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The use of artificial spawning substrates as media to support the reproduction of Eurasian perch in Lake Piediluco

Giovanni Pedicillo · Francesca Merulli · Antonella Carosi · Paolo Viali · Massimo Lorenzoni

Abstract Lake Piediluco is a naturally regulated lake used for hydroelectric purposes. Management of the lake and the eutrophic conditions of its waters have had a negative impact on fish populations, particularly that of Eurasian perch (*Perca fluviatilis* L.). In order to increase the natural reproduction of this species, an experimental program was undertaken from 1997 to 2003 to facilitate reproduction by providing artificial spawning substrates. In Lake Piediluco perch spawn from March to May. Egg ribbons ranged in length from 30 to 180 cm and contained from 12,740 to 205,466 eggs. The fraction of degenerated eggs ranged from 0.20% to 63.30% (average 10.20%). The results demonstrate the effectiveness of artificial substrates as suitable substrates for the reproduction of perch.

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Hydropower, Flood Control and Water Abstraction: Implications for Fish and Fisheries

G. Pedicillo (✉) · F. Merulli · M. Lorenzoni
Dipartimento di Biologia Cellulare e Ambientale, Università di Perugia, Via Elce di Sotto, 06123 Perugia, Italy
e-mail: pedicillog@yahoo.it

A. Carosi · P. Viali
Provincia di Terni, Servizio Programmazione Ittico-Faunistica, Via Plinio il Giovane 21, 05100 Terni, Italy

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Introduction

Many waterways, and particularly artificial ponds, lakes and canals, tend to be structurally homogeneous, which results in significant reduction of the littoral area. The absence of this shallow zone precludes colonisation by the macrophytes that provide fish with important spawning, juvenile and foraging habitats (Winfield, 1986). Eutrophication increases the turbidity of the water, which further reduces the area colonised by macrophytes (Sandström & Karas, 2002). Increased eutrophication reduces the production of salmonid fish, but may increase the production of cyprinids. This development has generally had a negative impact on predatory species, such as pike (*Esox lucius* L.) and perch (*Perca fluviatilis* L.) (Anttilla 1973; Hartmann 1977; Sandström et al. 1991).

Lake Piediluco is located in the south-eastern part of the Umbrian Region (Italy) and is currently used as a daily water-storage basin for the Galletto hydroelectric plant. Artificial regulation of the flow regime causes a daily oscillation of about 90 cm in the level of the lake. For the purpose of power generation, the hydrological basin of the lake was enlarged (from 74 to 3,204 Km^2)

by connecting the lake with the River Velino and the River Nera. The River Nera is the lake's main tributary, while the River Velino, thanks to the presence of a mobile dam, acts either as an inflow or an outflow, according to the needs of the Galletto power station. Lake Piediluco (max. depth: 21.0 m; mean depth: 11.46 m) displays marked thermal stratification in the summer months and full circulation in winter. During the period of thermal stratification, the oxygen content rapidly diminishes at increasing depths, until conditions of anoxia are reached. Field measurements have shown that Lake Piediluco currently has a high level of eutrophication (maximum chlorophyll values: 80–250 μg l^{-1}; minimum dissolved oxygen concentration: <2 mg l^{-1} at the bottom; maximum orthophosphate concentration values: 10–25 μg l^{-1}) (Cioffi & Gallerano, 2000). These measurements are indicative of an elevated level of eutrophication due to the present inflow of nutrients from tributaries (Enel-DCO, 1998). The eutrophication of the lake has been rapid: concentrations of total phosphorus, for example, show that the lake was classified as mesotrophic in 1980 and eutrophic in 1989; now, the concentrations of chlorophyll α and total phosphorus are such that it is considered to be hypertrophic.

The general worsening of the environment has had a marked negative impact on fish stocks, particularly of Eurasian perch. In 1988, the annual yield of Lake Piediluco was estimated to be 143 kg ha^{-1}, 43% of which was constituted by Eurasian perch. By 1993, however, the annual yield had declined to only 0.51 kg ha^{-1}, with perch accounting for only 10%.

In 1996, fishing for perch was banned, and in 2002, this ban was extended to all commercial fishing. The Eurasian perch is of considerable commercial value. In 1997, in an effort to increase the population of this species, the Terni Provincial Authorities implemented a plan to support the natural reproduction of perch by placing artificial spawning substrates along the shores of Lake Piediluco.

The aim of the present research was to evaluate the efficacy of the artificial spawning substrates in supporting the natural reproduction of perch.

Materials and methods

Perch spawning in Lake Piediluco was studied from 1997 to 2003. Artificial spawning substrates were made of bundles of brushwood fixed in a 70 × 25 × 25 cm metal framework, which were deployed along the perimeter of the lake, at depths between 2 and 3.8 m, at the beginning of the spawning period. The bundles were inspected two or three times a week; each time, the number of new egg ribbons laid was recorded. Each egg ribbon was measured and classified in one of three size categories: small (<20 cm), middle-sized (20–40 cm) and large (>40 cm). During 2002 and 2003, ribbon samples of 1 cm length were taken and fixed in formalin (10%). The length of the ribbon from which each sample was taken was also recorded. In the laboratory, the samples were weighed by means of a precision balance (±0.1 g) and examined under an optical microscope. For each fragment, the number of degenerated and live eggs was computed. The number of eggs (degenerated and alive) per ribbon was calculated by multiplying the number of eggs (dead and alive) present in each fragment by the total length of the ribbon from which the fragment had been taken.

Results

A total of 3,332 egg ribbons were found over the 365 spawning substrates collected from 1997 to 2003, with numbers of egg ribbons laid yearly (see Table 1) ranging from 376 (1999) to 616 (2002).

Large ribbons were the most plentiful in the samples (2,713 = 81.32% of the total), and medium-sized ribbons were well represented (543 = 16.30%), whereas small ribbons were collected in relatively few cases (80 = 2.40% of the total). The total number of eggs laid was about 200,000,000, 187,000,000 of which were enclosed in large ribbons, 12,000,000 in medium-sized ribbons and 600,000 in small ribbons (see Table 2).

As can be seen from Table 1, the number of ribbons laid yearly correlated positively with the number of spawning substrates placed in the littoral area of the lake. On the other hand, the average number of ribbons laid per year on a single substrate showed a decreasing trend during the period investigated (see Fig. 1), particularly with regard to medium-sized and small ribbons. Indeed, in the samples collected in 1997, large ribbons represented less than 60% of the total, whereas throughout the

Table 1 Composition of the sample examined

Year	Number of egg ribbons	Number of spawning substrates	Number of eggs	Number of eggs per spawning substrate
1997	475	40	22 898 420	572 460.5
1998	396	35	24 197 458	691 355.9
1999	376	35	21 199 679	605 705.1
2000	401	43	23 743 948	552 184.8
2001	576	71	36 234 694	510 347.8
2002	616	71	40 001 135	563 396.3
2003	492	70	32 514 373	464 491
Total	3332	365	200 820 454	550 193

Table 2 Descriptive statistics of the samples examined in 2002 and 2003

	Number of values	Mean	Median	Minimum	Maximum	Standard deviation
Ribbon length	145	89.172	85.000	30.000	180.000	34.475
Number of eggs per ribbon	145	69 362,759	59 950	12 740	205 466	40 468,087
% eggs degenerated	136	0.102	0.056	0.002	0.633	0.119
Mean diameter of eggs (cm)	142	0.195	0.190	0.128	0.417	0.044

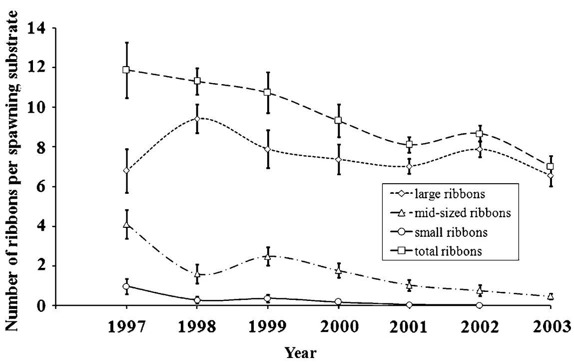

Fig. 1 Annual mean number of egg ribbons per substrate

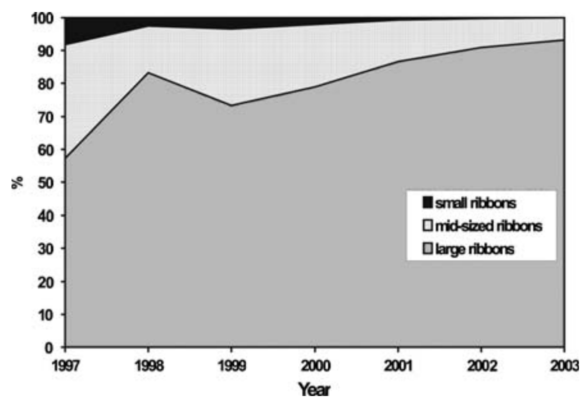

Fig. 2 Percentage of the three size categories of egg ribbons per year

subsequent years, the relative abundance of this size-class tended to increase, reaching 93% in 2003 (see Fig. 2).

Analysis of variance revealed that the number of ribbons laid on a single substrate differed significantly among the various years investigated and that this phenomenon concerned all size-classes considered (large: $F = 7.824$, $P = 0.001$; medium-sized: $F = 43.064$, $P = 0.001$; small: $F = 20.415$, $P = 0.001$).

Table 2 shows the statistics for 145 fragments taken from egg ribbons collected in 2002 and 2003. The fraction of degenerated eggs ranged from 0.20% to 63.30% (average 10.20%), but in 90% of cases, mortality was between 0% and 10%.

Discussion

Over the last decade, the perch population in Lake Piediluco has been modified with regard to several aspects of its biology.

Previous studies have shown that the growth parameters of the population have changed in a few years: in particular, the theoretical maximum size (L_∞) has increased significantly, whereas the growth rate (K) (Von Bertalanffy, 1938) has considerably decreased (Table 3). One factor that may contribute to increasing the maximum size of individuals is the parallel decrease in population density, which has

Table 3 Comparison of Von Bertalanffy's growth model parameters calculated in different periods

Research	Maximum theoretical length (cm)	Growth rate ($year^{-1}$)	Φ
Giovinazzo, 1988	18.76	0.408	2.16
Enel-Dco, 1989	27.73	0.212	2.21
Unpublished data 2000–2003	43.09	0.178	2.52
2004	49.16	0.128	2.49

been recorded since 1980 (Viali et al., 1999). Our results suggest that the sexual maturity of individuals is undergoing an appreciable delay, as indicated by the increasing size of egg ribbons laid during the period investigated. A study by Gillet & Dubois (1995) shows that the size of egg ribbons is positively correlated with the size of the females that lay them. The increased size of the ribbons laid could also be ascribed to the absence of natural recruitment in recent years and to the missing reproductive contribution of the younger age-classes. However, monitoring carried out in 2004 (unpublished data) did not indicate any disturbance of the age-structure of the population, which was seen to be made up of a relatively high percentage of younger individuals: more than 53% of the population was accounted for by specimens less than 16 cm long–a size which perch in Lake Piediluco reach by the age of two years. The worsening of the environmental condition of the lake due to the change in the trophic state (Mearelli, 1988) and increasing competition with some allochthonous species recently introduced into the lake (Pace et al., 2006; Trusso et al., 2006) probably play the greatest role in determining the change observed in the growth rate of the population: decreased growth rates and increased age at maturity suggest that prey levels are becoming inadequate to sustain perch production at existing levels (Hartman & Margraf, 2006). Food availability and population density affect the growth rate of perch (Shafy & Maitland, 1971; Paukert & Willis, 2001): low perch density is probably the most important determinant of this change in growth (Houthuijzen et al., 1993; Dörner et al., 2003). It is well known that this species displays mechanisms of density-dependent growth compensation, whereby the maximum possible size increases (Craig & Kipling, 1983; Holmgren &Appelberg, 2001).

Recent research has revealed that in Lake Piediluco, very marked dietary overlapping occurs between the perch and the ruff (*Gymnocephalus cernuus* L.) (Trusso et al., 2006), a species introduced into the lake in the 1980s (Carosi et al., 1998). Moreover, young perch may also be harmed by interaction with another recently introduced exotic species, the roach (*Rutilus rutilus* (L.)), which is increasing in number in Lake Piediluco. Indeed, in other European localities, very intense competition for zooplankton food resources between the younger age-classes of the roach and of the perch has been identified (Bergman, 1990; Persson, 1983, 1986).

The effectiveness of artificial substrates as spawning beds for perch is indicated by the high number of ribbons and high number of eggs (about 200,000,000 eggs in total, with an average of 550,000 per substrate) laid on them during the 7-year experiments conducted in Lake Piediluco. Although the observed mortality of eggs (10.20% on average) is slightly higher than that found in some previous studies on perch (Melotto, 1996; Sandstrom et al., 1997; Smith et al., 2000), it seems to be sufficiently low to guarantee the reproductive success of perch spawning on artificial substrates.

Overall, the results demonstrate the effectiveness of artificial substrates as suitable substrates for the reproduction of perch. However, they also show that the use of substrates alone is probably not sufficient to enable the perch population in Lake Piediluco to recover from the demographic crisis that has occurred in recent decades. Stocks seem to be declining steadily, as has been pointed out by the results of other studies (Viali et al., 1999), which is also consistent with the reduction in eggs laid on the artificial substrates from 1997 to 2003 (apparently with the exception of 2002) that we documented in the present study.

Worsening environmental conditions, the altered trophic level of the lake (Mearelli, 1988; Enel-DCO, 1989) and the introduction of exotic fish species that are potential competitors of the perch may be some of the most important factors determining the progressive decline of the Eurasian perch in Lake Piediluco.

The problems afflicting fish populations in Lake Piediluco appear to be complex and varied. In order to solve them, we will need to further our knowledge of the biotic and abiotic factors that influence the dynamics of the perch population and which act in the various phases of the biological cycle of this species. Management policies aimed at conserving the perch population should not, therefore, be limited to the reproductive phase; rather, they should be extended to the other biological phases of the species, to the control of competing allochthonous species and to the overall environmental restoration of the lake.

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