduction of total fish production (TSAI 1970). More often fishing results in an increase of production, especially in short-living and early maturing fish species. It takes very long continuous fishing with intensive methods leading to a high catch increase to reduce the ichthyomass. Even in the Danube River (high populated shores) it has taken centuries to overfish easy-to-catch giant huso, maturing for the first time at 20 years of age (BALON 1967). Overfishing of short-living and early-maturing bleak was found to be impossible (ENTZ 1952) and I have to agree with MESECK (1962) that usually bad landings "caused by a wrong fishing technique are frequently explained as overfishing".

If we take into consideration all the complicated relationships between different species in a stock and the environmental factors (e.g. HANDLER 1970) where we usually find a strong trend to balance the community, there is really very little fishing influence to be expected especially in a subsistence fishery. More harm is to be expected (and was proved, e.g. MILLER 1961; BALON 1967) from dam building and pollution where irreversible changes occur. Furthermore, this stands also in case of intensive fishing industries with catches over maximum sustainable yield. Continuous overfishing usually terminates the economy of a catch before the species affected is in danger of extinction. Then regulations

become a perpetual interest of exploiting institutions and they may be effective if no other factors interfere. As the latter is usually the case (e.g. pollution and lampreys in the Laurentian Great Lakes, river bank regulations and dam building on Europe main streams) preventive measures to forbid overfishing are vital. As empiric fish production data and maximum sustainable yield data are lacking, intensive research should be developed in this direction.

As REGIER (1970b) expressed so excitingly in his address to the Centennial Meeting of the American Fisheries Society in relation to pollution: "We have fought to have corrective technology applied to this or that case of pollution. We have won many small battles, but have been losing the war". Similar statements have been made in relation to water buildings equally by myself (BALON 1967). But still COUSTEAU (1964) is right in stating: "In our times the technocrats are at the summit. Almost everywhere they have powerful contact with politicians. It is clear that this will change again. Biological sciences will again be in the fore because without life even science cannot exist". Let's hope it will not be too late then. If we like to find out how our recent fish production studies are related to the much preferred fish yield predictions, "then the only logical conclusion is that the biomass of the future is likely to be just so much more or less than it is now, as man makes it to be" KESTEVEN 1962).

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## REFERENCES

- Allen, K. R. (1951). The Horokiwi Stream: a study of a trout population. *Fish. Bull. N.Z.* 10: 1-238.
- Allen, K. R. (1966). Determination of age distribution from age-length keys and length distribution, IBM 7090, Fortran IV. *Trans. Amer. Fish. Soc.* 95 (2): 230-231.
- Balon, E. K. (1953). Age and growth of the grayling (*Thymallus thymallus*) from Revúca (Slovakia) [in Czech]. *Zool. entom. listy* 2 (2): 131-137.
- Balon, E. K. (1955). Growth of the roach (*Rutilus rutilus*) and a revision of main method of its determination [in Czech]. Vyd. SAV, Bratislava, 166 p.
- Balon, E. K. (1957). Age and growth of spawning shoal of the Danube wild carp from the Smaller Danube above Kolárovo [in Slovak]. *Polnohospodárstvo* 4 (5): 961-986.
- Balon, E. K. (1960). Über die Entwicklungsstufen des Lebens der Fische und ihre Terminologie. *Zeitschrift für wissenschaftliche Zoologie* 164 (3-4): 294-314.
- Balon, E. K. (1962a). Age and growth of the chub in Orava River (1944-1952) and in Orva Riverine Lake in the years following its filling (1953-1958) (with methodical notes) [in Slovak]. *Práce Laboratória rybárstva* 1: 79-104.
- Balon, E. K. (1962b). The growth legality of the Danube ide (*Leuciscus idus* (L.)) [in Slovak]. *Práce Laboratória rybárstva* 1: 117-151.
- Balon, E. K. (1963). Altersstruktur der Populationen und Wachstumsgesetzmäßigkeiten der Donaubrachsen (*Abramis brama*, *A. sapa*, *A. ballerus*). *Bul. Inst. Chem. Techn. (Prague), Technology of Water* 7 (2): 459-542.
- Balon, E. K. (1964). On relative indexes for comparison of the growth of fishes. *Vest. Cs. spol. zool.* 28 (4): 369-379.
- Balon, E. K. (1965). Wachstum des Hechtes (*Esox lucius* L.) im Orava-Stausee. *Zeitschrift für Fischerei* 13 (1-2): 113-158.
- Balon, E. K. (1966a). The ichthyomass and abundance of fish of the Danube inundation arm below Bratislava with description of taxophene poisoning [in Slovak]. *Biologia (Bratislava)* (21) 4: 259-307.
- Balon, E. K. (1966b). Contribution to the knowledge of balance of the fish stocks in the inundation waters of the Danube [in Slovak]. *Biologia (Bratislava)* 21 (12): 865-884.
- Balon, E. K. (1966c). Bemerkungen über die Fischgemeinschaften und über die Ichthyomasse eines Inundationsarmes der Donau. *Verh. Internat. Verein. Limnol.* 16: 1108-1115.
- Balon, E. K. (1967). Evolution of the Danube River ichthyofauna, their recent state and a try to predict the further changes after dam buildings [in Slovak]. *Biologické práce* 13 (1): 5-121.
- Balon, E. K. (1968a). The periodicity and relative indexes of the growth of fishes (with notes on their terminology), p. 115-132. In International conference of ageing and growth of fishes, Smolenice [mimeographed].
- Balon, E. K. (1968b). Die Anwendung der Pisciziden für die Bestimmung von Fischabundation und Ichthyomasse in den Inundations-gewässern den Donau. *Z. Fischerei NF* 16 (3/4): 169-195.
- Balon, E. K. (1971a). The intervals of early fish development and their terminology. *Vest. Cs. spol. zool.* 35 (1): 1-8.
- Balon, E. K. (1971b). The eels of Siengwazi Falls (Kalomo River, Zambia) and their significance. *Zambia Museums Journal* 2: (in press).
- Balon, E. K. (1971c). Age and growth of *Hydrocynus vittatus* Castelnau, 1861 in Lake Kariba, Sina-zongwe Area. *Fish. Res. Bull. Zambia* 5: 89-118.
- Balon, E. K. (1971d) Replacement of *Alestes imberi* Peters, 1852 by *Alestes lateralis* Boulenger, 1900 in Lake Kariba, with ecological notes. *Fish Res. Bull. Zambia* 5: 119-162.
- Balon, E. K. (1971e). First catches of Lake Tanganyika sardine (kapenta—*Limnothrissa miodon*) in Lake Kariba. *Fish. Res. Bull. Zambia* 5: 175-186.
- Balon, E. K. and Senes (1967). Expedition Cayo Largo. Natural history of the coral world of Antilles [in Slovak]. Vyd. SAV, Bratislava. 312 p.
- Baranov, F. I. (1918). On the question of the biological basis of fisheries [in Russian]. *Izv. Nauch. issledov. ichtiolog. Inst.* 1 (1): 81-128.
- Bastl, I., J. Holcik and I. Krupka (1969). Abundance and ichthyomass of fish populations in the Biskupické Branch of the Danube River. *Práce Laboratória rybárstva* 2: 253-268.
- Bell-Cross, G. and B. Bell-Cross (1971). Introduction of *Limnothrissa miodon* and *Limnocaridina tanganyicae* from Lake Tanganyika into L. Kariba. *Fish. Res. Bull. Zambia* 5:
- Berg, A. and E. Grimaldi (1967). A critical inter-

- pretation of the scale structures used for the determination of annuli in fish growth studies. *Men. Ist. Ital. Idrobiol.* 21: 225-239.
- Bertram, C. K. R., H. J. H. Borley and E. Trewavas (1942). *Report on the fish and fisheries of Lake Nyasa*. Crown Agents for Colonies, London.
- Beverton, R. J. H. and S. J. Holt (1957). On the dynamics of exploited fish populations. *Fishery Invest. Lond., Ser. 2, 19*: 533 p.
- Breder, C. M. (1960). Design for a fry trap. *Zoologica (N.Y.)* 45 (10): 155-160.
- Burmakin, E. V. and L. A. Zhakov (1961). An attempt to determine fish production in perch lake [in Russian]. *Nautshno-technicheskiy biull. GosNIORCH 13-14*: 25-27.
- Carter, B. T. (1958). What significant information can be gained from rotenone population studies in impoundments. *Proc. 11th Ann. Conf. S.E. Assoc. Game and Fish. Comm.*: 82-84.
- Chance, C. J. (1958). How should population surveys be made? *Proc. 11th Ann. Conf. S.E. Assoc. Game and Fish. Comm.*: 84-89.
- Chapman, D. G. (1948). A mathematical study of confidence limits of salmon populations calculated from sample tag ratios. *Int. Pac. Salmon Comm. Bull.* 2: 67-85.
- Chapman, D. W. (1967). Production in fish populations, p. 3-29. In Shelby D. Gerking, ed. *The biological basis of freshwater fish production*. IBP symposium. Blackwell Scientific Publications, Oxford.
- Chapman, D. W. (1968). Production, p. 182-196. In W. E. Ricker, ed. *Methods for assessment of fish production in fresh waters*. IBP handbook 3. Blackwell Scientific Publications, Oxford.
- Chodorowski, A. (1959). Ecological differentiation of tubellarians in Harsz-Lake. *Polskie Archiwum Hydrobiologii* 6: 33-73.
- Chugunova, N.A. (1952). Methods of studying the age and growth of fish [in Russian]. Izd. Sov. Nauka. Moskva.
- Chugunova, N. A. (1959). Handbook of age and growth studies in fish [in Russian]. Izd. AN. SSSR. Moskva. 194 p. [English translation 1963, National Science Foundation, Washington, 132 p.]
- Coche, A. G. (1968). Description of physico-chemical aspects of Lake Kariba, an impoundment, in Zambia-Rhodesia. *Fish. Res. Bull. Zambia* 5: 200-267.
- Coke, M. (1968). Depth distribution of fish on bush-cleared area of Lake Kariba, Central Africa. *Trans. Amer. Fish. Soc.* 97 (4): 460-465.
- Cousteau, J. Y. (1964). *Dech move*. Mladá fronta, Praha. [English translation: *The living sea*. Harper and Row, New York.]
- De Bont, A. F. (1950). Rapport annuel 1947-1948 de la Station de Reserches piscicoles. *Bull agric. Congo Belge* 41: 473-538.
- De Bont, A. F. (1967). Some aspects of age and growth of fish in temperate and tropical waters, p. 67-88. In Shelby D. Gerking, ed. *The biological basis of freshwater fish production*. IBP symposium. Blackwell Scientific Publications, Oxford.
- Derzhavin, A. N. (1922). The stellate sturgeon (*Acipenser stellatus* Pallas), a biological sketch [in Russian]. *Biull. Bakinskoi Ikhtiol. St.* 1: 1-393.
- Doi, T. (1959). On the yearly fluctuation in availability of the sardine *Sardinops melanosticta* population caught by drift net in the western part of the Japan Sea. *Bull. Tokai Fish. Res. Lab.* 26: 1-6.
- El Bolock, A. R. and R. Koura (1960). Age, growth and breeding season of *Tilapia zillii* Gervais in Egyptian experimental ponds. *Notes and Memoires of Inst. Freshwater Biology (Gizira-Cairo)* 49: 1-36.
- El Bolock, A. R. and R. Koura (1961). The age and growth of *Tilapia galilaea* Art., *T. nilotica* L. and *T. zillii* Gerv., from Beteha area (Syrian Region). *Notes and Memoires of Inst. Freshwater Biology (Gzira-Cairo)* 58: 1-27.
- El-Zarka, S. (1961). *Tilapia* fisheries investigation in Egyptian lakes. I. Annulus formation on the scales of the cichlid fish *Tilapia zillii* (Gerv.) and its validity in age and growth studies. *Notes and Memoires of Inst. Freshwater Biology (Gizira-Cairo)* 62: 1-18.
- Entz, B. (1952). Distribution of winter shoals of fishes in 1950-1951 year in the Small Tihany Bay (Kis-Öböl, Lake Balaton) with a special evaluation of commercial use of bleak [in Russian]. *Acta Biologica Academiae Scientiarum Hungaricae* 3 (4): 543-572.
- Eschmeyer, R. W. (1943). Fish population of a Small Norris Reservoir bay. *Tenn. Aca. Sci.* 18 (1): 47-48.
- Fox, W. W. J. (1970). An exponential surplus-yield model for optimizing exploited fish populations. *Trans. Amer. Fish. Soc.* 99 (1): 80-88.
- Fryer, G. (1961). Observations on the biology of the cichlid fish *Tilapia variabilis* Boulenger in the northern waters of Lake Victoria (East Africa). *Rev. Zool. Bot. Afri.* 64: 1-33.
- Garrod, D. J. (1959). The growth of *Tilapia esculenta* Graham in Lake Victoria. *Hydrobiologia* 12: 268-298.
- Gerking, S. D. (1965). Two computer programs for

- age and growth studies. *Progressive Fish Culturist* 27 (2): 59-66.
- Gulland, J. A. (1962). The application of mathematical models to fish populations, p. 204-217. In E. D. Le Cren and M. W. Holdgate, eds. *The exploitation of natural animal populations*. Blackwell Scientific Publications, Oxford.
- Gulland, J. A. (1965). Manual of methods for fish stock assessment. Part I. Fish population analysis. *FAO Fish. Biol. Tech. Pap.* 40. 68 p.
- Gulland, J. A. (1967). The effects of fishing on the production and catches of fish, p. 399-415. In Shelby D. Gerking, ed. *The biological basis of freshwater fish production*. IBP symposium. Blackwell Scientific Publications, Oxford.
- Gulland, J. A. (1968a). The concept of the marginal yield from exploited fish stocks. *J. Con. Int. pour l'Exploration de la Mer* 32 (2): 256-261.
- Gulland, J. A. (1968b). The concept of maximum sustainable yield and fishery management. *FAO Fish. Tech. Paper, FRs/T* 70: 1-13.
- Gulland, J. A. (1969). Manual of methods for fish stock assessment. Part I. Fish population analysis. *FAO Manuals in Fisheries Science* 4: 1-154.
- Handler, P., ed. (1970). *Biology and the future of man*. Oxford University Press, New York. 936 p.
- Hayne, D. W., G. E. Hall and H. M. Nichols (1967). An evaluation of cove sampling of fish populations in Douglas Reservoir, Tennessee. Reservoir Fishery Resources Symposium, Athens, Georgia, April 5-7, 1967: 244-297.
- Hempel, C. and D. Sahrhage (1961). Neuere Modellvorstellungen über die Dynamik der Grundfischbestände. *Ber. Dtsch. Wiss. Komm. Meerforsch.* 16 (2).
- Hemphill, J. E. (1954). Toxaphene as a fish toxin. *Progressive Fish Culturist* 16 (1): 41-42.
- Henegar, D. L. (1966). Minimum lethal levels of toxaphene as a piscicide in North Dakota lakes. *U. S. Bureau of Sport Fisheries and Wildlife Resource Publ.* 7: 1-16.
- Herr, E., E. Greselin and C. Chappel (1967). Toxicology studies of antimycin, a fish eradicant. *Trans. Amer. Fish. Soc.* 96 (3): 320-326.
- Hiatt, R. W. and D. W. Strasburg (1960). Ecological relationships of the fish fauna on coral reefs of the Marshall Islands. *Ecological Monographs* 30 (1): 66-127.
- Hile, R. (1941). Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. *Trans. Wis. Acad. Sci. Arts and Letters* 33: 189-137.
- Hile, R. (1970). Body-scale relation and calculation of growth in fishes. *Trans. Amer. Fish. Soc.* 99 (3): 468-474.
- Holcik, J. (1966). Some notes on the calculation of survival and mortality of fish [in Slovak]. *Biológia (Bratislava)* 21 (12): 885-893.
- Holcik, J. (1970a). The Kiliyava Reservoir (and ichthyological study). *Biologické pracé* 15 (3): 1-95.
- Holcik, J. (1970b). Standing crop, abundance, production and some ecological aspects of fish populations in some inland waters of Cuba. *Věst. Cs. spol. zool.* 34 (3): 184-210.
- Holden, M. J. (1955). Ring formation in the scales of *Tilapia variabilis* Boulenger and *Tilapia esculenta* Graham from Lake Victoria. *East African Freshwater Fisheries Research Organization, Annual Report 1954-1955; Jinja, Uganda:* 36-40.
- Holt, S. J. (1958). The evaluation of fisheries resources by the dynamic analysis of stocks, and notes on the time factors involved. *Spec. Publ. I.C.N.-A.F. [International Commission of the Northwest Atlantic Fisheries]* 1: 77-95.
- Holt, S. J. (1960). *Multilingual vocabulary and notation for fishery dynamics*, FAO, Rome. 42 p.
- Holt, S. J. (1967). The contribution of freshwater fish production to human nutrition and well-being. In Shelby D. Gerking, ed. *The biological basis of freshwater fish production*. IBP symposium. Blackwell Scientific Publications, Oxford.
- Holt, S. J., J. A. Gulland, C. Taylor and S. Kurita (1959). A standard terminology and notation for fishery dynamics. *J. Cons. Explor. Mer* 24 (2): 239-241.
- Hooper, F. F. and A. R. Grzenda (1957). The use of toxaphene as a fish poison. *Trans. Amer. Fish. Soc.* 85: 180-190.
- Hutchinson, G. E. (1967). *A treatise on limnology*. Vol. II. John Wiley and Sons, Inc., New York. 1115 p.
- Ivanov, L. S. (1961). A method of relative evaluation of the condition of a stock and prediction of expected catch of fishes having a short life cycle [English translation by W. E. Ricker]. *Transl. Ser. Fish. Res. Bd. Canada* 366: 8 p.
- Ivlev, V. S. (1945). The biological productivity of waters [in Russian]. *Usp. sovrem. biol.* 19 (1): 98-120 [English translation: *J. Fish Res. Bd. Canada* 23 (11): 1727-1759.]
- Jenkins, R. M. (1968). The influence of some environmental factors on standing crop and harvest of fishes in U.S. reservoirs. Reservoir Fishery Resources Symposium, Athens, Georgia, April 5-7, 1967: 298-321.
- Jensen, K. W. (1957). Determination of age and

- growth of *Tilapia nilotica* L., *T. galilaea* Art., *T. zillii* Gerv., and *Lates niloticus* C. et V. by means of their scales. *Det Kongelige Norske Videnskabers Selskabs Fordhandlingen* 30: 150-157.
- Johnels, A. G. (1952). Notes on scale rings and growth of tropical fishes from the Gambia River. *Arkiv f. Zool.* 3 (28): 363-366.
- Kesteven, G. L. (1962). World aquatic biomass-its future abundance, p. 9-22. In E. Heen and R. Kreuer, eds. *Fish in Nutrition*. Fishing News, London.
- Knight, W. (1968). Asymptotic growth: an example of nonsense disguised as mathematics. *J. Fish. Res. Bd. Canada* 25 (6): 1303-1307.
- Koura, R. and A. R. El Bolock (1958). Age, growth and survival of *Tilapia mossambica* (Peters) in Egyptian ponds. *Notes and Memoirs of Inst. Freshwater Biology (Gizira-Cairo)* 41: 1-18.
- Lambou, V. W. (1959). Use of machine methods in processing fishery data. *Proc. 13th Ann. Conf. S.E. Assoc. Game and Fish Comm.*: 116-120.
- Lambou, V. W. and H. Stern (1958). An evaluation of some of the factors affecting the validity of rotenone sampling data. *Proc. 11th Ann. Conf. S.E. Assoc. Game and Fish Comm.*: 91-98.
- Larkin, P. A. and A. S. Houston (1964). A model for simulation of the population biology of Pacific salmon. *J. Fish. Res. Bd. Canada* 21 (5): 1245-1265.
- Le Cren, E. D. (1951). The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *J. Animal Ecology* 20: 201-219.
- Leeper, B., H. Stern, and V. W. Lambou (1958). Some uses of punch card methods in the tabulation and analysis of fishery research data. *Proc. 11th Ann. Conf. S. E. Assoc. Game and Fish. Comm.*: 226-232.
- Lennon, R. E. (1966). Antimycin—a new fishery tool. *Wisconsin Conservation Bull.* 31 (2): 4-5 [Reprinted: The Izaak Walton Magazine, *Outdoor American* 31 (7): 16-17.]
- Loubens, G. (1969). Étude de certains peuplements ichtyologiques par des pêches au poison (re note). *Cah. O.R.S.T.O.M. (Hydrobiol.)* 3 (2): 45-73.
- Lowe, R. H. (1952). Report on the tilapia and other fish and fisheries of Lake Nyasa 1945-47. *Colonial Office Fishery Publ.* 1: 1-126.
- Mahdi, M. A. (1966). Mortality of some species of fish to toxaphene at three temperatures. *U. S. Bureau of Sport Fisheries and Wildlife Resource Publ.* 10: 1-10.
- Malaisse, F. (1969). La pêche collective par empoisonnement au "buba" (*Tephrosia vogelii* Hook. f.). Son utilisation dans l'étude des populations de Poissons. *Les Naturalistes Belges* 50 (9): 481-500.
- Marr, J. C. (1957). The problem of defining and recognizing sub-populations of fishes. *U.S. Fish Wildlife Service, Special Scientific Report—Fisheries* 208: 1-6.
- Marten, G. G. (1970). A regression method for mark-recapture estimation of population size with unequal catchability. *Ecology* 51 (2): 291-295.
- Mayr, E. (1963). *Animal species and evolution*. The Belknap Press of Harvard Univ. Press, Cambridge, Massachusetts.
- Matthes, H. (1968). The food and feeding habits of the tiger-fish, *Hydrocyon vittatus* (Cast., 1861) in Lake Kariba. *Beaufortia* 15 (201): 143-153.
- Meseck, G. (1962). Importance of fisheries production and utilization in the food economy, p. 23-28. In E. Heen and R. Kreuer, eds. *Fish in Nutrition*. Fishing News, London.
- Miller, R. R. (1961). Man and the changing fish fauna of the American southwest. *Papers of the Michigan Aca. Sci., Arts, Letters* 46: 365-404.
- Monastyrsky, G. N. (1926). Methods of determining fish growth from scale measurements [in Russian]. *Sbornik statej po metodike opredeleniya vozrasta i rosta ryb (Krasnoyarsk)*: 41-79.
- Munro, J. L. (1967). The food of a community of East African freshwater fishes. *J. Zool. Lond.* 151: 389-415.
- Neess, J. and R. C. Dugdale (1959). Computation of production for populations of aquatic midge larvae. *Ecology* 40: 425-430.
- Nikolskij, G. V. (1964). On the biological basis of mathematical models for the dynamics of fish population. *Cons. Perm. intern. pour l'explor. de la mer. Rapp. et procès verbaux* 155: 199-201.
- Nikolskij, G. V. (1965). Theory of fish population. Dynamics as the biological background for rational exploitation and management of fishery resources [in Russian]. *Izd. Nauka, Moskva*. 382 p.
- Okedi, J. (1969). Observations on the breeding and growth of certain mormyrid fishes of the Lake Victoria Basin (Pisces: Mormyridae). *Rev. Zool. Bot. Afr.* 79 (1-2): 34-64.
- Oliva, O. (1955). The composition of fish population in three natural ponds in the Elbe River region [in Czech]. *Universitas Carolina, Biologica (I)*: 61-74.

- Oliva, O. (1960). Further contribution to the knowledge of fish populations composition in Elbe River backwaters [in Czech]. *Vest. Cs. zool. spol.* 24 (1): 42-49.
- Pella, J. J. and P. K. Tomlinson (1969). A generalized stock production model. *Inter-Amer. Trop. Tuna Comm. Bull.* 13 (3): 421-496.
- Popova, O. A. (1967). The 'predator-prey' relationship among fish (a survey of Soviet papers), p. 359-376. In S. D. Gerking, ed. *The biological basis of freshwater fish production*. IBP symposium. Blackwell Scientific Publications, Oxford.
- Powers, J. E. and A. L. Bowes (1967). Elimination of fish in the Giant Grebe Refuge, Lake Atitlan, Guatemala, using the fish toxicant, antimycin. *Trans. Amer. Fish. Soc.* 96 (2): 210-213.
- Randall, J. E. (1963). An analysis of the fish population of artificial and natural reefs in the Virgin Islands. *Carib. J. Sci.* 3 (1): 31-47.
- Regier, H. A. (1962). On estimating mortality coefficients in exploited fish populations, given two censuses. *Trans. Amer. Fish. Soc.* 91: 283-294.
- Regier, H. A. (1970a). Community transformation—some lessons from large lakes. Reprint of paper presented at the 50th year Anniversary Celebrations, University of Washington, College of Fisheries, Seattle. 13 p.
- Regier, H. A. (1970b). Mary, Mephistopheles, Machiavelli, and Menhaden, Reprint of invited address at the 100th Annual Meeting of the American Fisheries Society. 15 p.
- Ricker, W. E. (1946). Production and utilization of fish populations. *Ecol. Monogr.* 16: 374-391.
- Ricker, W. E. (1954). Stock and recruitment. *J. Fish. Res. Bd. Canada* 11: 559-623.
- Ricker, W. E. (1958a). Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd. Canada* 119. 300 p.
- Ricker, W. E. (1958b). Production, reproduction and yield. *Verh. internat. Verein. Limnol.* 13: 84-100.
- Ricker, W. E., ed. (1968). Methods for assessment of fish production in fresh waters. IBP handbook 3. Blackwell Scientific Publications, Oxford.
- Ricker, W. E. (1969). Effects of size-selective mortality and sampling bias on estimates of growth, mortality, production, and yield. *J. Fish. Res. Bd. Canada* 26 (3): 479-541.
- Ricker, W. E. and K. F. Lagler (1942). The growth of spiny-rayed fishes in Fouts Pond, Indiana. *Invest. Indiana Lakes and Streams* 2 (5): 85-97.
- Robson, D. S. and D. G. Chapman (1961). Catch curves and mortality rates. *Trans. Amer. Fish. Soc.* 91: 181-189.
- Robson, D. S. and H. A. Regier (1968). Estimation of population number and mortality rates, p. 124-158. In W. E. Ricker, ed. *Methods for assessment of fish production in fresh waters*. IBP Handbook 3. Blackwell Scientific Publications, Oxford.
- Ryder, R. A. (1965). A method for estimating the potential fish production of north-temperate lakes. *Trans. Amer. Fish. Soc.* 94 (3): 214-218.
- Schaefer, M. B. (1967). Dynamics of the fishery for the anchoveta, *Engraulis ringens*, off Peru. *Boletin Inst. Mar. Peru.* 1 (5): 189-304.
- Schaefer, M. B. (1970). Man, birds and anchovies in the Peru Current—dynamic interactions. *Trans. Amer. Fish. Soc.* 99 (3): 461-467.
- Segerstraale, C. (1933). Über scalimetrische Methoden zur Bestimmung des linearen Wachstums bei Fischen, insbesondere bei *Leuciscus idus* L., *Abramis brama* L. und *Perca fluviatilis* L. *Acta Zool. Fennica* 15: 1-168.
- Surber, E. W. (1959). Suggested standard methods of reporting fish population data for reservoirs. *Proc. 13th Ann. Conf. S.E. Assoc. Game and Fish Comm.*: 133-325.
- Swingle, H. S. (1950). Relationships and dynamics in balanced and unbalanced fish populations. *Ala. Poly. Inst. Agri. Exp. St. Bull.* 274: 73 p.
- Swingle, H. S. (1958). How fish population surveys should be reported. *Proc. 11th Ann. Conf. S.E. Assoc. Game and Fish Comm.*: 103-104.
- Swingle, H. S. (1961). Some relationships within fish populations causing fluctuations in production. *Proc. Pacific Sci. Cong. (Fisheries)*: 8 (10) 43-45.
- Swingle, H. S. (1968). Estimation of standing crops and rates of feeding fish in ponds. Proc. World Symposium on Warm-Water Pond Fish Culture, *FAO Fisheries Report* 44: 416-423.
- Swingle, H. S. and W. E. Swingle (1968). Problems in dynamics of fish populations in reservoirs. Reservoir Fishery Resources Symposium, Athens, Georgia, April 5-7, 1967: 229-243.
- Swingle, W. E. and H. S. Swingle (1966). Population analysis program, IBM 1620, Fortran/Format. *Trans. Amer. Fish. Soc.* 95 (2): 232-233.
- Tarzwel, C. M. (1940). Fish populations of a small pond in Northern Alabama. *Trans. Amer. Wildl. Mgt. Conf.* 5: 245-251.
- Tsai, Ch. F. (1970). Changes in fish populations and migration in relation to increased sewage pollution in Little Patuxent River, Maryland. *Chesapeake Science* 11 (1): 34-41.
- Van Rensburg, K. J. (1966a). Growth of *Tilapia mossambica* (Peters) in De Hoop Vlei and

- Zeekoe Vlei. *Dept. Nat. Conserv. Investig. Rep. 9*: 1-7.
- Van Rensburg, K. J. (1966b). The fishes of the Olifant River (West Coast) with particular reference to the yellowfish (*Barbus capensis*) and sawfin (*Barbus serra*) [in Afrikaans]. *Dept. Nat. Conserv. Investig. Rep. 10*: 1-14.
- Van Someren, V. D. (1950). The 'winter check' on trout scales in East Africa. *Nature 165*: 473-474.
- Van Someren, V. D. (1952). *The Biology of trout in Kenya Colony*. Col. and Prot. Kenya, Gov. Printer, Nairobi. 114 p.
- Varley, G. C., W. H. Pearsall, and M. Graham (1962). Comments in the general discussion. 7. Mathematical models, p. 381-383. In E.D. Le Cren and M. W. Holdgate, eds. *The exploitation of natural animal populations*. Blackwell Scientific Publications, Oxford.
- Vovk, F. I. (1956). Methods of reconstructing a fish's growth from its scales [in Russian]. *Trudy biol. st. Borok 2*: 351-392.
- Zawisza, J. (1951). Growth of bream, zarte, barbel and white bream in middle part of Vistula by Warsaw [in Polish]. *Roczniki Nauk Rolniczych 57*: 237-271.