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The distribution and growth of lacustrine 0+ perch, *Perca fluviatilis*

James W. Treasurer
Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen, Scotland, U.K.

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Synopsis

The distribution and growth of 0+ Eurasian perch were studied for two years in two shallow lacustrine habitats. Eleutheroembryos were rapidly dispersed from inshore spawning areas to open water. The planktonic larval period was followed by the inshore migration of metamorphosed 0+ perch. Some juveniles remained in shallow water through the summer and all moved offshore in autumn. Growth in length was linear from hatching through the summer but declined and tended to an asymptote from September. Two stanzas were identified for growth in weight, one for the ten days following hatching and the other for the remainder of the first summer. The first stanza coincided with largely endogenous nutrition and limited initial feeding on small zooplankters and the second commenced with intense feeding on zooplankton.

Introduction

The ecology of the 0+ stages of yellow perch *Perca flavescens* is well documented (e.g. Noble 1968, 1970, 1975, Forney 1971, Tarby 1974, Henderson 1977, Mills & Forney 1981). Less information is available for 0+ Eurasian perch *P. fluviatilis* and most studies have been confined to deep highland lakes (Černy & Pivnička 1973, Guma'a 1978a, b, Coles 1981, Coles et al. 1977).

This is a report of a study of the distribution and growth of 0+ Eurasian perch during the eleutheroembryonic, larval, and juvenile intervals (Balon 1975) in two shallow (mean depth = 1.2–1.5 m) lakes. The habitat afforded 0+ perch in these lakes differs from that in previous studies as there is little distinction between littoral and limnetic zones and waterplants are found in most areas of the lakes.

Methods

Description of study areas

Loch Kinord and Loch Davan are adjacent kettle-hole lakes 165 m above sea level, situated on middle Deeside, Scotland (57° 05′ N, 2° 55′ W) on the perimeter of the Grampian Highlands. Kinord has an area of 82.2 ha and Davan 41.9 ha and mean volumes are 1 002 090 m^3 and 383 098 m^3 respectively. The catchment areas of Kinord and Davan are 7 km^2 and 30 km^2. The lakes are not connected and the efferent streams are tributaries of the River Dee. Kinord and Davan have been classified as relatively rich oligotrophic and base-poor mesotrophic, respectively.

Fishes are only lightly exploited by anglers and species diversity is low. Perch, pike *Esox lucius* and eel *Anguilla anguilla* are common; the minnow *Phoxinus phoxinus* is only found in the vicinity of afferent and efferent streams of Loch Davan, and the brown trout *Salmo trutta* is rare and confined to Loch Davan.

Sampling methods

Coles (1981) reported that 0+ perch are found in several different habitats in the first year of life and a number of different sampling gears was therefore required. The shallowness of the lakes permitted a visual survey of the perch egg ribbons over the entire lake areas. Egg strands were censused at intervals of 3–5 days from 1 April until hatching was completed. Methods used are given elsewhere (Treasurer 1983).

Planktonic stages were collected with an Icelandic high-speed sampler (Einarsson 1960) supported by a beam held in front of a small boat. The sampler was attached to a vertical pole and could be adjusted by a clamp to sample water strata from the surface to a depth of 1.75 m. The boat was powered by a $3^1/_2$ hp outboard motor and sampling speed was held constant at 8.3 km hr^{-1}. A 240 μm mesh detachable filter bag fitted over the rear of the sampler. Larvae and other zooplankton retained in the bag were preserved in 4% neutralised formaldehyde. Eleutheroembryos and larvae were sampled weekly in open water until metamorphosis was complete. Hauls were made over two standard courses on each lake, every 3 h through 24 h. Two hauls were made over each course and therefore at each 3 h interval four samples were taken.

Juvenile perch were sampled at bi-weekly intervals through the first summer at Kinord using a beach seine net with a stretched mesh of 1.25 cm. Shallow depths prevented use of trawls (Forney 1971, Noble 1975) and miniature purse seine nets (Coles 1981). Dense reed beds at Davan made netting of juveniles from the shore difficult and comparative data for this lake for the juvenile period are therefore not available.

Estimation of growth

The length on hatching was determined from measurements of newly hatched embryos reared in the laboratory. The eggs were stripped from a female, fertilised in the field, transferred to the laboratory, and incubated under controlled conditions (Treasurer 1983). Total length, the distance from the tip of the snout to the posterior portion of the caudal fin, was measured using a binocular microscope with eyepiece micrometer. Fish were grouped in length intervals of 1 mm. Wet weight was measured, and dry weight after freeze-drying samples for 12 h. Fish in length categories 6 to 9 mm were weighed in batches of 20, 10 to 19 mm in batches of 10, and fish >19 mm were weighed individually. Mean lengths and weights were calculated and used as an estimation of seasonal growth (Chapman 1967).

Two sub samples of 300 eggs were incubated in circular polypropylene containers of 2.5 l volume at mean temperatures of 7.7° C, 10.5° C, 13.6° C and 16.8° C as in Treasurer (1983) to determine the length of the incubation period and date of mass hatch (>50%) of embryos.

Results

Distribution

Spawning commenced simultaneously in both lakes on 20 April in 1976 and 21 April 1977. Water temperature recorded 25 cm below the surface was 11° C at noon in 1976 and 9° C in 1977. Although spawning continued for 10 days, mass spawning (>50% of eggs deposited) was complete on 22 April. Mean incubation temperature was 10.5° C (S.D. 0.25) in 1976 and 9.6° C (S.D. 0.43) in 1977.

All lake areas were exhaustively surveyed and it was observed that spawning grounds were discrete and located in shallow sheltered water in bays and in the lee of islands. The principal substrates utilised were the stems of the macrophytes *Schoenoplectus lacustris* and *Carex rostrata*. Substrates used much less frequently were *Iris pseudocorus, Phragmites communis, Menyanthes trifoliata, Potamogeton* sp., *Juncus fluitans* and submerged tree branches. A full description of the spawning areas and substrates is given in Treasurer (1983).

The regression equation $\log_{10}$ days to hatch $= 3.0286 - 1.6728 \log_{10}$ incubation temperature in °C (n = 4, r = 0.996, p<0.05) was used to predict the date of mass hatch. For both lakes this was 12 May in 1976 and 16 May in 1977 and field observations of perch egg strands confirmed that mass hatch was complete by these dates.

Dispersal from the spawning grounds was rapid and eleutheroembryos were caught in open water from 17 May in both years. The whole water column in these shallow lakes may be disturbed by wind and the spawning grounds are also in proximity to open water. Both eleutheroembryos and larvae are planktonic and these 0+ stages have been descriptively termed the 'planktonic phase' (Coles 1981) and 'pelagic phase' (Noble 1968).

The high speed sampler was routinely towed at a depth of 50 cm but 7 series of samples were taken at Kinord at the surface (0–20 cm), 50 cm and 100 cm, to determine the depth distribution of larvae (Table 1). Each series comprised one sample taken at each of the three depths. For each series of samples the numbers of larvae at each depth were compared by χ^2 analysis. All values were found to be significantly different (p<0.05) with the exception of the identical night figures given for 50 and 100 cm on 15 June 1976. The restricted data presented here indicate that the preferred depth distribution of larval perch in these lochs is 50–100 cm. Few larvae were captured at the surface on any occasion and the 17 larvae comprising the only sample taken at 150 cm represented only 4.2% of larvae taken in a series of samples over four depths on 25 May 1976.

Metamorphosis of larvae was complete by mid-June when an inshore migration commenced. No pelagic larvae were caught on sampling dates after 16 June (the next sampling date was 23 June), although there is the possibility that larger pelagic fish avoided the Icelandic high-speed sampler. This was confirmed by comparing the number of larvae caught in day and night hauls. For example, significantly more larvae were caught in night samples on 9 June 1977 (day $\bar{x} = 92$ vs. night $\bar{x} = 310$, t = 4.88, d.f. = 14, p<0.001), indicating that larvae were avoiding the sampler in daytime. Despite avoidance of the sampler near the end of the larval period it appears that few 0+ perch were pelagic after June as none was caught with the high-speed sampler even in hauls taken in darkness.

Juveniles were first observed inshore at Kinord in water of 10–20 cm depth on 16 June 1976, five weeks after hatching, at a midday water temperature of 16° C. Juvenile perch were caught by beach seine net through the summer (Table 2) and shoals of 0+ perch were observed up to 50 m from the shore, although never in water as shallow as on 16 June. This period has been called the 'inshore phase' (Coles 1981) and 'demersal phase' (Noble 1968, Forney 1971). It may be that juveniles were more widely distributed throughout the lake but were readily observed and captured inshore. As there is little distinction between littoral and limnetic zones in these shallow lakes it is possible that offshore juveniles did occur. It would have been desirable to confirm by quantitative method that offshore demersal juveniles did not occur but this was not possible. In 1977 0+ perch were first ob-

Table 1. The depth distribution of larval perch at Loch Kinord determined from samples taken by Icelandic high-speed sampler (day = 1800 h; night = 2400 h).

Depth (cm)	Number of larvae per haul on various dates:						
	25.5.1976		31.5.1976	7.6.1976	15.6.1976		9.6.1977
	Day	Night	Day	Day	Day	Night	Day
10	11	0	0	0	0	4	0
50	263	17	223	205	2	72	113
100	78	151	61	47	19	72	162
150	17						

served inshore at Kinord on 16 June at a water temperature of 13° C. Mean length was significantly less than in 1976 (1976: 19.9 mm vs. 1977: 17.4 mm; $t = 7.62$, $p<0.001$, d.f. = 98).

Perch caught inshore on 16 June in both years were significantly larger than planktonic larvae (Table 3). The smallest fish caught inshore on 16 June in 1976 was 16.6 mm, and 15.4 mm in 1977. Smaller perch may have escaped through the mesh of the seine net but, if large numbers had been present near the shore, a number would have been retained as the net was frequently clogged by waterplants.

Catches of juveniles in the seine net declined after September (Table 2) and were negligible through the winter, indicating an offshore movement of inshore populations of 0+ perch to deeper water.

Growth

The mean length of perch on hatching was 6.32 mm (S.D. 0.36, n = 60). The length frequency distribution of the planktonic 0+ stages (Fig. 1) indicates that hatching was confined to a short period and confirms field observations on spawning grounds that mass hatch was completed by 16 May. Mean length progressed steadily from 18 May.

Mean length of perch for each sampling occasion was plotted against time expressed as the number of days after hatch (Fig. 2). Growth in length was linear in all four populations until the beginning of September, when growth declined and tended to an asymptote. Lines were fitted by regressions using the method of least squares. There was no significant difference between regression coefficients for 1976 and 1977 when tested by analysis of variance ($p>0.05$) and a single regression line of length (L) in mm against time (t) was calculated for each loch. This relationship was described by the equations:

Kinord $L = 7.82 + 0.331\ t$
Davan $L = 3.76 + 0.376\ t$

Growth in length derived from the regression coefficient was 0.331 mm day^{-1} at Kinord and 0.376 mm day^{-1} at Davan. No significant difference could be found in regression coefficients ($p>0.05$) for larvae from Kinord and Davan indicating that rate of growth was similar.

The relationship of dry weight on time showed distinct curvature and data were therefore converted to $\log_{10}$ to give a linear relationship (Fig. 3). Two growth stanzas were identified, one for the 10 days following hatching and the other for the remainder of the first summer. Two regression lines were therefore fitted for each loch, for the periods ≤10 days and >10 days following hatching. For each of these periods there was no significant difference in the regression coefficients between years

Table 2. The numbers of 0+ perch captured by beach seine net at Loch Kinord in 1976.

Date	Mean no. 0+ perch per haul	No. of hauls
17 June	250	4
7 July	67	6
14 July	60	5
4 August	53	14
17 August	22	7
25 August	14.5	4
13 September	9.6	7
20 September	81.6	5
21 October	0.7	6
16 November	0.4	5

Table 3. A comparison of the mean length of 0+ perch caught inshore and in open water at Loch Kinord.

Date	Total length (mm)		d.f.	*t*	Significance level
	Open water	Inshore			
16 June 1976	17.95	19.90	86	8.21	p<0.001
16 June 1977	15.78	17.39	79	6.26	p<0.001

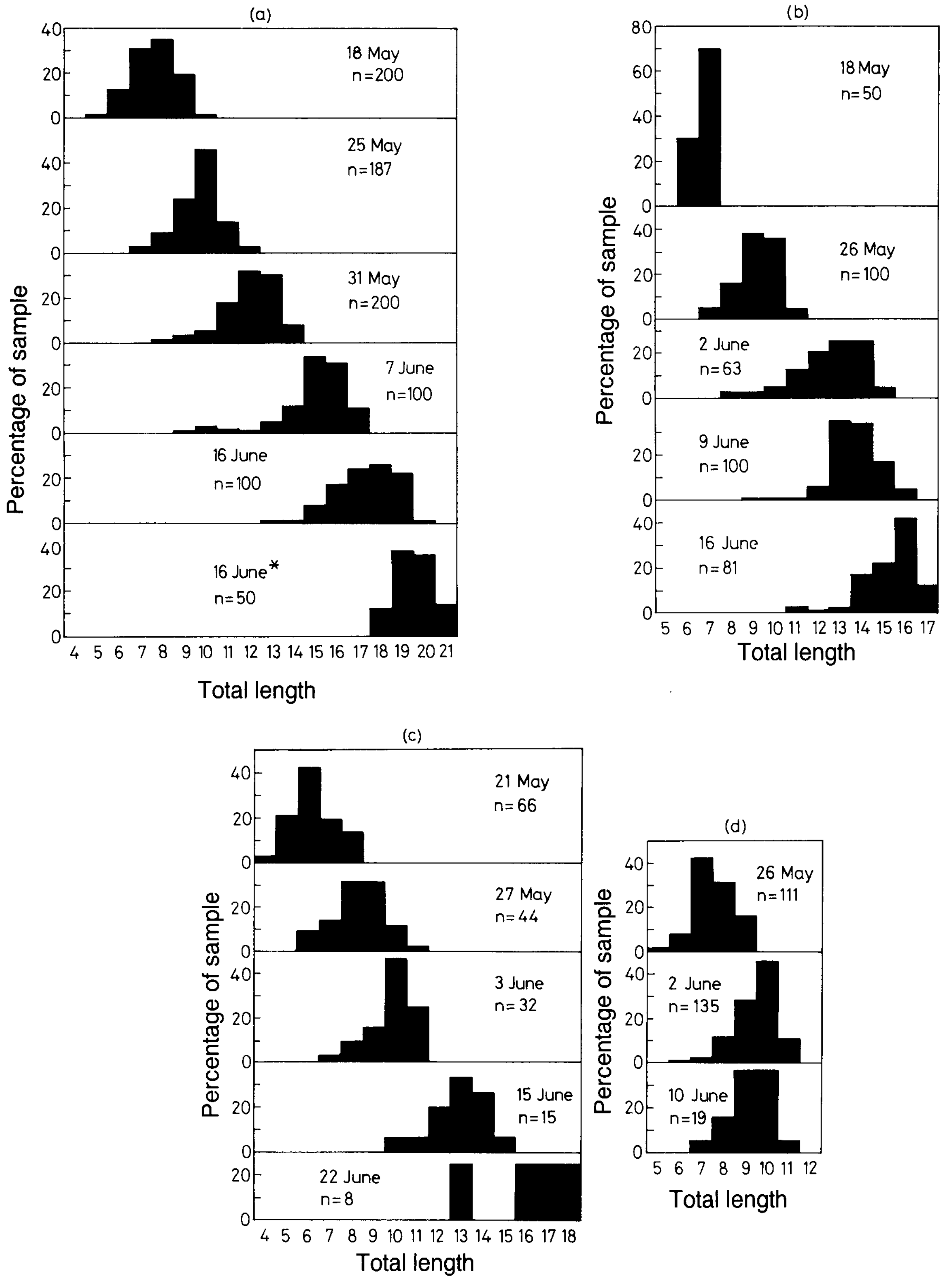

Fig. 1. The percentage length composition (in mm) of larval perch caught with an Icelandic high-speed sampler at Kinord in (a) 1976 and (b) 1977 and at Davan in (c) 1976 and (d) 1977. A histogram* is given for 0+ perch caught inshore on 16 June 1976 at Kinord for comparative purposes.

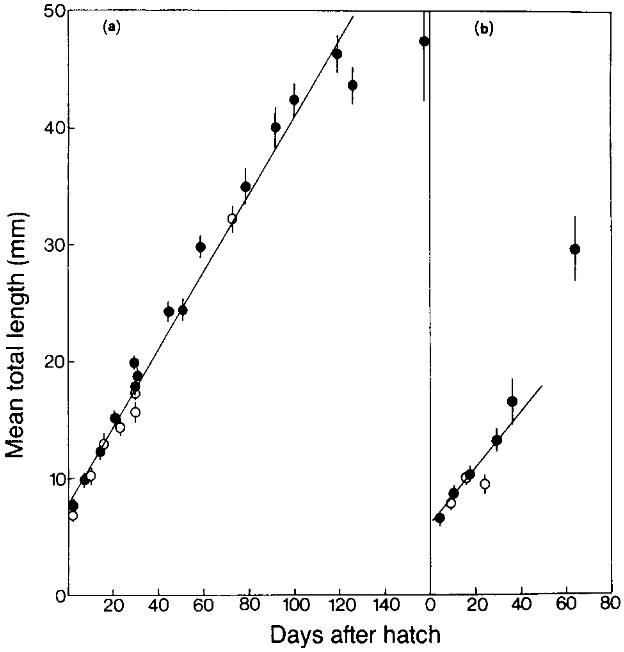

Fig. 2. Growth in length of 0+ perch at (a) Kinord and (b) Davan. The 95% confidence limits of the mean are shown. ●, 1976; ○, 1977. Each data point represents a sample of 50 fish. The date of mass hatch was 12 May in 1976 and 16 May in 1977.

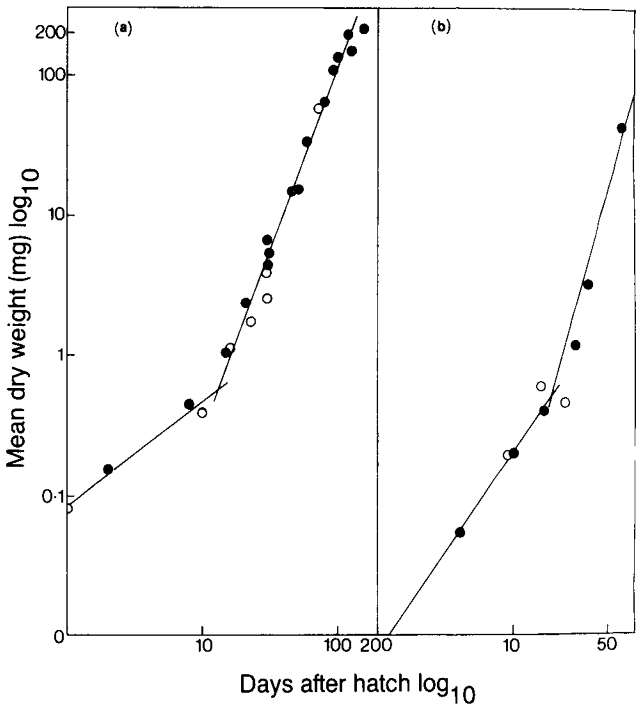

Fig. 3. The relationship of mean weight with time of 0+ perch at (a) Kinord and (b) Davan. ●, 1976; ○, 1977.

for 0+ perch from each loch ($p>0.05$) and data for 1976 and 1977 were therefore combined. Growth in dry weight (W in mg) on time in days was described by:

Kinord $\log_{10} W = -1.07 + 0.728 \log_{10} t \quad t \leq 10$ days
$\log_{10} W = -3.16 + 2.606 \log_{10} t \quad t > 10$ days
Davan $\log_{10} W = -2.10 + 1.422 \log_{10} t \quad t \leq 10$ days
$\log_{10} W = -4.47 + 3.257 \log_{10} t \quad t > 10$ days

For each loch, analysis of variance of the regression coefficients for the periods ≤10 days and >10 days indicated a significant difference ($p<0.05$) in growth in weight. There was also a significant difference ($p<0.05$) in growth between Kinord and Davan in each of the stanzas. Larvae in Kinord were initially heavier than those in Davan but the Davan fish increased weight more rapidly and by the end of August 0+ perch in Davan attained the same weight as those in Kinord.

Discussion

The habitats occupied by perch during the first year of life on Deeside (spawning grounds, open water, inshore and offshore) are similar to those described in other studies (Noble 1968, Henderson 1977, Coles 1981) but there are differences in distribution from previous reports. The dispersal of eleutheroembryos to open water from spawning areas was rapid on Deeside because the lochs are shallow and the entire water column is disturbed by wind. Fish larvae are weak swimmers (Henderson 1977) and it is concluded that dispersal throughout the lakes must be a passive process (Houde 1969). High densities of eleutheroembryos, many of 5 and 6 mm length, were found in open water just two days after hatching. In contrast Henderson (1977) reported that 0+ yellow perch in West Blue Lake, Manitoba, were not found in the limnetic zone until two weeks after hatching.

The inshore movement of 0+ perch on Deeside was over a short period and was complete by 23 June, unlike 0+ yellow perch in Oneida Lake which remain pelagic until August (Noble 1968). Lin (1975) reported that most 0+ yellow perch are pelagic until attaining a length of 30 to 50 mm in July. However, the maximum total length reported for Eurasian perch for completion of migration is 19–20 mm (Nellen & Schnack 1974, Coles 1981) and the maximum length at Kinord and Davan was 20.4 mm in 1976 and 17.9 mm in 1977.

The various migrations of perch in the course of the first year of life may ensure the maximum utilization of a number of food sources. The planktonic phase, for example, may be an adaptation to reduce losses from predation but dispersal from the spawning sites where zooplankton may become rapidly depleted by high larval concentrations ensures access to the abundant zooplankton populations of open water (Coles 1981). The movement inshore on Deeside was coincident with a decline in open water zooplankters such as *Diaptomus gracilis* and *Cyclops strenuus abyssorum* (unpublished data) and permits access to the alternative food sources of cladocerans and benthic invertebrates inhabiting the loch margins. These species were the main items in the diet following transition to the juvenile period (unpublished data).

Growth

Growth of 0+ perch has been described in terms of developmental stanzas (Kuznetsov 1972, Henderson 1977, Guma'a 1978b). Guma'a considered that two major stanzas characterised the growth of 0+ perch in Lake Windermere, one during metamorphosis and one following this. In contrast Henderson (1977) described a stanza which occurred in the eleutheroembryonic phase of yellow perch when the 0+ fish were dependent on the yolk sac for nourishment and a second stanza characterised by a high growth rate which coincided with the start of intensive feeding.

Two stanzas in growth in weight were identified for 0+ perch from the Deeside lochs (Fig. 3), one for the first 10 days following hatching and the other for the remainder of the first summer. The two stanzas are not apparent in the plots for length (Fig. 2) because either the growth changeover was so small that it could not be detected or feeding transition did not affect the rate of increase in length. Growth in length may have been the same during the first ten days as in the second stanza as nutrition was being derived at the expense of the yolk sac.

Water temperature and food availability are the most important factors affecting growth of young fish (Blaxter 1969). There was no sudden increase in temperature at the Deeside lochs on transition from the first to the second growth stanza. Commencement of the second stanza coincided with the change from endogenous to exogenous nutrition. The mouth and jaws of newly hatched fish are poorly developed and not able to handle food (Blaxter 1969). From analyses of the digestive tracts (unpublished data) it was found that eleutheroembryos on Deeside did commence feeding on small zooplankters but only to a limited extent.

The change in growth rate of 0+ perch at Lake Windermere occurred during a sharp decline in the density of zooplankton and this led Guma'a (1978b) to conclude that the major factor responsible for the occurrence of stanzas on the growth of 0+ perch is food. Mills & Forney (1981) reported that 'growth inflections' of 0+ yellow perch in Oneida Lake were associated with the depletion of *Daphnia pulex*. It is suggested that the occurrence and timing of growth stanzas in 0+ perch following absorption of the yolk sac could vary between years (cf. Mills & Forney 1981) and between waters according to the composition of the zooplankton communities and their annual cycle of abundance.

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