GCP/RAF/271/FIN-TD/78 (En) November 1997

STUDY ON ZOOPLANKTON DEVELOPMENT TIME AT LAKE TANGANYIKA

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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS

Bujumbura, November 1997

PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika project (LTR) became fully operational in January 1992. It is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Finnish International Development Agency (FINNIDA) and the Arab Gulf Program for the United Nations Development Organization (AGFUND)

LTR's objective is the determination of the biological basis for fish production on Lake Tanganyika, in order to permit the formulation of a coherent lake-wide fisheries management policy for the four riparian States (Burundi, Tanzania, D. R. Congo and Zambia).

Particular attention is given to the reinforcement of the skills and physical facilities of the fisheries research units in all four beneficiary countries as well as to the build-up of effective coordination mechanisms to ensure full collaboration between the Governments concerned.

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Hyvönen, K., 1997 Study on zooplankton development time at Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries of Lake Tanganyika. **GCP/RAF/271/FIN-TD/78 (En): 11p.**

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1. Introduction

Secondary production measurements are an important tool in estimating the carbon flow between trophic levels. As consumers of phytoplankton and as food for fish, the zooplankton provide the trophic link between primary production and fish production in the pelagic ecosystem. Although some species of fish feed exclusively on phytoplankton, most pelagic fish are dependent for some or all their life on zooplankton as food (Irvine and Waya, 1995).

The open-water zooplankton community in Lake Tanganyika is species poor. However, the pelagic zooplankton forms a central role in the lake ecosystem, transferring the energy from primary producers to the pelagic clupeids and juveniles *of Lates stappersii* (Kurki and Vuorinen 1995).

It has been assumed that the egg production rate of females of several copepod species is representative of the growth rate of other stages (except for first nauplius stage and males) (Berggreen *et al*. 1988). Thus the production of a population could be calculated on the basis of the egg production rates of females. In any event, several studies have indicated that the egg production of females is not always representative of the growth rate of juvenile stages; it is probable that not all species exhibit stage-independent growth rates (Berggreen *et al*. 1988, Peterson *et al*. 1991).

The other method used for copepods is the growth increment summation method, (the mathematically similar instantaneous growth method) which takes into account the development rates of each distinct life stage or group of life stages (*e.g*. nauplii) (Irvine 1995). At its simplest, production is defined as 'the biomass (expressed usually as wet or dry weight or carbon biomass) accumulated by a population per time unit and can be calculated by multiplying the biomass of species by their growth rate (Downing and Rigler 1984).

Earlier estimations of the zooplankton production in Lake Tanganyika are based on published P/B ratios and the assumed mean biomass of 2 g dry wt m^{-2}. Burgis (1986) estimated the production as 50-60 g C m^{-2} $year^{-1}$, equivalent to about 100-200 g dry wt m^{-2} $year^{-1}$

According to earlier studies, the pelagic zooplankton is dominated by the crustacean copepod *Tropodiaptomus simplex* (Diaptomidae) and Cyclopidae. Therefore the objective of this study was to estimate the development time of the Calanoid copepod *Tropodiaptomus simplex* and cyclopoid copepoda in Lake Tanganyika. The results will be used for the estimation of copepod production in Lake Tanganyika as part of lake fish productivity assessments.

2. Materials and methods

2.1 Collection of zooplankton

The zooplankton was collected with a 100 µm mesh and 25 cm opening plankton net with a cod end cuvette volume of approximately 20 ml with a single haul from the depth of lOOm to the surface in Kigoma Bay. The collected zooplankton was transferred to lake water taken from the depth of 20 m, so the total volume in which the zooplankton was concentrated was 7.4 - 7.5 l The zooplankton samples were then transported to the laboratory and acclimatized for approximately 24 - 48 hours at room temperature (23-28°C).

2.2 Egg-development times

After the acclimatization period, the surviving adult female copepods with eggs were picked out with a pipette, isolated individually, and immersed in flat-bottomed petridishes containing about 10 ml of lakewater which had been filtered through a 25 µm mesh plankton net. They were then kept at room temperature under normal light conditions and .observed under low-power with a dissecting microscope every 2 hours between 0700 and 2300 hours. The females carrying eggs were recorded and counted.

Table I shows that there were two groups of female cyclopoids, a total of 60, which were treated and observed in the same way. There were also two groups of female calanoids which were treated in this way, except that the groups were collected and observed at different dates.

Table 1. Number of calanoida and cyclopoida females

	Number of calanoida females	Number of cyclopoida females
Collecting date		
5th December, 1995	30	60
9th December, 1995	30	-
Observation period		
6th-l2th December, 1995	30	60
lOth-l2th December, 1995	30	
Total number	∑=60	∑=60

2.3 Post-embryonic development

To study the development times, the copepod females with eggs were isolated on a petri-dish so that there were 3 females to each dish. The females were kept at room temperature until the nauplii had hatched. The nauplii that hatched at the same time

were transferred to culture bottles with 25 ml of filtered lakewater. The hatching time of the nauplii was taken as the beginning of the naupliar state. The water in the culture bottles was changed daily and the nauplii or copepodids were fed only with natural lake water. The water was collected daily from the lake from a depth of 20 meters with a 7.4 l Limnos sampler and filtered through a 25 µm mesh plankton net. Phytoplankton concentrations (measured as fluorescence of chlorophyll *a*) were measured daily using a fluorometer calibrated previously.

The nauplii or copepodid stages in culture bottles were settled on a table during the day and kept in a water-bath during the night to avoid the changes in ambient temperature. Controlling the ambient air by setting the culture bottles in a water-bath did not always succeed, and during the warmest season, the water temperature even rose to 30°C. Then the culture bottles were kept on the table during the day and the temperature was kept at a maximum of 28°C with the help of fans. During the night, the culture bottles were set in the water-bath to keep the temperature higher than in the ambient air.

The nauplii were inspected once a day by lighting them from behind with a normal table lamp so that the animals could be clearly seen. The transition from the nauplii to the copepodid stage was observed when larvaes' appearance and mode of swimming changed. The adult stage was recognized from the appearance of a genital segment in females and from the change in structure in the first antenna in males. The development time of the nauplii varied from 5 to 10 days. The calanoid males reached their adult stage in 26 or in 31 days and females in 29 or in 35 days under the above mentioned laboratory conditions.

The first group of nauplii that were settled in special culture bottles in a volume of 25 ml of water died, perhaps because of lack of oxygen or food, or because the ambient temperature was too high. The cultivation method was changed because of the high mortality rate among the nauplii. They were then cultivated in flasks with volumes from 50 ml up to 250 ml. The cyclopoids did not manage well at all. They were able to reach the naupliar stages only, and never lived long enough to reach the copepodid stages.

After the calanoids had reached the copepodid stage, they were fed with extra food. The phytoplankton for extra feeding was collected by pulling a 25 µm plankton net with a motorboat, very slowly for ten minutes. The collected phytoplankton was then diluted in a greater amount of water taken with the Limnos sampler from the depth of 20 m and filtered through the 50 µm plankton net in the laboratory. This allowed some extra naupliar stages to pass through to the cultivation flasks, and was thus not an appropriate way for feeding the naupliar stages.

2.4 Data handling

The numbers of egg-carrying females whose eggs had hatched were plotted against the time (Burgis 1970). The mean development time of the eggs was calculated. Normally all the eggs of one female hatched at the same time. In some cases, some of the eggs did not hatch simultaneously with the others, but the hatching

was observed in the second or third observation (two to four hours after the first hatching). The observations were done every 2 hours, except at night (2300-0700). The number of nauplii that had hatched during that time was divided by 4 in calculating the average development time. The cyclopoids also developed a second batch of eggs. The second batch was observed in the same way as the first one.

3. Results

3.1 Egg-development times

3.1.1Calanoids

The calanoids' average egg-development times are shown in Figure 1. The average egg-development time is around one day (0 = 24.1 ± 7.7), but the variation (S.D.) on the average is rather high. In Figure 1, the mode (or highest rate of hatching) for calanoids is 18 hours. Removing from consideration those eggs which hatched during the night (i.e. 18 hrs), then the highest rates of hatching are 20 and 26 hours.

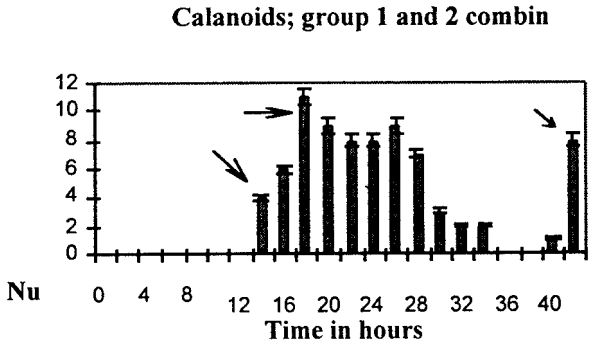

Figure 1. The calanoid's average egg-development time in hours. Marked times (14, 18 and 42) refer to the actual numbers of the eggs that were hatched during the night when no observation was made. (The number of nauplii that had hatched during that time was divided by 4 in calculating the average development time).

3.2.2 Cyclopoids

The average egg-development time and S.D. (0 = 29.0 ± 11.0) of cyclopoids are shown in Figure 2. In the same figure, the mode (or highest rate of hatching) for cyclopoids is 36 hours. Removing from consideration those eggs which hatched during the night (i.e. 36 hrs) then the highest rate of hatching is 40 hours.

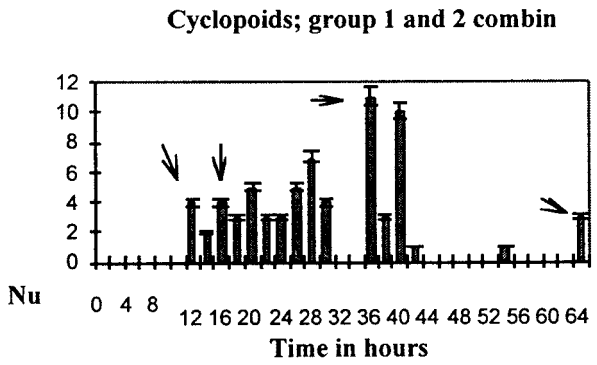

Figure 2. The cyclopoids's average egg-development time in hours. Marked times (12, 16,36 and 64) refer the actual numbers of the eggs that were hatched during the night when no observation were made. (The number of nauplii that had hatched during that time was divided by 4 in calculating the average development time).

Cyclopoids also developed a second batch of eggs. The egg-development times and S.D. (0 = 48.5 ± 16.4) can be seen in Figure 3. In the same figure, the mode (or highest rates of hatching) for the second batch of the eggs of the cyclopoids are 40 and 44 hours. Removing from consideration those eggs which hatched during the night (i.e. 44 hrs), then the highest rate of hatching is 40 hours.

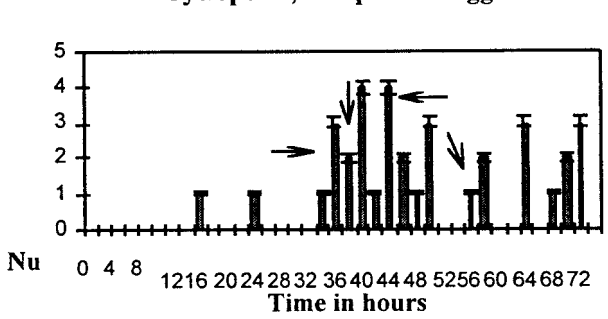

Figure 3. The cyclopoid's average egg-development time in hours. The second batch of hatched eggs. Marked times (36,38,44 and *56)* refer the actual numbers of the eggs that were hatched during the night when no observation was made. (The number of nauplii that had hatched during that time was divided by 4 in calculating the average development time).

3.2 Post-embryonic development time of calanoids

The post-embryonic development times of calanoids are shown in Figure 4. The development time from naupliar to copepodid stage varied from 5 to 10 days (n=52) and the development time from the copepodid stage to the adult varied in males from 26 to 31 days (n~3) and in females from 29 to 35 days (n=4). The mode for naupliar development is shown in the Figure 4 and is 6 days while the average ± S.D. is 7.4 ± 1.4 days.

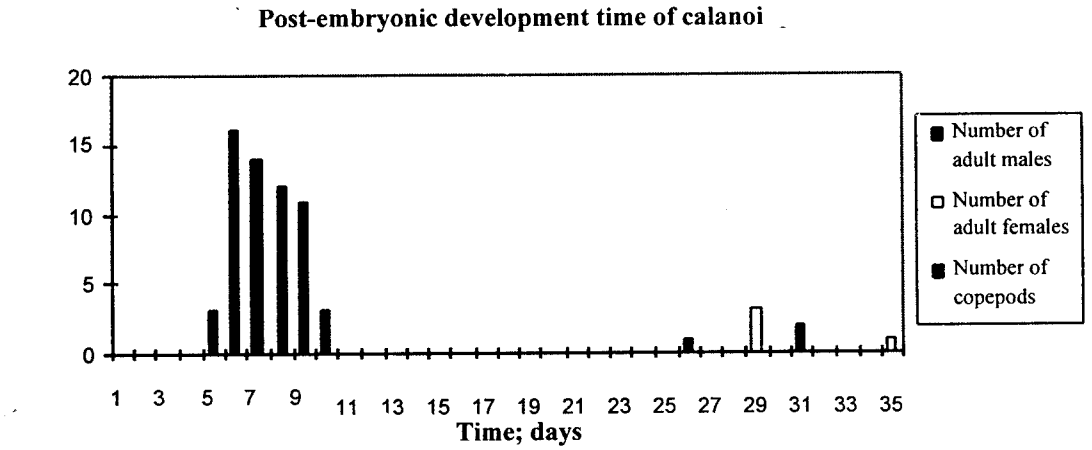

Figure 4. The post-embryonic development time of calanoids

At the end of the experiment there were still 12 copepodids that had lived from 29 to 36 days without molting into the adult stage.

The experiment did not manage well in cyclops, because they never lived long enough to reach the copepodid stage.

4. Conclusions and recommendations

This experiment should be regarded as a preliminary one because some of the laboratory conditions were not fully controlled. The method for controlling the temperature should be developed for future experiments, because the temperature varied up to 8°C during the experiment. This could be a very important source of error, especially for egg-development time experiments, as the development time of copepod and cladocerans eggs appear to be mostly dependent on temperature (Bottrel *et al.*, 1976; Vijverberg, 1980). In another experiment concerning the egg-development time of Lake Malawi zooplankton, the temperature range was 3°C and in post-embryonic development studies even up to 11°C (Irvine and Waya, 1995). Thus the results now obtained in these studies are comparable in terms of temperatures, and can be used in rough production calculations.

The development time can also be dependent on food concentration. For example, in an experiment by Santer and van den Bosch (1994) on naupliar (*Cyclops vicinus*), the development time decreased from 40 days to 28 days with increased food. Also the complete development time, from the first naupliar stage to the adult stage, was reduced to almost half of the initial time by increasing the amount of food (from 64 days to 31 days in males; from 67.5 days to 35 days in females).

The reason for the high mortality in cyclops could have been the unsuitable diet. For example according to Santer and van den Bosch (1994) for *Cyclops vicinus,* only the flagellate algae were sufficient food for newborn nauplii. The newborn nauplii died after a few days on the diet of the chlorococcale algae *Monoraphidium minitum* or *Scenedesmus acutus* or the diatom

Cyclotella meneghiniana. They reached only the second naupliar stages. Nauplii also seemed to be more sensitive to low food concentrations than the copepodites. For example food densities **<**0.4 mg C^{-1} of *Chlamydomonas reinhardii* were not sufficient to cover the food requirements of the early naupliar stages. Newborn nauplii feeding on food densities **<** 0.4 mg^{-1} reached the second instars stage, but died after a few days.

Also, in our experiment in cyclopoids when the average egg-development time of the second batch of the cyclopoids is compared to the average egg-development time of the first batch, it can be noticed that the development has slowed. The reason for the longer development time of the new batch of eggs could be the lack of food for the females that developed the second batch of the eggs. During the egg-development time experiment, the measured chlorophyll (*a*) level of the lake water varied from 0.8 to l.38 chl mg/m^3

Nauplii need a much higher food concentration for development than copepodites. Their low ingestion rates indicate that low feeding efficiency can be a reason for their food demand: the first two naupliar stages might be more sensitive to shortage than the later instar stages. It has also been reported by Soto and Hulbert that under conditions of food scarcity *Acanthycyclops* nauplii had a lower survival rate than *Diaptomus* nauplii (Santer and van den Bosch 1994). This could explain the lower survival rate in cyclopoids in our rearing experiments. If it were necessary to supply extra food for naupliar stages, it would be ideal to use a 20 m mesh plankton net to collect the appropriate sized phytoplankton. The coarser, 25 m mesh plankton net is needed to exclude the other naupliar stages.

According to Irvine (1995), the development time of *(Tropodiaptomus cunningtoni)* nauplii in Lake Malawi was around five days, while in our experiment it ranged from 5 to 10 days (Table 3). The average egg-development time of *T. cunningtoni* in Lake Malawi was almost twice as long as in our experiment (see Table 2). In Lake Naivasha, Kenya, it was observed that the average egg-development time of *Thermocyclops oblongatus* accelerated when the temperature was raised 3°C (see Table 2). The same trend also occurred in the development time of *Diaphanosoma excisum* eggs (Mavuti, 1994). The egg-development times of *D. excisum* in Lake Chad, (Lévêque and Saint-Jean, 1979), and of *Thermocyclops neglectus* in Lake George, Uganda, (Burgis, 1970) increased almost ten hours when the temperature decreased 5°C (see Table 2). When comparing these results with ours, similarities can be noticed in the development times of cyclopoids at a higher temperature, but for calanoids the development time in our experiment was faster than that of Lake Naivasha, but about the same as the egg-development time at higher temperature in Lake Chad.

Average development times in our experiment are compared to those of Irvine (1995), Mavuti (1994), Burgis (1970) and Lévêque & Saint-Jean (1979) in tables 2 and 3.

Table 2.
Average development time ± S.D. of eggs of cyclopoids and calanoids in our experiments

Zooplankton	Number	Development time ± S.D. (hours)
calanoids	78	24.1 ± 7.7
cyclopoids	69	29.0 ± 11.0
II batch of hatched eggs of cyclopoids	33	48.5 ± 16.4

Average development time ± SE (hours) in Lake Malawi (Irvine 1995)

calanoids	49 ± 2.1	*Tropodiaptomus cunningtoni*
cyclopoids	60 ± 2.5	*Mesocyclops aequatorialis aequatorialis*
	43 ± 3.6	*Thermocyclops neglectus*

Average development time ± S.D. (hours) in Lake Naivasha (Mavuti, 1994)

cyclopoids *Thermocyclops oblongatus*	
temperature 28°C	28.8 ± (1.2 ± 0.6 days)
temperature 25°C	36 ± (l.5 ± 0.5 days)
calanoids *Diaphanosoma excisum*	
temperature 28°C	33.6 ± (1.4 ± 0.5 days)
temperature 25°C	40.8 ± (1.7 ± 0.4 days)

Average development time (hours) in Lake Chad (Lévêque and Saint-Jean 1979)

calanoids *Diaphanosoma excisum*	
temperature 30°C	24 (1.0 day)
temperature 25°C	36 (1.7 days)

Average development time ± SE (hours) in Lake George (Burgis 1970)

cyclopoids *Thermocyclops oblongatus*	
temperature 30°C	27.0 ± 1.99
temperature 25°C	36.4 ± 2.83

Table 3. Post embryonic development time

Post embryonic development time of calanoids in our experiment

	Number	Development time (days)	Average ±S.D.
from nauplii to copepodid stage	52	5-10	7.4 ± 1.4
male	3	26-31	
female	4	29-35	

Post embryonic development time of calanoids and cyclopoids in Lake Malawi (Irvine 1995)

	Development time (days)	Average ± SE
Tropodiaptomus cunningtoni from nauplii to copepodid stage	4.8-5.2	5.0 ± 0.13
Mesocyclops aequatorialis aequatorialis from nauplii to copepodid stage	6.8 - 7.3	7.0 ± 0.14

In our experiment, the results indicate the development time of calanoids in given conditions. Under a different set of conditions, especially at better controlled temperatures, the development time would most likely differ. However in calanoids, the egg-development time compared to post-embryonic development should confirm the reliability of the results. The technical problems met during the experiments will help in the planning of future trials.

4.1 Preliminary production estimates

If the post embryonic development times of our experiment are used to estimate the production in Lake Tanganyika, we obtain a smaller figure than Burgis' (1986) production level of 50-60 g Cm^2 $year^{-1}$ (equivalent to about 100-120 g dry wt m^2 $year^{-1}$). The reason for this might be the lack of food during the experiment that reduced the development rate. More realistic figures might be achieved if the egg-development times were used for estimation.

5. Acknowledgements

I would like to express my thanks to Profs. O.V. Lindqvist and H. Mölsä of the University of Kuopio, Finland, for offering me the possibility to carry out this study. I would also like to thank Piero Mannini, Heini Kurki and the project personnel at Kigoma station for their great assistance in the field and lab. Dr. Ilppo Vuorinen of Turku University has patiently advised me in the completion of this report.

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