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Notes on egg development and larval and juvenile growth of crucian carp (*Carassius carassius* (L.))

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Eggs of crucian carp (*Carassius carassius* (L.)) were fertilized and incubated at different constant temperatures in the laboratory. The eggs hatched normally at 15–28°C but died at 5–10 and 30°C. The shortest embryonic development time (<3 days) was achieved at 24–28°C. In two natural ponds in Eastern Finland, eggs hatched in six days at 18–19°C. Exogenous feeding started at 6.5–7.2 mm, after 2–4 days development at 20–30°C.

The growth of young fish was followed 50–64 days at five experimental temperatures (10–30°C). The fastest growth in this period (0.32 mm/day) was achieved at 28.5°C. Growth of 0.1–0.2 mm/day was observed at 15–20°C, but none at 10°C.

Growth during the first year of life in a natural population was monitored by examining size distributions of fish samples. The lengths in the 0+ age group varied from 2.5–10.5 cm (mean = 6.3 cm, mean weight = 4.9 g) at the end of September. Rapid growth (0.4–0.8 mm/day) between June and September is believed to be primarily due to low population density and reduced intraspecific competition for food after the experimental removal of the population in the previous year.

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1. Introduction

Larvae and juveniles of many cyprinid fish species prefer high temperature habitats in small water bodies or in shallow areas of larger ones (e.g. Lenkiewicz 1964, Rheinberger et al. 1987).

Small, often dark-water forest ponds are currently a typical habitat of crucian carp in Finland. These ponds are often characterized by winter anoxia, which leaves crucian carp as the only fish species to exploit the high invertebrate production caused by high summer temperatures (e.g. Holopainen & Hyvärinen 1985). Crucian carp is a multiple (fractional) spawner with up to three spawning periods between late May and early August (Holopainen & Pitkänen 1985). Eggs are laid on plant substrate in the shallow areas of the ponds.

Some data are available on the effects of temperature on the incubation times of cyprinid fishes, e.g. common carp (*Cyprinus carpio*; Penaz et al. 1983), tench (*Tinca tinca*; Kokurewicz 1970) and three cyprinids including bream (*Abramis brama*; Herzig & Winkler 1986), but knowledge of optimal temperatures for different developmental stages is scanty (cf. Lenkiewicz 1964). The lethal and disturbing temperatures in crucian carp and some other cyprinids are given by Horoszewicz (1973).

As part of a larger study on the biology of crucian carp (see e.g. Piironen & Holopainen 1986), we examined the effects of temperature on the early development and growth of larvae and young fish in the laboratory. In addition we followed growth during the first summer in nature and compared the size distribution of juveniles at the beginning and end of winter when they were exposed to low temperatures and prolonged anoxia.

2. Material and methods

2.1. Egg development

Eggs were fertilized using the dry method at room temperature and placed on plant substrate (juniper twigs), in 0.5 l plastic boxes filled with pond water. The fertilized eggs (50–100 in each box) readily attached to the substrate. Boxes were placed in 12 constant temperature baths, one box in each (10.3, 14.8, 16.4, 18.4, 20.3, 21.5, 23.7, 25.5, 26.0, 28.0 and 29.6°C, Fig 2). In this work no acclimation period to test temperatures was used, but the water (0.5 l) and the eggs were allowed to warm or cool gradually to the test temperature. Water was changed, dead eggs removed and counted and the advancement of egg development checked daily during the incubation period. A curvilinear quadratic equation $y = a + bx + cx^2$ (cf. Elliott et al. 1987) was used as a model of the relationship between water temperature (x, °C) and the time taken (y, days) for 50% of the eggs to hatch.

Approximately 100 fertilized eggs on their substrate were also placed into a cage composed of steel net (1 mm mesh) and lowered into both ponds close to the surface. Water temperature and the developmental stage of the eggs were checked daily.

2.2. Growth of free embryos on yolk sac energy in the laboratory (trial 1)

After hatching at 20°C, samples of five embryos were placed at five temperatures (10, 15, 20, 25 and 30°C) in 0.5 l plastic boxes (one at each temperature). The length of the larvae were measured daily under the stereomicroscope and their developmental stage noted. Water was changed daily but no food was given before the fourth day, after which *Artemia* nauplii were given daily *ad libitum*.

2.3. Larval and juvenile growth in the laboratory (trials 2 and 3)

Samples of five two week old larvae, hatched and kept at 15°C, were placed at the same five temperatures (one box at each) as in trial 1 (trial 2).

For comparison, five free embryos from Hermanninlampi were kept at the same five temperatures and 10 embryos caught in Kivilampi were kept at 28°C (trial 3).

In trials 2 and 3 *Artemia* nauplii and natural net plankton from the ponds were abundantly given *ad libitum* right from the start (always after the daily change of water). Larval development was examined weekly under a stereomicroscope. Both fork and total lengths were measured, but only total lengths are used in the following. Daylight from windows was the principal source of illumination in all experiments.

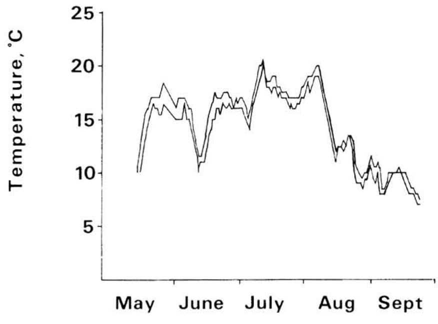

Fig. 1. Daily minimum and maximum temperatures of the Kivilampi surface water in 1984.

2.4. Field studies

The field material was collected in 1983 and 1984 from two natural ponds, Hermanninlampi (1.5 ha, maximum depth 1.6 m) and Kivilampi (0.6 ha, 1.6 m), both situated ca. 9 km from Joensuu, Finland (62° 41'N, 29° 41'E).

Hermanninlampi

For a map and description of Hermanninlampi see Holopainen & Pitkänen 1985.The only fish inhabiting Hermanninlampi is the crucian carp. In July 1982 the entire fish population was removed by rotenone and a new population of 280 crucian carp (6.5–11 cm) was introduced in the same autumn and next spring (Holopainen & Pitkänen 1985). In the two following summers, larvae and juvenile fish were caught with hand nets (mesh size 1×1 mm) and with a small seine (mesh size 7×7 mm) in order to follow the growth and to ascertain the minimum size required for fish to overwinter. In addition, larvae and mature fish in spawning condition were taken to the laboratory for growth experiments and as sources for gametes, respectively.

Kivilampi

Kivilampi is a pond with turbid water and lush vegetation, probably due to infiltration of wastewaters. Mean values for some water quality data at the depth of 0.5 m in 1983–1984 were: pH 7.2, colour 38 ppm Pt, COD_{Mn} 5.4 mg/l O_2, conductivity 270 µS/cm, total P 26.3 µg/l, total N 505 µg/l, Mg 6.6 mg/l, K 4.7 mg/l, Ca 28.3 mg/l, Na 23.3 mg/l; for temperature dynamics of surface water, see Fig 1. Kivilampi is connected to a canal between two larger lakes, and the landowner has introduced pike into the pond. Natural predation by pike and predatory insects appears heavy since the population of crucian carp in this pond mainly consists of large fish (length 20 cm). Spawning fish were caught with traps from

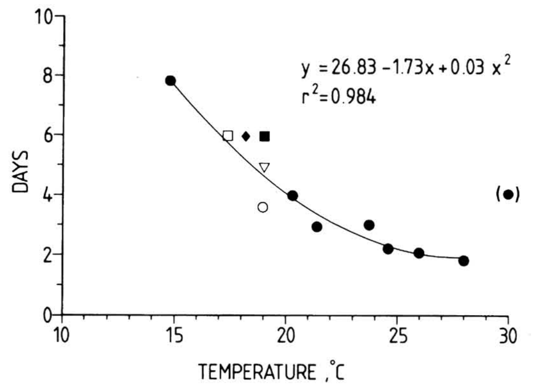

Fig. 2. Development times for eggs of crucian carp at different temperatures. In the laboratory: •. In ponds: ♦ = Hermanninlampi 1984, ■ = Kivilampi 1984. Results of ○ = Hakala (1915), □ = Kryzhanovskij (1949) and ▽ = Schäperclaus (1953). The datapoint in brackets (30°C) was not used in the equation.

May to July and taken to the laboratory. Young fish were caught with hand nets for determination of annual growth.

3. Results and discussion

3.1. Development time and mortality of eggs

In the laboratory the eggs developed normally and hatched at 15–28°C. No eggs developed to the larval stage at 5–10°C and very few (< 1%) at 30°C. The length of free embryos at hatching varied between 4.5–5.5 mm, those below 5 mm all came from 15°C. Egg mortality was highest in the first day of incubation and the lowest overall mortality (41%) was measured at 22°C; at 16–18 and 26°C the mortality varied from 55 to 72 %. The shortest development times were noted at 24–28°C (Fig. 2). In our experiments the optimal temperatures (mortality < 55%, development time < 3 days) were those between 21 and 28°C. These values agree with laboratory results on other cyprinids: optimal temperatures for common carp ranged between 20–24°C (Penaz et al. 1983) and for tench between 19–24°C (Kokurewicz 1970).

The development time of eggs (50% hatching) held in a cage, lowered into Hermanninlampi, was 6 days at 18.2°C (range 16.0–20.4°C) and in Kivilampi, also 6 days, at 18.6°C (17.5–20.5°C). These values are somewhat longer than those from the laboratory, probably because of fluctuating temperatures in the field. Our laboratory results agree well with data given by Hakala (1915), Kryzhanovskij (1949) and Schäperclaus (1953) for development in some pond populations (Fig. 2). The rate of egg development in crucian carp is lower than for fish like tench which hatch in < 2 days at 25°C and 3 days at 20°C (von Lukowicz & Proske 1979).

A low fertilization rate, poor quality of the gametes, infections, predation and harsh abiotic environment (low pH, low oxygen content or inappropriate temperature) are the main causes for high mortality. The influence of extreme values as well as abrupt changes in temperature are fatal, especially before gastrulation (in crucian carp during the first day after fertilization at 20°C) (Braum 1978). After this period eggs of bream at least are able to tolerate changes of more than 10°C without damage (Reznichenko & Gulidov 1978).

The lack of an acclimation period possibly increased the mortality especially in temperatures deviating most from room temperature. In addition, fungal infections were noted and the removal of all infected and dead eggs was not always possible without harmful effects on living eggs. Oxygen deficiency may be another factor to affect egg development inside clusters. Anyhow, variation in the length of the incubation time of surviving eggs, at any of the temperatures, was low (all hatched within a day) and the results agree with those given previously. This suggests that shortcomings in the experimental design probably increased the mortality rather than affected the incubation time. The delay in development at 30°C may more likely be partly due to culmination of the experimental problems (e.g oxygen deficiency) at high temperatures.

3.2. Growth of free embryos on yolk sac energy

During the first days after hatching the embryos grew about 0.5 mm/day at 20–30°C and 0.1–0.3 mm/day at 10 and 15°C (Fig. 3). The growth continued 3 days at 30°C, 4 days at 25°C, 7 days at 20°C and 12 days at 10–15°C. At 5°C no increase in the length was observed but the larvae were deformed and all died after 8 days. At 20 and 25°C a maximum size of 7.6 mm, and at 30°C 7.4 mm were achieved. The survival time (50% mortality) on yolk sac energy was 8 days both at 5 and at 25–30°C, 9 days at 20°C and 14 days at 10–15°C. Even when *Artemia* nauplii were available on the fourth day, feeding (food in the gut) was noted at 15°C only, but its importance even here is not known since all died at the embryonic

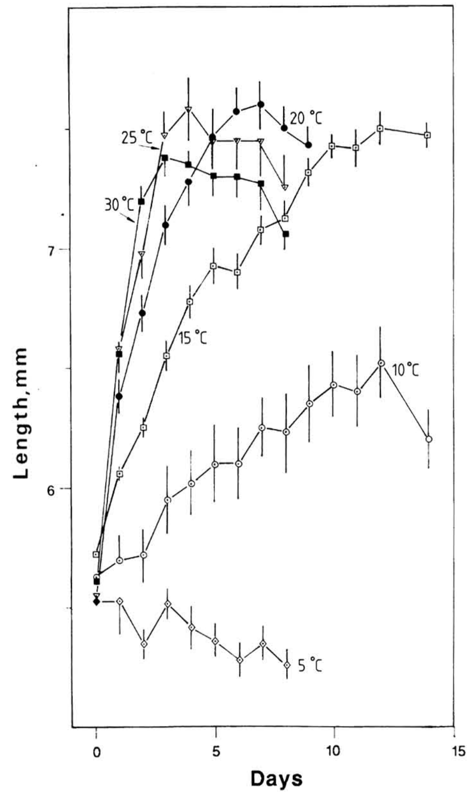

Fig. 3. Growth of free embryos on yolk sac energy at different temperatures. *Artemia* nauplii were given *ad libitum* from the fourth day onwards.The eggs hatched at 20°C.

stage (whereas in the control trials 2 and 3, all survived to juvenile stages). At the two lowest temperatures (5 and 10°C) the embryos were passive, ignored food and died with most of their yolk present. At higher temperatures the food probably came too late (cf. Tsunikova 1972, Cerny 1975) and could not be utilized. This stresses the importance of a long overlap period in yolk absorption and exogenous feeding. This limited material suggests highest yolk utilization efficiency (cf. Kamler & Kato 1983) at 20–25°C.

When food was available from the start, larvae began mixed feeding at lengths of 6.5–7.2 mm, after 2–4 days development at 20–30°C, when much of the yolk was still present.

According to Kryzhanovskiy (1960) cyprinid eggs contain ca. 6.2% fat and the larvae can grow for 3 days on their yolk reserves but die of starvation after 7–10 days at 19–24°C. In nature the free embryos are passive and often attach themselves to plants, where they stay hiding the first 1–2 days of the endogenous feeding period (Kryzhanovskij 1949). At the end of this period the mouth is open, the intestine is fully developed and the larvae are capable of feeding on small planktonic organisms. If no food is available or if it is too scarce, larvae starve and irreversible damage soon occurs (Blaxter 1969, May 1974, Braum 1978). The transformation period (mixed feeding) from endogenous to exogenous feeding is one of the critical periods in fish development and especially sensitive to the environment (temperature, food availability); mortality is often high even when food is available as was reported for roach (*Rutilus rutilus*) larvae by Cerny (1975). The importance of temperature on the time of hatching, the early start of mixed feeding and the efficiency of yolk utilization (and hence growth) during the embryonic period is most prominent (e.g. Braum 1978, Muntyan & Reznichenko 1978).

3.3. Growth of larvae and juveniles

In the laboratory all larvae developed to the juvenile stage and were 13–27 mm long after the 50–64 days experimental period. Growth was fastest at 28°C, averaging 0.32 mm/day (maximum 0.72 mm/day) and at 30°C, with 0.31 mm/day (maximum 0.57 mm/day, based on one fish only). Average growth rates of 0.12–0.20 mm/day (trial 2) and 0.10–0.16 mm/day (trial 3) were recorded at 15–25°C (Figs. 4 and 5). Because of our limited material, the deviating result at 25°C or slower growth rate from the 18th day (14 mm) may be accidental.

Increase in temperature generally accelerates growth of fish larvae, but sharp changes in temperature may inhibit growth (Brett 1979). Growth of the larvae of many cyprinid fish (roach, tench, bream) is inhibited by a temperature of 28°C already (Wilkonska 1979). The data of Lenkiewicz (1964) suggest, however, 27°C as the minimum estimate of preferred temperature for crucian carp and Horoszewicz (1973) gives disturbing temperatures as high as 35–36°C for this species when acclimated to ca. 27°C. In addition to the direct effect on the growth of fish, temperature affects the availability of food (Broughton & Jones 1978). In Poland roach larvae kept in ponds, with heated water influx, were 1.5–2 times larger than normal in September. Above 26°C there was a drop in zooplankton abundance, however, and more larvae had empty stomachs (Wilkonska 1979).

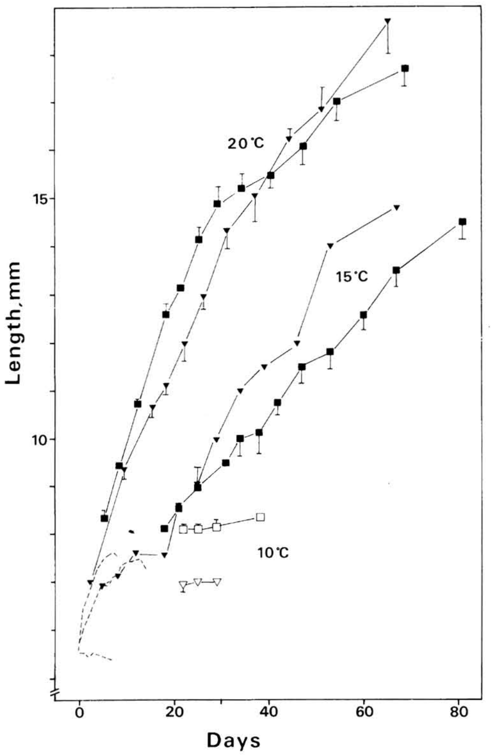

Fig. 4. Growth of larvae and juveniles at 10–20°C in the laboratory. Commercial *Artemia* nauplii and natural plankton from the pond were given daily *ad libitum*. Growth during the endogenous feeding period is shown by a broken line. Squares = larvae fertilized in the laboratory, triangles = larvae captured from Hermanninlampi.

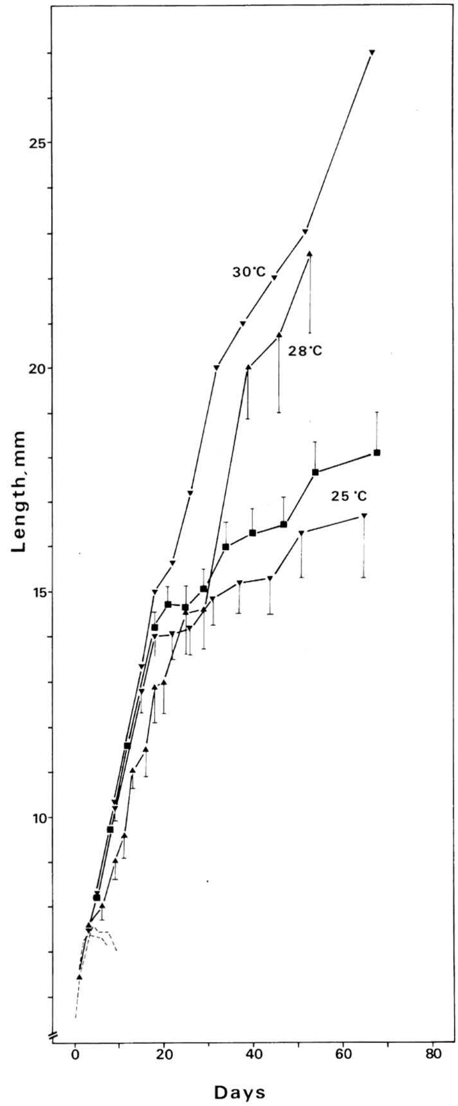

Fig. 5. Growth of larvae and juveniles at 25–30°C in the laboratory. Symbols as in Fig. 4.

3.4. First year growth in the ponds

In summer 1983 crucian carp reproduced successfully in both the natural ponds studied. Two main spawning periods were observed, the first in late May and the second in late June. In Hermanninlampi, the existence of a third period later in July was suggested by the size distribution of juveniles in early spring 1984 (Fig. 6). Fish of the introduced parent population had all achieved lengths >14 cm by spring 1984 (see Holopainen & Pitkänen 1985).

The juveniles in Hermanninlampi grew quickly in 1983. Their length, after the first summer varied from 2.5–10.5 cm (depending on the time of spawning, Fig.6) with a mean length of 6.3 cm and weight of 4.9 g achieved before spring. The weight–length relationship of the autumn catch, of 0+ age group, was $y = 0.008\ x^{3.396}$, ($r^2 = 0.998$), where y is weight in g and x length in cm.

The average growth rate in the period from late May to September, of the largest (probably earliest hatched) larvae was 0.8 mm/day, which exceeds the maximum found in the laboratory. This suggests that environmental conditions (temperature, food availability) in the shallow areas of the pond, with a very low fish population density, were better for the larvae and young fish than the environmental conditions were for those in the laboratory. In the previous year

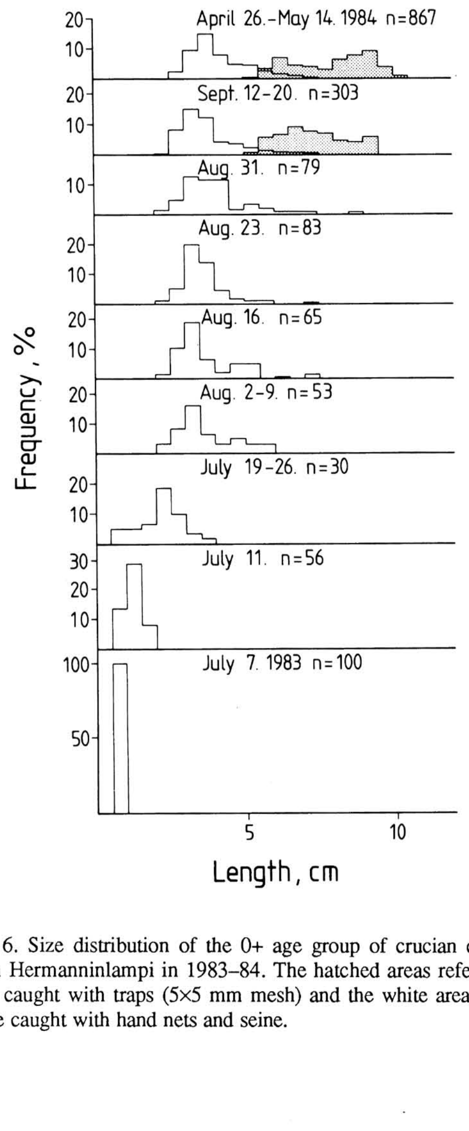

Fig. 6. Size distribution of the 0+ age group of crucian carp from Hermanninlampi in 1983–84. The hatched areas refer to carp caught with traps (5×5 mm mesh) and the white areas to those caught with hand nets and seine.

(with 100 times higher population density) the size of fish after the first year of growth in Hermanninlampi was estimated to be 2.4–5.0 cm (Holopainen & Pitkänen 1985).

Newly hatched larvae were found close to floating vegetation in the center of both ponds (*Potamogeton* and *Myriophyllum* stands). Later, larvae moved to shallow shoreline waters and were found close to the mud bottom (Hermanninlampi). Water temperature often rose above 30°C in the shallows and was subject to considerable daily variation (15°C). Although no continuous recording of temperature in the shallows was done, the observed small scale horizontal (inshore–offshore) and depth gradients of temperature in these small ponds allow the fish a possibility, at least, for choice of preferred (optimal) temperature at the active ontogenetic phases.

First year growth could not be determined in the other pond, Kivilampi. In August and September no juveniles >24 mm were caught. Next spring and summer no juveniles were caught, probably because few survived pike predation.

According to Hakala (1915) crucian carp achieve a length of 4–6 cm and a weight of 8 g in natural ponds at the age of 3.5 months. Crucian carp achieved a length of 3.5–4.2 cm during their first year in Siberia (Volgin & Dubinina 1976). According to Schäperclaus (1953), crucian carp can grow up to 9.5 cm during their first year in Central European ponds with superabundant food resources. Compared with this, the natural growth rate of fish in Hermanninlampi was high. Yet, compared with other cyprinid species like common carp which can exceed 20 cm and tench (Quolsdorf tench) which can reach 17 cm in their first year (von Lukowicz & Proske 1979) crucian carp lag behind.

Since the size distributions of the 0+ age group caught in late autumn and early spring (1984) were almost identical (Fig. 6), all or most of the juveniles (from 2.5 cm in length) successfully overwintered in this pond (for anoxia tolerance of young crucian carp see Piironen & Holopainen 1986). According to Disler (1971) crucian carp have to achieve a length of 25–27 mm at the end of the growth period to overwinter successfully. The juveniles in Hermanninlampi met this criteria but the wintering ability of fish <25 mm remains unknown.

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