EXPERIMENTS ON DIFFERENT STOCKINC RATES OF THE COMMON CARP*

(*Cyprinus Carpio* L.) IN NURSING PONDS

by

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ABSTRACT

A series of experiments on stocking rate was carried out in the hatchery of the Laboratory for Inland Fisheries, Bogor, Indonesia.

The individual growth and the total yield at different stocking rates were determined. The relationship between food ingested, food. used for maintenance and food available for growth could be calculated from the figures obtained.

Biota in the water and on the bottom of the pond as well as excrements were investigated every eight days. At the end of the stocking period the contents of the intestines were investigated.

From a consideration of all results obtained it was concluded that at the optimal stocking rate the minerals are most rapidly incorporated by the carp into the flesh of their body; in this case they are no longer available for phytoplankton. So the total amount of organic matter formed is low, but the food is utilised in a most economic way. At overstocking a large amount of minerals is circulating rapidly, a high amount of organic matter is formed, but almost the entire amount is needed for maintenance. At low stocking rates, the minerals are circulating slowly and part of the food formed is left uneaten by the carp. However the amount needed for maintenance is low.

INTRODUCTION

Freshwater pond culture is carried out in Indonesia in densely populated districts. For this reason it is most important to obtain maximum yields from minimum areas. To accomplish this it is necessary that the amount of fish food available be converted into fish flesh in the most economic way. One of the principal factors in this respect is the optimal stocking rate. Moreover attention should be given to the amount of natural food produced in the pond and ingested by the carp during the period of growth and the influence of various stocking rates on these factors, regarding the pond as a closed ecosystem.

In Germany Walter (1931) carried out numerous experiments on fish production in ponds and Contag (1931) investigated the development of food organisms at various stocking rates.

At the Third International Inland Fisheries Training Centre at Bogor in 1955, the present author presented an essay on the biological interpretation of Walter's results.

This theory was summarised in a set of graphs (Fig. 1).

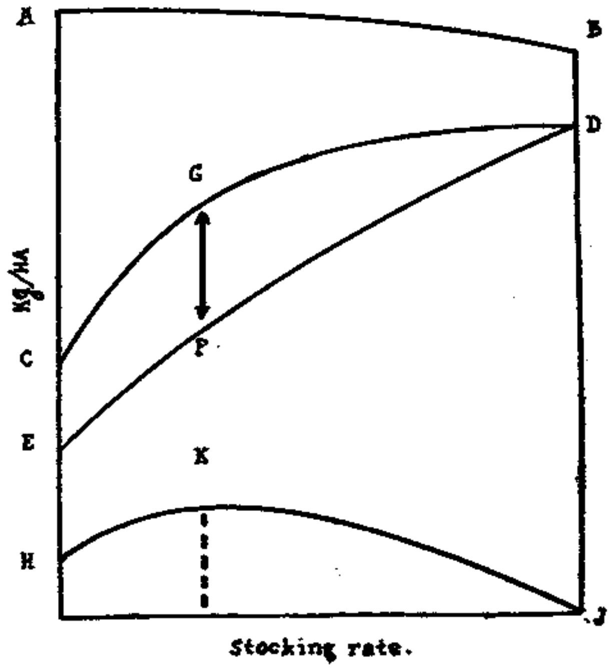

Fig. 1. Theoretical scheme of food and feeding of carp in a pond at increasing stocking rate.
AB = Total supply of food.
CD = Amount of food ingested.
ED = Amount of food needed for maintenance.
HJ = Amount of food available for growh.

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It was supposed that actual growth would be proportional to the amount of food available.

In the present paper we shall describe an attempt to test this theory, especially under tropical conditions.

The investigations were carried out by a team, consisting of the following members of the staff of the Laboratory for Inland Fisheries, Bogor : Abdul Rachman, Suherman, Much. Machfud and N.R. Harahap, under the direction of the author.

Chironomidae from the mud and the gut contents of the carp were studied by K.F. Vaas.

The author is indebted to Hasanuddin Saanin, Director of the Laboratory, for being given the opportunity to carry out this work and for various valuable suggestions in the course of the experiments.

J.A. Schuurman, Bogor, kindly reviewed the English of the text.

DESCRIPTION OF THE PONDS AND EXPERIMENTS

Four experiments were carried out in 12 concrete tanks with a surface area of 18 square metres each, and a depth of 30 cm.

The inflowing water contained a good deal of particulate organic matter, originating from domestic sewage. The sediment amounted to 0.5 cc./l. The sides of the sewer from which the water entered the tanks were overgrown with filamentous algae, forming a slimy mass together with mud. In the mass many Chironomidae, Oligochaetae etc. were found. After the tanks had been filled, no water was let out and only the losses caused by evaporation were replaced. So the tanks were almost closed systems, containing equal amounts of organic substance.

The particulate organic matter settled on the bottom, and some leaves from neighbouring trees fell into the tanks in the course of the experiment and a layer of approximately 2 centimetres of mud was always formed on the bottom. In normal ponds the surface layer of the mud is the most important site of physico-chemical interrelations. It therefore seems justified to compare our tanks with ordinary tanks.

The tanks were stocked with various numbers of fry and drained and cropped after one month.

Owing to the small size of the tanks it was necessary to stock with advanced fry. The optimal stocking rate for bigger carp would probably have been less than 1 carp per tank.

After 1 month the following determinations were carried out :

1) Total number and weight of the crop.

2) Individual weight, total length and standard length of approximately 10% of the fish.

3) Net plankton, strained from 10 × 1 litre of water, taken from 10 different spots immediately before draining the tank.

4) Nannoplankton from 1 litre of water passing the plankton net during the straining of the net sample. The numbers of organisms in both samples were computed on the basis of counts of twice 0.02 cc. of the sample.

5) In 8 different places mud samples were taken with a glass tube with an opening width of 1 square cm. The whole mud sample was studied under the binocular microscope and conspicuous organisms, such as Chironomidae, Oligochaetae insect larvae and snails were picked out and identified as far as possible. Afterwards the mud was diluted with water to a volume of 100 cc. and microscopically studied in the same way as the plankton samples. The number of algae on the bottom was only counted at the time the tanks were drained. Large differences between the tanks were observed, and no correlation with the stocking rate could be found. The average number for all tanks combined amounted to 6.5 million/dm^2 of mud.

6) The gut contents of 2 carp were studied.

7) Samples of the contents of the rear part of the guts of about 10% of the live carp were collected by gently pressing the region of the vent. The fish treated in this way were released in their original tanks. The faeces collected were studied in the same way as the gut contents. This determination was carried out in the fourth experiment only.

Four experiments were run. In the first three experiments, 4 different stocking rates were used with 3 parallels; in the fourth experiment, 6 different stocking rates with 2 parallels. The numbers used were the following :

Experiment	I	30	45	50	75			
„	II	20	40	60	80			
„	III	3	10	17	24			
„	IV	10	15	20	35	65	110	—

In Experiments I, II and III fry of an average weight of 1.5 g. were used, in Experiment IV the average weight amounted to 1 g. The external circumstances in Experiments I, II and III were similar, but for minor differences in climatic conditions. Therefore the results were combined. As losses were heavy at stocking rate 110, the average between the number stocked and that cropped was used in the calculations. This was about 100.

RELATION BETWEEN TOTAL YIELD AND INDIVIDUAL GROWTH

The average individual growth of the carp and the total yield per tank are shown in Tables I and II. The discrepancies between the parallels are caused by incidental differences in fertility between the tanks and by climatic conditions. Inevitable losses of fish during the growth periods also cause difference in yield and in individual growth. If the loss occurs in the beginning of the period, the individual weight at the time of draining will be too high, if the loss takes place towards the end of the period and if it involves the bigger carp, the average weight may become too low. The figures obtained were plotted in Fig. 2 and 3, in which individual growth is represented by dots. Through these dots the best fitting curve was drawn by eye.

Multiplication of the various values, as read from this line, by the relevant stocking rated, provided theoretical values for the total yield. These theoretical values are indicated in the figures by crosses. The actual total yield is marked by circles.

In agreement with Walter's results the curves rise rapidly up to a certain optimum and decline slowly afterwards.

The following considerations enable us to calculate the amount of maintenance food (expressed in arbitrary units U), the amount of food used for growth (expressed in the same way) and, by adding up these values the amount of food ingested by the entire population.

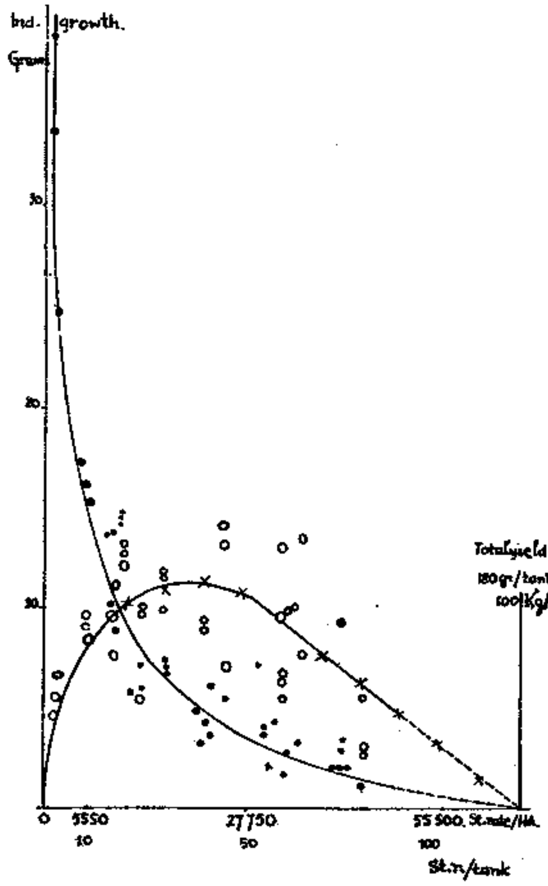

Fig. 2. Growth of carp at increasing stocking rates. Experiments. I, II and III
.—.—. Individual growth in grams.
x—x—x Total yield, calculated from individual growth.
o o o Total yield, actual values.
— — — Hypothetical part of the curve.

It is a well known fact in animal physiology that the amount of maintenance food needed by an animal is proportional to the surface of the body, which value again, is proportional to the ratio between weight and length.

It can be inferred from Fig. 2 that, in the tanks used here, a total yield of zero will be reached at a stocking rate of 120 carp per tank (equal to 66, 660/ha.) when fry of 1.5 g. is used. The dotted line in the figure represents the hypothetical values at higher stocking rates than those used. However, such values are seldom reached in actual practice. At higher

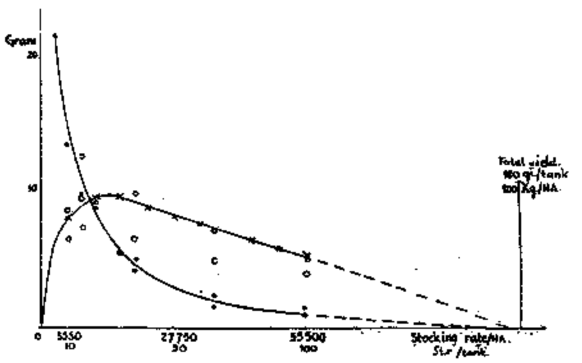

Fig. 3. Growth of carp at increasing stocking rates. Experiment IV. Legend as in Fig. 2.

stocking rates heavy losses will occur and the rate is automatically reduced, enabling the remaining carp to grow on. It is even possible that under such conditions some of the dead carp are eaten by the remaining ones (Kostomarov and Hrabé, 1943). In aquaria the author saw carp nibbling at the bodies of carp of similar size lying on the bottom.

With carp of 1 g. a total yield of zero will be reached at a rate of 175 fish per tank.

As it was necessary to obtain a formula expressing the relationship between standard length *(L)* and weight *(W)*, a number of carp were weighed and measured every 8 days in Experiment IV. Logarithms of the figures found

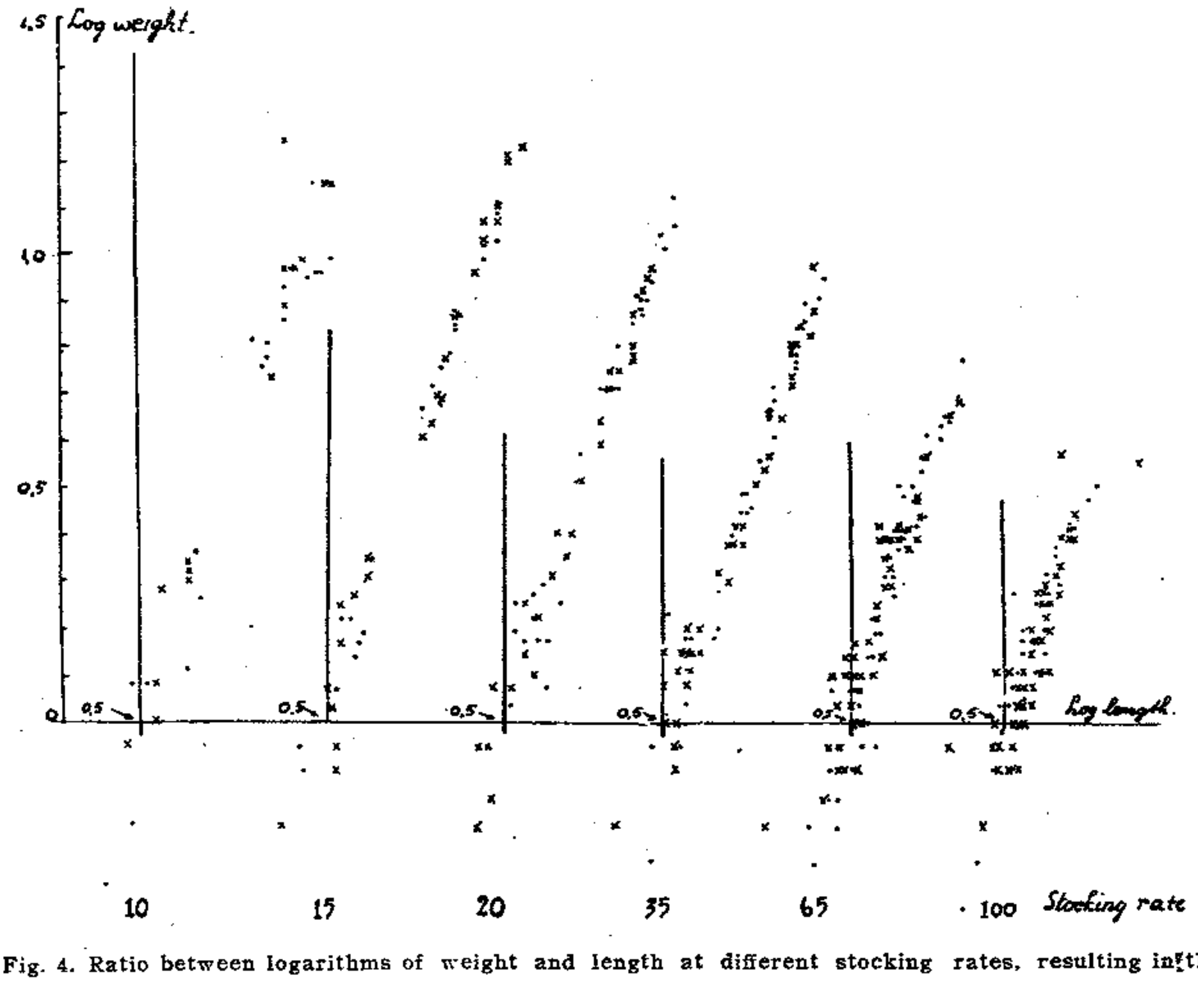

Fig. 4. Ratio between logarithms of weight and length at different stocking rates, resulting in the formula $\log W = 3 \log L - 1.5$.

are plotted in Fig. 4. For each stocking rate the figures obtained in the first parallel are indicated by dots, and those found in the second parallel by crosses.

As will be seen in the figures the relationship between the two values can be represented by straight lines, representing the formula:

$$\log W = 310 \text{ g. } L - 1.5 \text{ (or: } W = 0.032\, L^3)$$

If the total weight and the number of a certain stocking of carp are known, the average length can be calculated with this formula.

However, what matters here is the average weight of the carp during the whole length of the growing period. In Experiments I, II and III the initial weight and the ultimate weight only were determined. The average of these two values need not represent the actual average during the entire period. For this reason weights found at various intervals during Experiment IV were plotted and growth curves were obtained at different stocking rates, by the use of these values (Fig. 5).

By comparing the average values at various points on these curves with the averages between initial and ultimate weight, we obtained a correction key, to be applied to the different individual weights found in Experiments I, II and III (Table III). It will be observed that this correction key need only be applied at low stocking rates.

As was pointed out earlier, the amount of maintenance food needed by one fish is proportional to the quotient of weight and length. In our case this value amounted to 0.31 for carp of 1 gram. As a unity of food *(U)* we wish to introduce the amount of maintenance food needed during 1 month by 1 carp. The amount of maintenance food *(A)* needed during 1 month by a population of carp of known average weight and length as expressed in *U*, may be calculated with the aid of the formula:

$$A = N \frac{q}{0.31}$$

in which N = stocking rate and q = quotient of weight and length.

It appears from Fig. 3 that no growth occurred at a stocking rate of 175 carp of 1 gram. Consequently, in that case 175 *U* of food were ingested and totally needed for maintenance. At a rate of 150 carp per tank, the individual growth amounted to 0.2 gram, and the average weight of the carp during the entire period was 1.1 gram. The quotient of weight and length in this case being 0.34, the amount of maintenance food needed by the whole population of the tanks was:

$$150 \, \frac{0.34}{0.31} = 168 \; U$$

If it is assumed that the amount of food ingested by 150 carp equals that ingested by 175 carp, which assumption seems justified at such a high stocking rate, 175-168 = 7 *U* are left for growth. The total yield being 150 x 0.2 = 30 gram, we find that 1 *U* of food yields 4.3 gram of carp.

We already stated before that the amount of maintenance food needed may be calculated for every stocking rate. Since the total yield divided by 4.3 represents the amount of food used for growth, expressed in *U*, the total amount of food ingested is obtained by adding the two figures mentioned. Calculations along these lines were carried out for Experiments I, II and III combined as well as for Experiments IV and are shown in Table IV and Fig. 6.

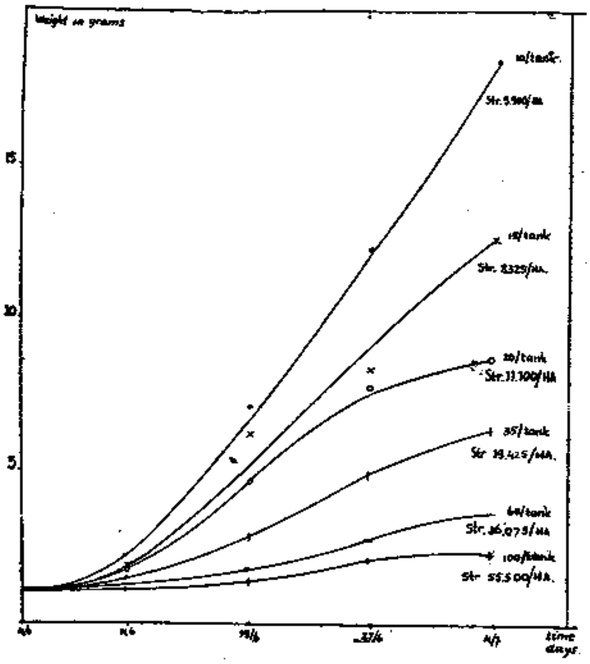

Fig. 5. Growth curves at various stockings with fish 1 gram each.

The general conclusions to be drawn from these calculations are the following :

1) Individual growth declines as the stocking rate increases. This decline is rapid at low stocking rates and slow at high ones.
2) The total yield rises rapidly at increasing stocking rates, up to a certain optimum. Beyond that optimum a very slow decline takes place.
3) At increasing stocking rates the amount of food ingested rises rapidly at first and slowly afterwards. At stocking rates of more than 60 carp of 1.5 gram, this amount hardly increases at all.

These conclusions are based on the assumption that individual growth is primarily determined by the amount of food available for each carp.

In pond-culture practice it is usually assumed that food production during the whole period of growth in the pond is independent of the stocking rate.

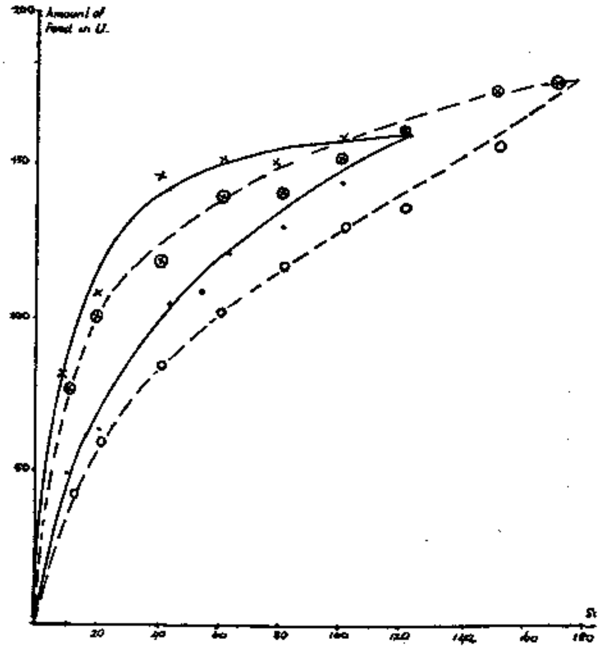

Fig. 6. Total amount of food ingested and maintenance food calculated at increasing stocking rates.

—.—.	Maintenance food	Stocking with fry of 1.5 gram.
x–x–x	Total amount of food ingested	
o–o–o	Maintenance food	Stocking with fry of 1 gram.
⊗–⊗–⊗	Food ingested	

This assumption is the basis of the usual calculation of the stocking rate. If this were true in our case, and food production amounted to 175 *U* at all stocking rates, the amount of food available for each carp could be calculated. The amount of food needed for maintenance at various stocking rates may be calculated from the values given in Table IV. By subtraction the amount of food available for growth may be determined (see Table V), and by multiplication with 4.3 the expected growth in grams is found. By comparing these figures with growth actually measured, large discrepancies are found at low stocking rates. So it must be concluded that, at low stocking rates, either part of the food is left unused, or food production is less than 175 *U*.

Which of these two conclusions is correct, may be decided on the basis of limnological investigations. It is also possible that both are true. However, the large differences between the amount of food ingested at stocking rates 10 and 20 seem to indicate that the first hypothesis is the more probable one. The graphs showing individual growth during the whole period (Fig. 4) prove that growth is slow in the first week, accelerating during the second week, and that the lower the stocking rate the longer the increase in growth continues.

LIMNOLOGICAL INVESTIGATIONS

A) Ecology of the tank.

In Table VI the results of plankton counts are given in a simplified form, in which only genera of special importance are mentioned separately, while the others are combined into taxonomic groups.

The most important organisms found in the mud are shown in Table VII Spyrogyra was encountered often, but not in large quantities. *Lebistes reticulatus* P. and frog larvae were always present in the tanks.

The gut contents of all animals present in the ecosystem of the tank were briefly studied and the results are given in Table VIII

Table VIII. Gut contents of water biota in the tanks.

Rotatoria	Phytoplankton, Protozoa.
Crustacea	Phytoplankton
Chironomidae	detritus, algae from the mud.
Oligochaetae	do do
Ephemerid larvae	do do
Vivipara	do do
Melania	do do
Frog larvae	Phytoplankton, notably Euglena from the surface Rotatoria.
Lebistes	Chironomidae, Crustaceae, Rotatoria, Oligochaetae detritus.
Cyprinus carpio	Chironomidae, Crustaceae, Oligochaetae, Insect larvae, Less Frequent: Spirogyra, snails.

These organisms may be classified in the following ecological groups, on the basis of their relationships with the carp and of the way in which they affect the circulation of free minerals dissolved in the water.

1) **Phytoplankton.** Forming organic matter rapidly. Using dissolved minerals, but equally rapidly eaten by various animals, for which reason minerals are quickly liberated.
2) **Bottom algae.** Using free minerals. Forming organic matter. Eaten by Chironomidae, some other insect larvae, Oligochaetae and snails.
3) **Spirogyra.** Forming organic matter and using free minerals rapidly. Eaten by very few animals only, therefore often "side tracking" minerals by incorporating them for a long time.
4) **Protozoa.** Living on phytoplankton and on other Protozoa. Eaten by Rotatoria.
5) **Rotatoria.** Living on phytoplankton. Eaten by Lebistes to a small extent.
6) **Crustaceae.** Living on phytoplankton. Principal food of the carp. Eaten by Lebistes.
7) **Insect larvae** (mainly Chironomidae). Living on detritus and mud algae. Not propagating in the tank, only growing, and leaving the ecosystem when adult. Eaten by carp and Lebistes.
8) **Oligochaetae.** Living on detritus and algae. Propagating in the tank. Eaten by carp and Lebistes. Not significant as food for the carp, owing to low numbers and small volume.
9) **Snails.** Living on mud with algae. Small ones eaten by large carp. They accumulate in the tank, "side tracking" minerals.
10) **Frog larvae.** Living on phytoplankton. Not eaten by any other animal present. "Side tracking" minerals, but not a real food competitor of the carp. The food stored inside the body leaves the tank at the time the metamorphosis is accomplished.
11) **Lebistes.** Living on Chironomidae, Crustaceae, Oligochaetae and Rotatoria. Not eaten by any other animals present. Propagating very rapidly. Serious food competitor of the carp. Storing minerals in the body, which are only liberated after complete mineralisation of the dead body in the tank.
12) **Carp.** Living on Chironomidae, Crustaceae, other aquatic insects and their larvae, to a certain extent also on snails and Spirogyra.

INVESTIGATION OF THE PLANKTON AND THE BIOTA OF THE MUD

In Experiment IV, samples of the plankton and the mud were collected every 8 days. The number for each genus was counted and finally the volumes of these organisms were calculated by multiplication with certain factors, previously established.

Such calculations were made for: Phytoplankton, Rotatoria and Crustaceae.

The results are presented in Fig. 7, the solid line representing the first of the two parallels, and the broken line the second one. Protozoa are not represented, because they were abundant during the first 8 days only, their numbers being negligible afterwards.

Although oscillations in the numbers of plankters were encountered, as was the case in the course of investigations by other workers (Wirzhubsky 1953, Yun An Tan 1954) it is nevertheless possible to draw certain conclusions.

In all tanks the inflowing water introduced hardly any plankton, after 8 days a small amount only had been formed. After 16 days phytoplankton was abundant. In most cases the lines representing the numbers of adult Crustaceae and Rotatoria followed those of the phytoplankton. The number of nauplii was seen to fluctuate more than that of all other biota.

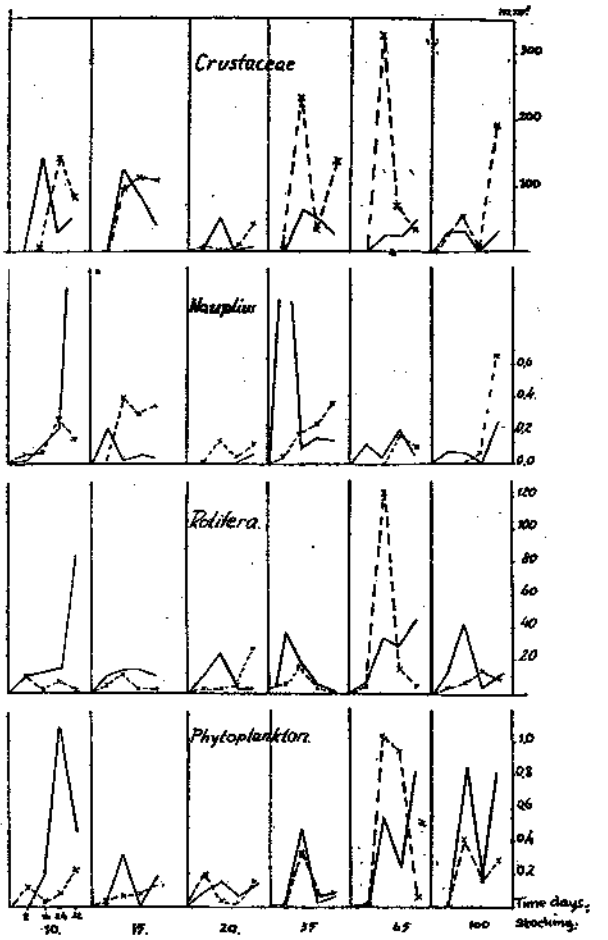

Fig. 7. Volumes of the most important groups in the plankton during the period of growth at different stocking rates.

By comparing the results at different stocking rates we see that, at the optimal rate of 20 carp per tank, both phytoplankton and zooplankton reach a minimum. This may be explained as follows: The minerals in the water are rapidly incorporated into the body of the carp, rendering them unavailable for the formation of phytoplankton. In heavily stocked tanks a good deal of zooplankton is eaten but almost all food is used for maintenance of the carp. Only a small fraction of the minerals is incorporated by the carp and a large fraction is excreted and becomes once more available to the phytoplankton. Minerals circulate rapidly and the amount of organic material formed in the tanks is high, as is demonstrated by the large amounts of plankton. Rotatoria are especially abundant in this instance because these organisms are hardly ever eaten by other biota in the tank.

In slightly stocked tanks the amount of maintenance food needed is low. The total amount of food ingested by the small number of carp is rather low too, so that the average life span of the Crustaceae must be rather long. But, as the circulation of minerals is slow, so the formation of phytoplankton must be slow too. The incorporation of minerals into the body of the carp will be less than in the case of intermediate stocking at the optimal rate. Therefore more minerals will remain available for phytoplankton until the end of the growth period.

The total amount of organic matter formed in the tank by photosynthesis will be minimal at intermediate stocking rates, intermediate at low stocking rates and maximal at high stocking rates.

The consideration set forth above may by summarized as follows (Table IX).

Table IX. Relation between stocking rate, circulation of minerals and production of organic matter in a fish pond.

	Stocking rats		
	Low	Intermediate	High
Maintenance food	Low	Intermediate	High
Minerals incorporated by the fish	Intermediate	Much	Little
Circulation of minerals	Slow	Intermediate	Rapid
Amount of minerals circulating	Intermediate	Small	Large
Organic matter formed	Intermediate	Little	Much

Among the organisms living in the mud, Oligochaetae and, notably, Chironomidae are the most important food for the carp.

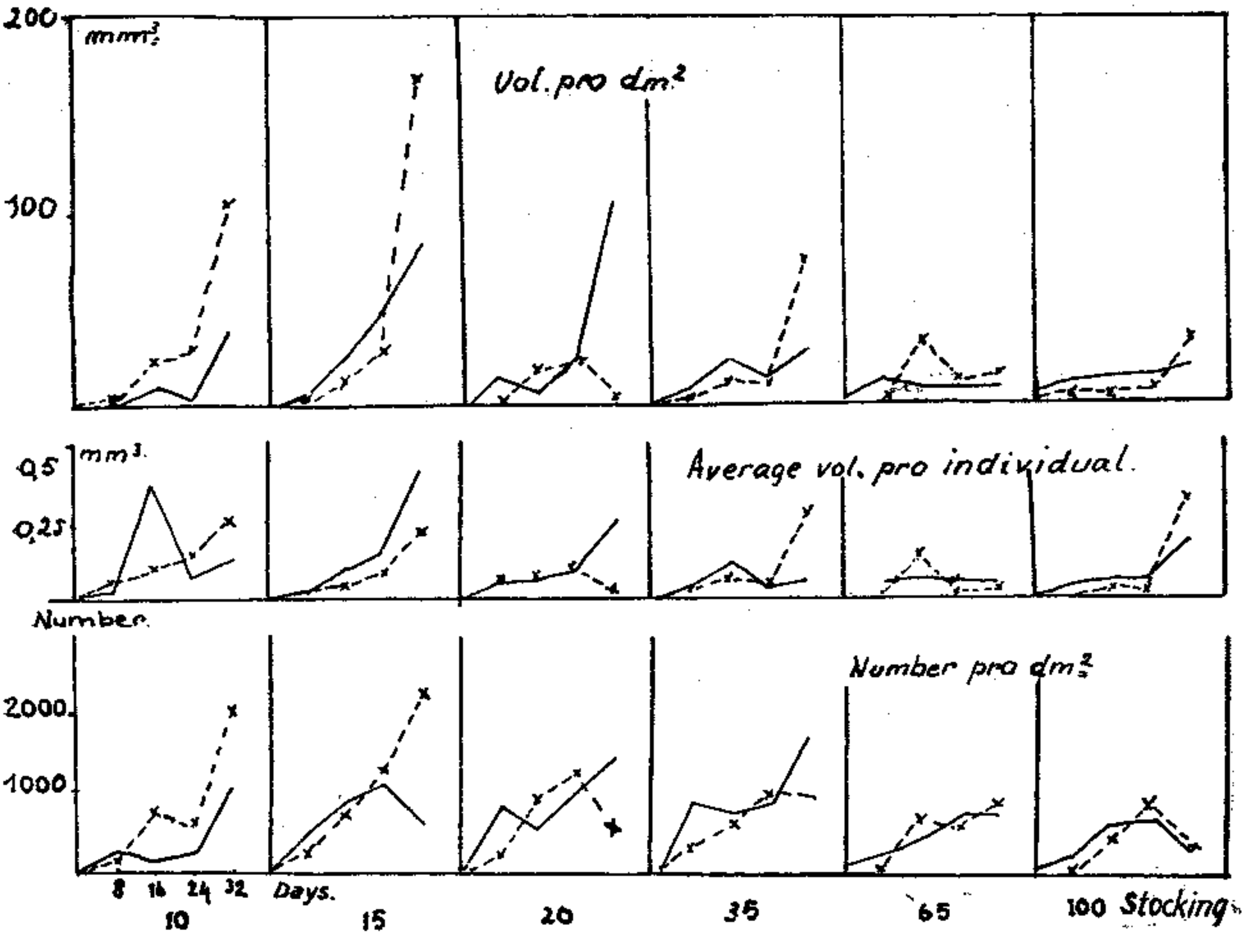

Fig. 8. Numbers and volumes of Chironomides collected from the mud during the period of growth at different stocking rates.

The numbers found in our experiments are shown in Fig. 8. The numbers will be seen to rise during the course of the growth period, except in some heavily stocked tanks. The total quantity proves to be high in the tanks with a low stocking rate. As the size of the Chironomidae seems to vary, all larvae were measured and their volume calculated. The results are given in Fig. 8. It will be seen that the number, as well as the average volume of Chironomidae is higher in the slightly stocked ponds. This is in accordance with Contag's findings.

No connection can be observed between the number of Chironomid larvae and the phytoplankton. These larvae obviously do not propagate in the tanks and a heavy stock of them is always present in the sewers. As the metamorphosis there remains undisturbed, the number of ovulating midges is permanently high and egglaying females do not have any reason to prefer any special tank. It seems warranted to assume that the number of eggs deposited in each tank is the same.

The number of algae found in the mud is always very high and no effect of the different stocking rates was observed. For this reason the food supply will not be a limiting factor for Chironomid larvae. Therefore the number and volume of Chironomidae will almost exclusively depend on the amount consumed by the carp. In heavily stocked tanks these larvae will be eaten almost immediately after hatching and only few of them will have the opportunity to grow to a large size.

Therefore, both number and volume, will be low.

EXAMINATION OF THE GUT CONTENTS AND FAECES OF THE CARP

After the tanks had been drained at the end of Experiments II and III, the gut contents of 2 carp from each tank were examined by K.F. Vaas.

From our point of view, the most inter-

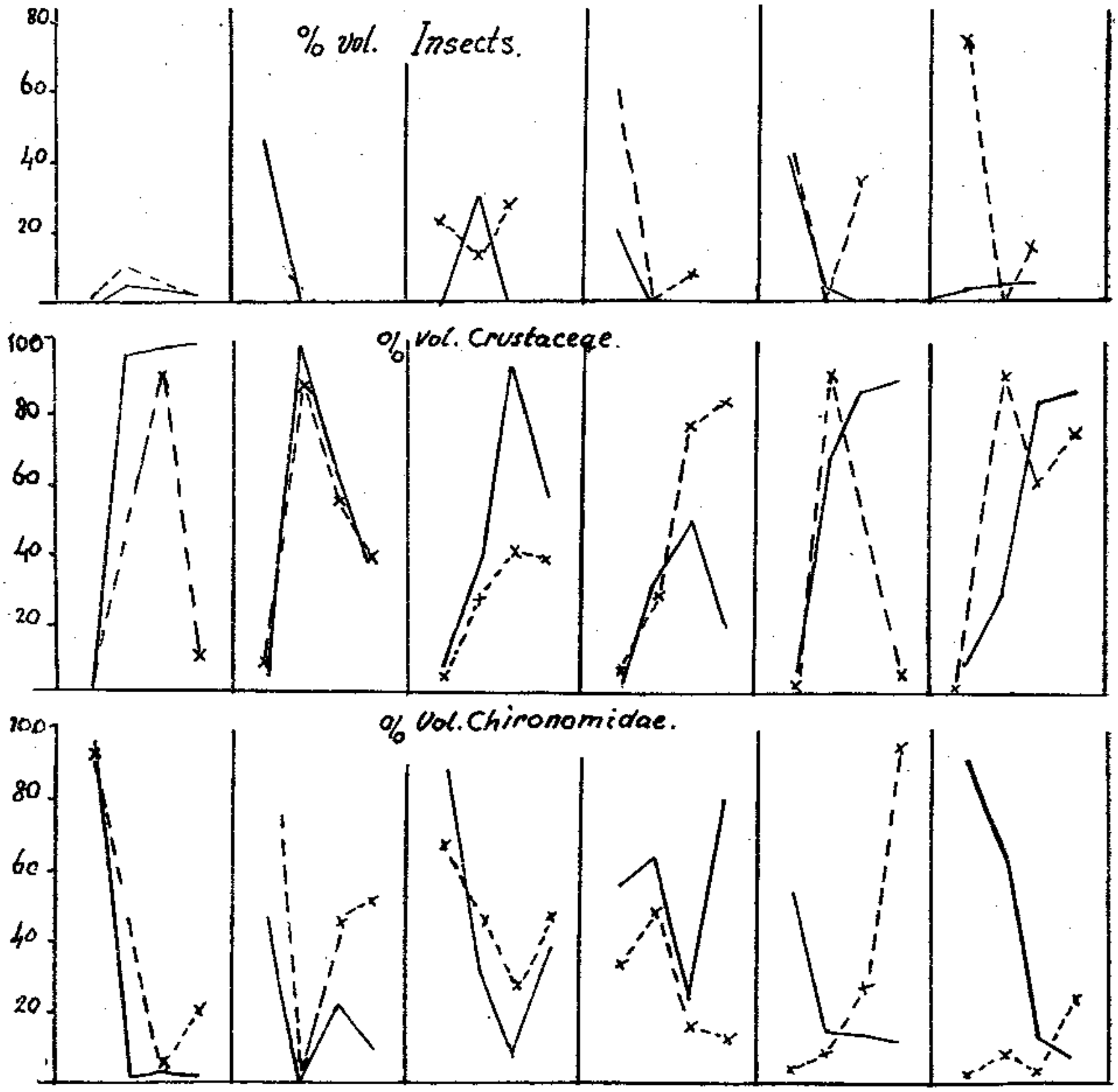

Fig. 9. Organisms found in the faeces, in percentages of the total volume.

esting figures are those representing the percentages for the volume occupied by various organisms in the guts. These figures are contained in Tables X and XI.

It will be observed that the percentage of Crustaceae remains constant for all four stocking rates, whereas the percentage of Chironomidae declines as the stocking rate decreases.

The amount of plant tissue is higher at the higher rates.

Only at the very low rate of 3 carp per tank in Experiment III (Table 9), was a high percentage of plant tissue found.

As stated in other papers by Vaas (in these Proceedings) big carp often eat plant tissue even when other food is available.

However, it appears that the less the other food is available the more plant tissue is eaten.

Only small differences observed in the percentage of Crustaceae may be explained by the fact, mentioned in an earlier chapter, that a large amount of zooplankton is formed in the heavily stocked tanks.

However, the number of Chironomidae available is primarily determined by the number eaten by the carp. Consequently, at the end of the experiment their number is low at high stocking rates. Then the carp turns to other food such as plant tissue including thread algae.

The best insight into the feeding habits of the carp during the course of an entire period of growth cannot be obtained from samples taken at the end only, but from samples taken at intervals. As it was impossible to reduce the number of fish during the period, it was decided to examine their faeces, simultaneously with the biota of the tank. The number of carp from which faeces were collected bore the following relation to the stocking rate :

Stocking rate :	10	15	20	35	65	110
Number of carp :	4	5	6	8	10	12

The amount of faeces not being constant, the volumes of identifiable organisms were expressed in percentages of the total volume. The results are presented in Fig. 9.

At the end of the first period of 8 days it was found that, in most tanks, mainly Chironomidae had been ingested, at the end of the second period mainly Crustaceae, and during the third and fourth poriod of 8 days both groups in varying ratios.

Comparison of these results with the data showing availability of Crustaceae in the tanks at the same time, shows a positive correlation.

At the end of the first period of 8 days, the amount of Chironomid larvae in the guts was high for all tanks, although the amount available in the tanks was low. However, in the second period the amount of the larvae in the mud increased, but the amount in the guts decreased rapidly. During the third and the fourth period the percentages of these larvae in the guts and in the mud appear to correspond. In conformity with conclusions drawn from limnological observations, the number of Crustaceae was found to be determined by the number of phytoplankters in contrast to the situation found in the case of Chironomidae, for which ingestion by the carp proved to be the main regulating factor.

Summarizing we obtain the following picture concerning the choice of food by the carp. In the early period of growth, when plankton has not yet developed, Chironomidae are eaten as soon as hatched. Their number is therefore reduced by the carp, but, by the time zooplankton has formed, the stress on the midge larvae is somewhat reduced, as Crustaceae are ingested in increasing numbers, and the Chironomidae can grow out. Later on, as the carp have increased in size, the development of the zooplankton is too slow to supply the increasing amount of food needed by the fish and they again turn to Chironomidae. Particularly in heavily stocked ponds their numbers are greatly reduced; they do not have sufficient opportunity for growth and the detritus on the bottom cannot now be utilised by the carp.

In a pond with a low stocking rate sufficient zooplankton will be available and far less Chironomidae will be ingested.

Having enough opportunity to grow, part of them will pupate and, ultimately, leave the econsystem, causing a loss of food.

In ponds with intermediate stocking rates less zooplankton is available and more insect larvae are eaten, but, because the stocking rate is not very high, their number is not so rapidly reduced. The larvae have the opportunity to convert detritus into the flesh of their bodies and this food becomes available to the carp.

In this case, therefore, the minerals, originally present in the water, the basic elements of metabolism, of which a limited supply only is available during a single period of growth between filling and draining the pond, are used in the most economical way to synthesize fish flesh.

As long as the concentration of Crustaceae is high, the fish take this easily obtainable food.

When the concentration of Crustaceae is too low, the carp fails to collect sufficient for its needs per unit of time, and begins to feed from the bottom. If Chironomidae are also hard to collect, the carp will turn to snails, plant tissue and thread algae. Very big carp seem to form an exception, showing a certain preference for plant tissue in any case.

A comparison of these data with the growth curves in Fig. 5, shows that during the first period, when tiny midge larvae only are eaten, growth is slow.

During the second period, when Crustaceae are eaten, growth is rapid. In the third period Crustaceae begin to decrease and Chironomidae are ingested as well. Moreover, the amount of food needed for maintenance has also increased. At the stage when food needed for maintenance equals food ingested, no more growth can take place. In our experiments. this stage was not reached at all at stocking rates 10 and 15. At stocking rate of 20, it was almost reached. The amount of food was greatly reduced and the number of fresh Crustaceae was very low, whereas the amount of maintenance food was high. Consequently, a decrease in total weight of the crop would probably take place, if cropping were postponed.

At high stocking rates the amount of tood ingested equals the amount of maintenance food from the very beginning. Both the decrease of the amount of food available and the increase of maintenance food proceed at a slow rate. So the danger of decrease in weight at high stocking rates is small, but at optimal stocking rate it is of primary importance to crop the pond at the right moment.

It was assumed above that growth was most rapid during the time Crustaceae were the main food. However, it should not be inferred, from this statement, that the coefficient of food digestion for Crustaceae is higher than that for other sources of food. It even follows from Karsinskin's (1935) work that Chironomidae are a better digestible kind of food. We only wish to point out that in our tanks during the stage at which natural food was abundant, the ratio between the concentration of Crustaceae and Chironomidae was such, that the carp selected the former. In the tanks with the highest yield the supply of Crustaceae was low and, as stated above, Chironomidae were ingested during the period of rapid growth as well.

At the end of the experiment the gut contents of 2 carp from each tank were examined. The figures obtained were combined with the results of investigations of the faeces collected at the same moment. The outcome is shown in Table XII.

Table XII. Gut contents of 12 x 2 carp from concrete tanks, stocked at different rates, in Bogor, experssed in percentages of volume.

Stocking rate	10	15	20	35	65	100
Chironomidae	7.9	36.8	43.0	38.2	39.0	35.0
Other Insects	1.1	4.3	5.9	-	1.1	2.6
Oligochaetae	3.5	1.8	2.5	-	-	-
Crustaceae	72.5	45.2	48.2	62.5	50.2	63.0
Plant tissue	16.5	22.5	-	0.5	0.5	0.5

These results are not in accordance with those obtained in Experiments II and III. In this instance the larger carp from the lower stocked tanks have eaten a large percentage of plant tissue. Moreover, as the number of Crustaceae was still fairly high, they hardly fed on Chironomidae.

At the intermediate rates of 15 and 20 carp per tank, the number of Crustaceae was low in the water as well as in the guts. At the stocking rate of 15, the deficit of Crustaceae is met by Chironomidae and plant tissue, at the optimal rate of 20, by Chironomidae alone. These larvae were eaten in maximum quantities at this stocking rate. At each of the higher rates—35, 65 and 100 carp/tank—Crustaceae formed about 2/3rds of the total quantity and Chironomidae about 1/3rd.

It is surprising that at those high stocking rates, at which hardly any growth occurred, no other food was taken.

Probably the carp from these tanks, were still too small, 2 grams, to eat such coarse food as snails, thread algae and plant tissue.

As mentioned before small differences in climatological conditions between the periods during which the experiments were carried out have to be taken into account.

Similarily, small differences in the ecological conditions of the tanks may exist in the course of á single experiment.

Thus, the second parallel of stocking rate 10 showed a heavy growth of Spirogyra resulting in a very low development of phytoplankton.

DISCUSSION

The general trend of metabolic processes in a carp pond may be described as follows :

After the pond has been filled with water rich in particulate organic substances and bacteria, the silt will settle on the bottom. A rich protozoan fauna and bacterial flora will develop on this silt, liberating minerals. Moreover, Chironomidae and Oligochaetae will develop, converting the detritus into the flesh of their bodies and again liberating a certain amount of minerals with their excreta.

These animals are eaten by the carp and thus partly converted into fish flesh. The excreta of the carp will liberate a fair amount of minerals into the water and thus form the basis for the development of phytoplankton. On this group zooplankton will grow, serving as food for the carp. The above processes take their course during the first two weeks.

Part of the faeces of the carp and all plankters dying from natural causes will settle on the bottom, contributing to the food for the bottom fauna. Using the minerals liberated in the mud on the bottom, an algal bottom flora will develop, mainly Diatomeae. These algae, together with the detritus mentioned above, form the food of the bottom fauna and the latter, in turn, is eaten by the carp.

However, in these metabolic cycles certain "side tracks" occur; organisms are not or hardly eaten by any other animal in the pond. Lebistes, frog-larvae, snails and thread algae are a case in point. The latter two organisms are sometimes eaten by the carp to a slight extent. Lebistes, frog-larvae and snails will accelerate the circulation of minerals because they eat other organisms, but together with Spirogyra they tend to accumulate minerals in their bodies, making them unavailable for vegetable organisms, in other words unavailable for further synthesis.

All biota in the pond fluctuate in numbers for the reasons described above. Gradually more and more minerals will be incorporated, either in fish flesh or in the "side tracks", and the amount available for circulation will gradually decrease. For this reason less phytoplankton will be formed in course of time and consequently also less zooplankton.

This is what happens in the fourth week. Bottom algae still abound at the end of the month, so the number of detritus-feeding animals on the bottom can still increase, unless they are too rapidly devoured by the carp.

According to Buschkiel (1938) the ideal type of a European carp pond is a pond showing a heavy bloom of phytoplankton, which upon decaying at the bottom after death, is eaten by a large number of Chironomidae serving as food for the carp.

This hypothesis is based on the assumption that large numbers of Chironomidae will occur in a pond whenever there is sufficient food for them. So the amount of phytoplankton or its rate of growth is here deemed to be the limiting factor.

This might be the case in Europe, but the question arises whether this type of pond exists in the tropics.

According to Beauchamp (1953) the process of assimilation in the tropics is too rapid ever to become a limiting factor.

Such a factor must be sought in the katabolic part of the metabolic cycle : in the herbivorous animals mineralising the large amount of organic matter formed.

In our case the part of the herbivores is played in the water by Rotatoria, Crustaceae and frog-larvae and in the mud by Chironomidae, some other insects and their larvae, Oligochaetae and snails.

Conversion of phytoplankton into zooplankton seems to be a most rapid process in our carp ponds, as we have seen that fluctuations of the phytoplankton are closely followed by similar ones of the zooplankton.

However, a large number of Diatomeae is left untouched on the bottom.

The limiting factor seems to be the number of detritus-feeders, their rate of growth and their propagation. Oviposition of Chironomidae, propagation of Oligechaetae and the rate of growth of either group seem to be too slow to mineralise the amount of organic material on the bottom.

Only once the present author witnessed an outburst of Chironomidae, following a heavy bloom and decay of *Euglena sanguinea* in a very small and heavily manured pond in which production of fish was very high.

By comparing the influence of different stocking rates we have seen that in understocked ponds a fairly large amount of minerals is circulating slowly, in optimally stocked ponds a very small amount is circulating somewhat faster and in overstocked ponds a large quantity circulates very rapidly. The explanation was sought in the difference between maintenance food and growth food. If a certain kind of food is used for maintenance, the minerals will be excreted to a large extent; if it is used for growth, minerals will be incorporated and withdrawn from circulation. This relation explains why development of plankton continues until the end of the period in the case of high rates (Fig. 7, stocking rate 100). However, sometimes the concentration of zooplankton is insufficient for large carp, and many Chironomidae are eaten as well. As these larvae are unable to develop quickly enough, their numbers and total volume are decreasing towards the end of the period.

The investigations of Vaas and Vaas-van Oven (to be published elsewhere) concerning the composition of the gut contents of the common carp during growth show that in carp of increasing size the number of Crustaceae in the guts is low, each time the pond had been refilled with water, it increased afterwards until an optimum is reached, and finally it decreases again.

The number of Chironomidae was found to rise more slowly towards the end of the period or to show a less definite optimum.

Although no concomitant limnological data were available, there are perhaps indications that, in the case of these carp too, a large number of Crustaceae was present some time after the pond had been filled, and that a decrease followed afterwards. In some instances Chironomidae must have been plentiful, showing an optimum in others. Here ordinary ponds were used, with slowly running water and with a heavy supply of organic manure, while the carp were given some bran as well; yet a strong similarity with our concrete tanks could be noted. In spite of the simplified conditions in our experiments, we may assume that metabolic cycles proceed along similar lines in most instances of ordinary ponds fed with water containing a good deal of particulate organic matter.

From our calculations of growth and ultilisation of food we concluded that the total quantity of food ingested by the entire population rose as the stocking rate increased (Fig. 6). The question was raised at that stage whether this had to be explained by assuming that the total quantity of food was larger, or whether the utilisation of food was better. In order to evaluate food production certain limnological investigations were carried out. However, we are not yet in a position to give an exact answer, owing to our lack of knowledge about the average life time, the rate of growth and the propagation of the various organisms involved.

In a general way it may be stated that organisms in a tropical pond will differ from organisms in one in the temperate zone, in the following ways: the life span will be shorter, the rate of growth will be higher, the propagation will be more rapid, but the ultimate volume per animal will be smaller. The total quantity of Crustaceae will be at a maximum in ponds stocked at the highest rates. The large amount of rapidly circulating minerals gives rise to a heavy bloom of phytoplankton and consequently to a well developed zooplankton. Crustaceae will be at a minimum in optimally stocked ponds and the total quantity in understocked ponds will be in between these two values.

The volume of Chironomidae hatched during the entire period of growth decreases with increasing stocking rates. As it must be assumed that the number of eggs deposited in the ponds is constant, we can infer that the larvae are so quickly devoured in heavily stocked ponds, that they do not have the opportunity to get ahead.

When phytoplankton is well developed and zooplankton is growing rapidly, we must assume that usually the increase in volume of the Crustaceae exceeds that of the Chironomidae. Thus it would follow that the total supply of natural food is maximal at overstocking, minimal at optimal stocking and intermediate at low stocking rates.

It is surprising at first sight to have to realize that the total production of natural food stands in an inverse relation to the total yield of fish flesh but this relation will be explained in the following paragraphs.

The difference between the total quantities of food ingested at various stocking rates higher than the optimal one is a result of the fact that the supply was maximal at the highest rate. But this does not yet explain the differences between the amounts ingested in the tanks with low stocking rates. Here the total amount of food formed was higher, therefore we are led to believe that part of it was left untouched, as we have seen that many Chironomidae were not ingested (situation at low stocking rates, shown in Fig. 8 and 9).

We may however look at the "availability of food" from another angle.

From all our considerations we concluded that the part played by dissolved minerals is of primary importance for all metabolic cycles in the pond. There will hardly ever be a high concentration of dissolved minerals in the water, because they are incorporated into phytoplankton immediately after they have been released, thus they ultimately determine the rate of all metabolic processes.

Nearly the only source of minerals is the water supply, or rather, the particulate organic matter in which minerals are still enclosed. Moreover, the total amount of mineral matter in the tanks is slightly increased in course of time by leaves falling in. However, the total amount is quite independent from the way of stocking and can be seen as constant throughout. At too low stocking rates minerals circulate so slowly that not much organic matter is formed. A good deal is taken up by animals that are not eaten themselves.

At too high stocking rates the minerals are constantly used for the formation of new maintenance food. Besides, a part of the minerals remains on the bottom without being of any further use. It is incorporated into bottom algae that are not eaten by the bottom fauna, because the animals constituting this fauna are eaten too rapidly by the carp. Part of the minerals will be absorbed by snails. These snails subsist on bottom algae, but are not often eaten themselves. In a way "side tracking" organisms also profit by the rapid circulation. At optimal stocking rate the minerals are taken up by the fish at the most rapid rate. The part of the minerals that settles on the bottom is also used, because Chironomidae and other members of the bottom fauna are still present to consume it. But since minerals are stored by the carp to a large extent, the "side tracks" do not have much opportunity to get hold of them.

Natural food decreases quickly in the course of the growing period and the rapidly increasing fish population needs a lot of maintenance food.

The optimal stocking rate is characterised by rapid conversion of minerals into fish flesh, rapid growth during the second and third period of 8 days and rapid decline of the growth rate during the next period.

SOME CONCLUSIONS IMPORTANT FOR PRACTICAL POND CULTURE OF THE COMMON CARP

1) It is most important to ascertain the optimal stocking rate.

The total yield falls rapidly at decreasing stocking rates. In the event of overstocking the total yield will decrease much slower, but the danger of losses will increase. A correct rate of stocking means an economic use of fry. By finding the total number and the total weight of fish at the time of stocking and of cropping, it is possible to obtain the data necesary to determine the optimal rate for carp of different size in every pond complex. Calculations based only on an estimation of the yield, a desired weight of fish or a desired duration of the growing period, are apt to cause great disappointments because the total yield depends on the duration of the period, on the stocking rate and on the initial weight of the stocked material and may not be seen as a constant characteristic for a certain pond.

At high stocking rates the total yield cannot be increased by a prolongation of the growing period.

2) No correct estimation of the total yield can be made by determination of the quantity of plankton only.

3) On the basis of an analysis as referred to above, limnological improvements in the pond may be effected, causing an increased yield of fish.

In the situation described, the limiting factor seems to be the number of animals eating the bottom - detritus, such as Chironomidae and Oligochaetae. Chironomidae might be attracted by the use of small tanks full of decaying vegetable material, situated near the pond. Another way might be the use of Oligochaetae, cultivated separately in tanks and added to the ponds.

Still another way might be to try to eliminate the "side tracks" by introducing animals, preferably other fish, living on them.

In our case the "side tracks" were: frog larvae, Lebistes, snails and Spirogyra. The introduction of fish feeding on these organisms might be beneficial.* It will be difficult to eliminate frog larvae and Lebistes in this way, as the introduction of predatory fishes is out of the question. Still the eradication of Lebistes merits attention, as this fish is not only a "side track" but also a competitor for food. In any case, the introduction of Lebistes for larvicidal purposes in regions where this species is still absent and where Common carp are raised should be avoided.

4) An obvious way of improving is the increase of the amount of minerals available. Next to the use of fertilizers having the disadvantage of high cost and causing an intensive bloom of phytoplankton with the concomitant danger of absorption of oxygen at night time, the use of green manure and stable manure might be considered.

Some of the improvements mentioned above are being examined at the present time in our Laboratory. The preliminary results of some of these investigations will be published in another paper.

SUMMARY

1) In concrete tanks the optimal yiel d and individual growth of carp fry at various stocking rates was studied, together with the influence of the fish on the metabolic cycles in the tanks.

2) Connections between stocking rate, individual growth and total yield are given in Fig. 2 and 3.

3) The individual growth of carp at various stocking rates are illustrated in Fig. 5.

4) The relationship between food ingested, maintenance food and food available for growth for the entire population was calculated. The results of this calculation are given in Fig. 6. It appears that the amount of food ingested rises with increasing stocking rates, as does the amount of food needed for maintenance. At the stage where the difference between these two values reaches a maximum, we find the optimal stocking rate.

5) It was inferred from limnological investigations that the amount of food formed in the tanks was maximal at high stocking rates, minimal at optimal stocking rates and

* The Indian carp, *Labeo calbasu* (Ham.) and the Chinese black carp, *Mylopharyngodon piceus* (Rich.) are reported to eat snails.

intermediate at low rates. These relations were explained by assuming that minerals are incorporated rapidly at optimal stocking rates and, for this reason, are no longer available for the phytoplankton (Fig. 7 and 8).

6) From a consideration of the connection between limnological data (Fig. 7 and 8) and the gut contents (Fig. 9), we concluded that at the optimal stocking rate the available food is utilised to the best advantage, and that minerals are most rapidly incorporated by the carp into the flesh of their body, thus preventing those minerals from being absorbed by organisms not eaten by the carp or by other animals in the ecosystem ("side tracks").

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Table I. Experiment I, II, III. Individual growth and total yield per tank.

(Horizontal rows represent 3 different parallels, but 6 for stocking rate of 60, as at this rate Experiment I and III overlap).

Stocking Rate	3	10	17	20	24	30	40	45	60	75	80
Individual growth in grams	24.6 38.2 33.6	16.0 15.2 17.2	18.1 10.0 8.5	12,2 12.2 12.2	5.8 7.0 4.9	7.1 7.0 6.8	4.2 4.6 3.1	6.0 3.7 5.7	2'1 2.7 3.9 3.7 4.8 1.8	3.4 3.3 2.0	1.3 1.0 1.0
Total yield in grams per tank	77.9 144.6 100.0	159.4 151.8 171.7	197.5 171.4 131.2	215 230 230	159.7 138.1 95.6	205 210 180	165 160 115	235 125 235	165 160 175 175 125 110	170 245 135	100 50 55

Table II. Experiment IV. Individual growth and total yield per tank.

(Two paralells for each stocking rate).

Stocking Rate	10	15	20	35	65	100
Individual growth in grams	13.7 21.7	10.0 12.9	9.0 5.7	4.2 5.0	2.2 1.5	1.0 1.6
Total yield in grams per tank	122 149	140 179	170 200	119 182	135 89	72 84

Table III.

Correction table to be used when initial weight and ultimate weight only are known. *(For explanation see text)*

Individual growth in grams	Average 5 intermediate weights in grams	Average initial and ultimate weight in grams	Correction factor
17.5	8.1	9.7	0.83
11.5	5.8	6.7	0.86
7.6	4.7	4.8	1.00
5.3	3.3	3.1	1.00
2.6	2.1	2.3	1.00
1.3	1.6	1.6	1.00

Table V. Actual individual growth, compared with theoretical individual growth assuming that all food available were used.

1	2	3	4	5	6	7
Stocking Rate	Amount of food available per fish in *U*	Maintenance food needed per fish in *U*	Food available for growth in *U*	Growth in grams calculated	Growth in grams measured	Difference 5–6
10	17.50	4.20	13.30	47.2	15.0	32.2
20	8.70	3.00	5.70	24.5	9.0	15.5
40	4.40	2.10	2.30	9.9	4.0	5.9
60	2.90	1.70	1.20	5.2	2.3	2.9
80	2.20	1.45	0.75	3.2	1.4	1.8
100	1.75	1.30	0.45	1.9	1.0	0.9
120	1.45	1.20	0.25	1.1	0.6	0.5
150	1.20	1.15	0.05	0.2	0.2	0.0
175	1.00	1.00	0.00	0.0	0.0	0.0

Table IV. Growth and food at different stocking rates.

Stocking Rate	Individual Growth in gram	Average weight in gram	Average length in cm.	$\frac{\text{Weight}}{\text{length}}$	Maintenance food in *U* $\left(\frac{Q}{0.31} \times \text{st. rate}\right)$	Total yield per tank in gram	Food used for growth in *U* $\frac{\text{Total yield}}{4.3}$ (calculated)	Total amount of food ingested in *U* (calculated)
Experiment I,II,III								
120	0.0	1.50	3.60	0.42	165	0	0	165
100	0.6	1.80	3.75	0.47	151	60	16	167
80	1.2	2.10	4.08	0.51	131	196	22	158
60	2.6	2.80	4.50	0.62	120	156	33	153
40	4.9	3.95	5.00	0.80	103	196	45	148
20	10.0	5.40	5.50	0.98	63	200	46	109
10	14.6	7.50	6.00	1.20	49	146	33	82
Experiment IV								
175	0.0	1.00	3.20	0.31	175	0	0.0	175.0
150	0.2	1.10	3.25	0.34	168	30	7.0	175.0
120	0.6	1.30	3.40	0.38	147	72	16.5	163.5
100	1.0	1.50	3.60	0.41	130	100	23.0	153.0
80	1.4	1.70	3.80	0.45	116	112	25.5	141.5
60	2.3	2.15	4.10	0.52	101	138	[illegible]1.5	141.5
40	4.0	3.00	4.60	0.65	84	160	36.0	120.0
20	9.0	5.20	5.50	0.99	60	180	41.0	101.0
10	15.0	8.50	6.50	1.31	42	150	34.0	76.0

Table VI. Most important genera found in the Plankton of 12 concrete tanks in Bogor.

Plankton		*Protozoa*	
		Arcella	+
Volvocales		Difflugia	+
Pandorina	+ +	Ciliates (unidentified)	+
Chlorococcales		*Rotifera*	
Dictyosphaerium	+ + +	Brachionus	+
Golenkinia	+ +	Monostyla	+
Conjugales		Polyarthra	+
Cosmarium	+	Asplanchna	+
Xanthopyceae		*Crustacea*	
Botryococcus (incidental)	+ + +	Nauplius larvae	+ +
Diatomeae		Bosmina	+
Navicula	+ + +	Cyclops	+ +
Melosira	+ +	Diaphanosoma	+ +
Dinophyceae			
Peridinium (incidental)	+ + +		
Chloromonadineae			
Euglena			
Cyanophyceae			
Microcystis	+		
Oscillatoria	+		

Table VII. Most important organisms found in the mud of 12 concrete tanks in Bogor.

Chironomide larvae		Branchiodrilus	+
Chironomus	+ +	Dero	+
Tanytarsus	+ +	Limnodrilus (incidentally)	
Eutanytarsus	+ +	*Mollusca*	
Paratanytarsus	+ +	Vivipara	+ +
Tanypus	+ +	Melania	+ +
Protenthes	+		
Ephemeridae larvae (Not identified)		*Diatomeae*	
Oligochaetae		Navicula	+ + +
Nais	+	Melosira	+ + +
Aulophorus	+	Cymbella	+ +
Pristina	+	Pleurosigma	+ +

Table X. Experiment I. Organisms found in the guts of 12 × 2 carps, expressed in percentages of volume.

Biota \ Stocking	20	40	60	80
Chironomidae	44.8	24.2	28.4	4.7
Other insects	1.7	2.2	9.9	4.2
Crustacea	40.0	46.4	41.5	39.0
Oligochaetae	—	0.1	—	—
Gastropoda	1.2	—	1.1	2.8
Plant tissue and thread algae	12.3	27.2	19.2	80.0

Table XI. Experiment II: Organisms found in the guts of 12 × 2 carps, expressed in percentages of volume.

Biota \ Stocking	5	10	17	24
Chironomidae	32.1	33.6	22.9	9.1
Insects	4.9	15.6	4.2	6.9
Crustacea	52.5	52.0	59.3	55.6
Oligochaetae	—	0.6	0.5	0.1
Gastropoda	—	—	—	2.9
Plant tissue	10.3	1.1	13.8	25.2
Thread algae	0.2	0.1	0.2	—