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Length structure and reproductive potential of crucian carp (*Carassius carassius* (L.)) populations in some small forest ponds

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Trap catches from 12 forest ponds showed that in monospecific fish communities, populations of crucian carp attained high densities but were dominated by small (<13 cm) individuals. This contrasted with populations co-occurring with predaceous fishes (perch and pike), which were dominated by significantly larger fish (>15 cm) but at much lower densities. The removal of all fish from a 1.5 ha monospecific pond, and its restocking and subsequent monitoring over a two-year period revealed that crucian carp could rapidly repopulate the empty pond, increasing in population size from the 280 restocked fish to 16 600 in the first summer and to 25 500 in the next. After two years, the size structure of the introduced population closely resembled that of the original population.

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1. Introduction

Fish communities in large Finnish lakes usually comprise more than 20 species but in small forest lakes and ponds often only 1–6 species are found (e.g. Toivonen 1962, 1964, Sumari 1971). The depauperate nature of the community in small forest ponds is usually due to environmental severity (low pH, long periods of anoxia under ice, etc). Crucian carp is a common, though not abundant, cyprinid in Finnish lakes. The same is true for small forest ponds if other fish species, usually predaceous perch or pike, are present. Commonly, however, shallow ponds experience winter anoxia long enough to eliminate other species. These species lack the ability, possessed by the crucian carp, to tolerate long environmental anoxia (e.g. Blažka 1960, Johnston & Bernard 1983). In conjunction with a series of studies on physiology (Hyvärinen & Holopainen 1983, Holopainen & Hyvärinen 1985, Hyvärinen et al. 1985, Piironen & Holopainen 1986, Holopainen et al. 1986), and ecology (Holopainen & Pitkänen 1985, Laurila et al. 1987, Holopainen et al. 1988, Paszkowski et al. 1988) of crucian carp we describe here the size structures of 12 natural populations in forest ponds and follow for two years the growth of a population introduced into one pond following the removal of all its fish.

2. Materials and methods

The size structure of crucian carp catches from 12 natural forest ponds (0.1–1.5 ha) in eastern Finland (62°41′N, 29°41′E) close to the town of Joensuu is given. Traps of standard Finnish type but with 5 mm green plastic mesh were used on several occasions during the open water periods in 1982–1985. All yields from any one pond in any one summer were compiled to produce a rough idea of the size structure during the ice-free period. The size structure of the trap catch reveals some selectivity towards larger fish when compared with rotenone yield (Holopainen & Pitkänen 1985; see also Fig 1). This, together with a long trapping season prevents detailed discussion on absolute size structures. The broad relative picture, that is the presence or absence of predators and/or small/ large crucian carp, is clear enough for comparative purposes. The possible presence of predators was also checked from local fishermen, whenever possible. The following four ponds have been described in detail earlier: Hermanninlampi and Kuikkalampi (Holopainen & Pitkänen 1985), Kivilampi (Laurila et al.1987) and Marjalanlampi (Holopainen et al. 1987). The exact popu-

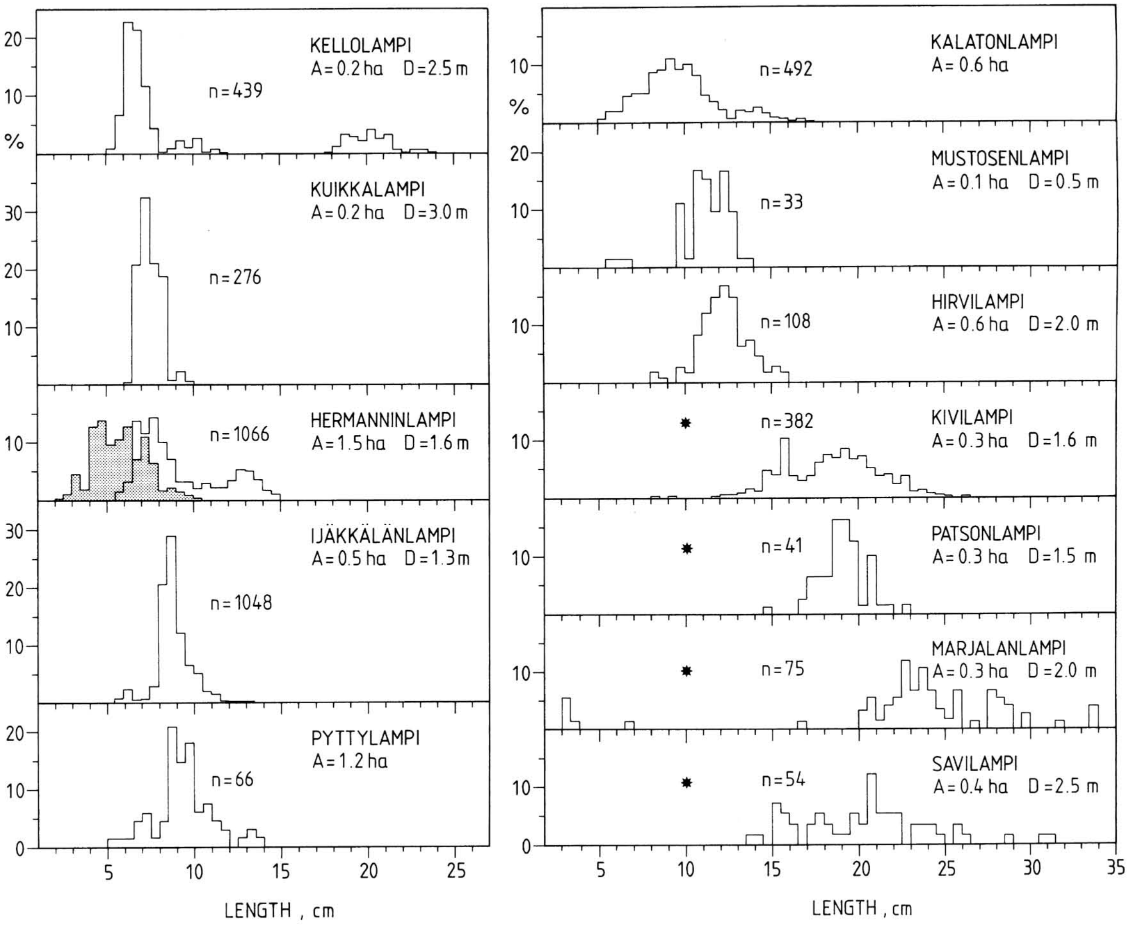

Fig. 1. Length frequencies of crucian carp populations in 12 natural ponds based on catches by traps with a 5 mm mesh. The shaded area in Hermanninlampi refers to the poisoning in 1982. The ponds inhabited by piscivores (pike and perch) are indicated by asterisks. A= the surface area (ha) and D= max. depth of the pond.

lation size of crucian carp (the only fish present) in Hermanninlampi is known in July 1982 (rotenone elimination), in May 1983 (introduction) and in May 1985 (rotenone elimination) and it was estimated in 1984 by the mark-recapture method. In addition, size structure and fish growth in this pond were followed by regular sampling in 1983–1984 (Holopainen & Pitkänen 1985, Laurila et al. 1987). Mark-recapture was arranged twice on 23–25 May 1984 and once on 24 August 1984: a total of 631 and 1305 carps (2.5–18 cm), respectively, were marked by clipping a small piece from the upper tip of the caudal fin and returned to the pond. After two days carp were recaptured from two randomly selected sectors (20 metres of shoreline) with two traps per sector set overnight, and also by seining each sector twice, and by hand netting from the shore. This was done in order to get all size classes and to cover all microhabitats. A simple Lincoln-Petersen index was used in calculations (Southwood 1978:92–99). On 20 May 1985, Hermanninlampi was treated with 60 l rotenone (following the procedure described by Holopainen & Pitkänen 1985) yielding a high concentration of about 3–3.5 μml/l in the pond, which effectively eliminated crucian carp in spite of the low water temperature (7.7°C). During the next seven days all fish were collected with hand nets from a boat and from the shore. The completeness of our collection was checked by scuba diving and by very intensive examination of 8 randomly selected 20-m sectors along the shore.

3. Results and discussion

3.1. Size structure of crucian carp populations

Length frequencies of fish in the 12 ponds are shown in Fig. 1. The size distribution in monospecific crucian carp ponds clearly differed from those with predaceous species (pike and perch) present ($P<$ 0.002, Mann-Whitney-test of mean lengths). Practically no overlap existed; 15 cm appeared to be the length that separated the two groups. Small carps of about 4–8 cm or 8–13 cm were most abundant in monospecific ponds, whereas in multispecies ponds few individuals <15 cm were found. In general, crucian carp form very dense populations of small fish when alone in a pond (e.g. Nikolskiy & Shubnikova 1974, Holopainen & Pitkänen 1985). The stunted size structure is thought to reflect the effects of high population density (e.g. for Hermanninlampi see Holopainen & Pitkänen 1985) and the resulting intraspecific competition for food. Because of the size bottlenecks (at 5–7 cm and 11–13 cm) in foraging efficiency (Paszkowski et al. 1988), the effect of intraspecific competition may be more severe for small crucian carp, contributing to stunted size structures in high-density populations. Cannibalism on the newly hatched juveniles by larger carp might also affect size structures, at least in dense populations with limited food resources (e.g. Holopainen & Pitkänen 1985).

Kellolampi had an exceptional distribution for a single-species pond. Two distinct size groups of crucian carp, viz. 5–12 cm and 19–23 cm were found (Fig. 1). This situation could have resulted from any possible introduction of predaceous fish. These reduced the densities and only large, fast growing crucian carp were left (the size refugium). Then even one anoxic winter in this shallow pond could have eliminated these predators. The remaining population of crucian carp, even if consisting of only a few adults, has since reproduced under the favourable conditions (reduced competition for food, no predators), producing a strong year class. The present population is dominated by the smallest fish (<8 cm), but the size distribution of the largest fish resembles that in multispecies ponds with pike and perch (Fig. 1).

In ponds with predaceous fish, particularly pike (Kivilampi, Patsonlampi, Marjalanlampi and Savilampi), the average size of carp was approx. 20 cm (Fig. 1) and the population densities lower than in one species ponds. The existence of only few if any, crucian carp <15 cm could be due to prolonged reproductive failure of the large fish. However, we have not found any indication of this. On the contrary, we have observed spawning and newly hatched larvae in these ponds (see Laurila et al. 1987).

The most probable cause for the absence of crucian carp <15 cm long appears to be heavy predation by piscivorous fish. Similar size-dependent effects of predation have been described with other species (e.g. Tonn & Paszkowski 1986) and the selection of smaller size-classes by fish predators is supported also by laboratory experiments (Tonn pers. comm.). In particular crucian carp appears exceptionally vulnerable to predation (and possibly to competition) when compared to other lake cyprinids, such as roach (*Rutilus rutilus* (L.)). The minimum size (refugium size) of crucian carp is probably even greater in larger water bodies with bigger predators. This is supported by two cases: the only crucian carp caught in Särkijärvi (approx. 25 km from Joensuu) were longer than 28 cm (mean length 28.9 cm, mean weight 632 g, n=10) and all those in Varaslampi (in Joensuu, for description see Holopainen 1987) were longer than 18 cm. Both are eutrophic lakes with multispecies fish assemblages. Lake populations of crucian carp, in general, seem to be dominated by large individuals (20–40 cm, mean mass = 1 kg) with a low population density (1–25/ha) (Berg 1964, Toivonen 1962, Sumari 1975, Hamrin 1979). Population densities of crucian carp in our ponds are known only for two monospecific ponds, Hermanninlampi and Kuikkalampi (29 000 inds/ha and 3150 inds/ha, respectively, Holopainen & Pitkänen 1985) and one multispecies pond, Marjalanlampi (250 inds/ha, see Holopainen et al. 1988). Thus the density in Marjalanlampi in the presence of predators was 1–2 orders of magnitude lower than predator-free ponds, even when compared to Kuikkalampi with its extreme environment (Holopainen & Pitkänen 1985).

3.2. Population growth in Hermanninlampi

After removal (in July 1982) of the original dense population (about 44 000 inds.), Hermanninlampi was restocked by a total of 280 crucian carp (October 1982 and May 1983) with lengths between 6.5 and 11 cm (Holopainen & Pitkänen 1985, and Fig. 2). The introduced carp reproduced successfully at least twice (in late May and in late June) in the summer of 1983, but the size distribution of juveniles in the early spring of 1984 suggested a third unobserved spawning period (possibly in July) in the previous summer. The mark-recapture procedure performed in the 1984 spring gave an estimate of 16 580 (SE= 1134) young produced and able to overwinter in Hermanninlampi (Fig. 3). The new age-class (0+) was composed of fish 2.5–10.5 cm long with a total biomass of approx. 40 kg (Laurila et al. 1987). During 1984 another 3 spawning periods (at about one month intervals) were

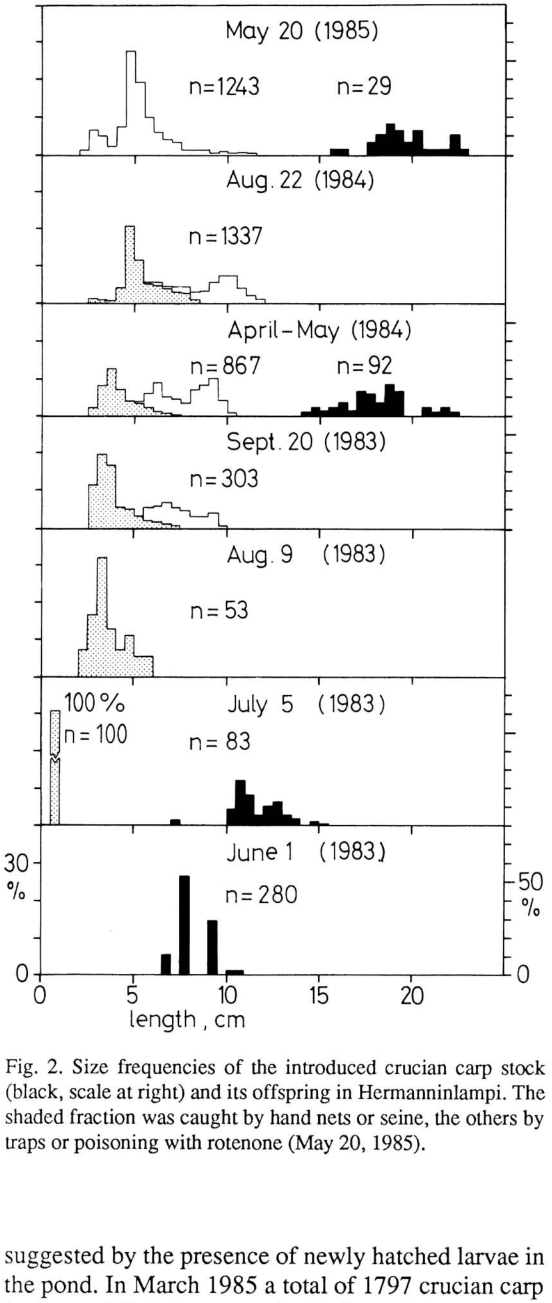

Fig. 2. Size frequencies of the introduced crucian carp stock (black, scale at right) and its offspring in Hermanninlampi. The shaded fraction was caught by hand nets or seine, the others by traps or poisoning with rotenone (May 20, 1985).

suggested by the presence of newly hatched larvae in the pond. In March 1985 a total of 1797 crucian carp (approx. 3.7 kg) were seined from the pond and another 1620 fish were removed before rotenone application in May. A total of 20 800 crucian carp were collected after poisoning from the main pond. An analysis of the collection efficiency produced a correction of 360 fish (0.75 kg) that, together with the estimate of approximately 450 fish in the small side pond, gave a total estimate of about 25 000 indiv-

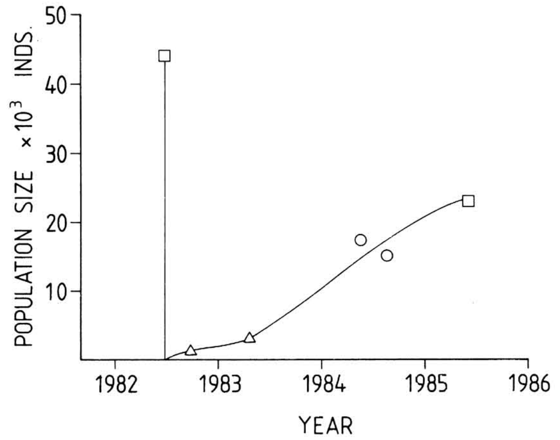

Fig. 3. Growth of population size in Hermanninlampi in 1982–1985. Population size based on rotenone poisoning is indicated by squares, the introduced population by triangles and the mark-recapture estimate by circles.

iduals (Fig. 3). This population included only 4000–6000 individuals of age class 0+ (product of summer 1984), the rest being of age class 1+. This means that around 70% of the population was born during the first reproductive season in the empty pond. This shows how quickly a limited number of fish can colonize an empty pond under favourable food conditions and the absence of predation. Only the introduced parents were reproducing again in 1984, and although three spawning periods were observed (as in 1983), the proportion of this 0+ year class was only 30%. This was probably due to smaller number of original parents surviving and the intensified intraspecific competition, as well as possible cannibalism in the second summer after introduction. A good reproductive and colonization capacity has been noticed in the congeneric German carp (*Carassius auratus gibelio*), which has expanded in the Danube area due to decreased predator pressure (Holcik 1980). This suggests that populations of German carp may also be controlled mainly by predation. The vast majority (>90%) of the crucian carp population eliminated in 1985 consisted of fish <8 cm long and only 0.7% were >10 cm (Fig 2.). The mean weight and length of the whole population were 2.1 g and 5.2 cm, respectively. In 1982, corresponding values of the dense original population were 3 g and 6 cm (Holopainen & Pitkänen 1985) suggesting that the new population had nearly returned to the original structure in just two years since the introduction. The introduced parent fish stock came from an extreme abiotic environment in Kuikkalampi (see Holopainen & Pitkänen 1985). They grew rapidly in Hermanninlampi, achieving lengths of 14–23 cm during their first growing season (Holopainen & Pitkänen 1985) demonstrating the flexibility in the growth potential of crucian carp. However, growth was clearly slower during their second season, which could be a result of competition for food with their offspring.

Whatever the cause, in May 1985 only 29 of the 280 originally restocked fish were found which, after accounting for the 66 fish we removed earlier, indicates a 86% natural mortality in two years. The scarcity in the original population in Hermanninlampi of individuals older than 4 years (Holopainen & Pitkänen 1985) also suggested a high natural mortality of older fish. In dense populations with high intraspecific competition for food, the susceptibility of larger individuals to winterkill may be higher due to an inability to collect sufficient reserves for overwintering. Even though they show higher overall foraging efficiency (Paszkowski et al. 1988), these larger fish would also require a greater absolute amount of reserves to survive the extended winter period during which they rely on anaerobic metabolism. This places a limit on the maximum sizes of individuals found in high density monospecific assemblages.

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