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ORIGINAL ARTICLE

Changes in the fish community of the upper Tiber River after construction of a hydro-dam

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ABSTRACT

The aim of this study was to assess whether the composition of the fish community in the upper Tiber River Basin changed after the construction of the Montedoglio Reservoir by comparing the composition of the fish assemblages before and after the creation of this structure. Data collected in 2010 from three different sampling sites (one above and two downstream from the dam) were compared with those recorded during previous studies (conducted in 1992) to reveal the change in fish community. In each sampling site, a census of the fish community was conducted, the estimated number of fish of each species was calculated and fish condition was assessed by relative weight. The structure of the communities downstream from Montedoglio Reservoir changed radically after the construction of the barrier, while the fish community upstream from the barrier appeared unaffected by the dam. The release of hypolimnetic cold water from the reservoir, over time, has caused a progressive decreasing of water temperature of the Tiber River. Montedoglio Reservoir and the release of hypolimnetic water had a marked impact on the fish community of the Tiber River because it interrupted the typical longitudinal zonation of the species in the river. In addition, without effective management, this reservoir can pose an increased threat to the native fish species, since it is a source of diffusion of various exotic species.

Key words: Montedoglio Reservoir, Tiber River, dam effects, fish community, fish condition.

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INTRODUCTION

River damming is the human activity that most drastically affects freshwater environments (Baxter, 1977; Dynesius and Nilsson, 1994; Dudgeon, 2000). Indeed, a dam on a river induces numerous changes in the aquatic ecosystems both upstream and downstream from it (Mérona *et al.*, 2001; Lorenzoni *et al*., 2004). By changing water flow, sediment, nutrients, energy and biota, dams interrupt the continuity of rivers and impact most of their important ecological processes (Ligon *et al.*, 1995). Such variations in physical conditions affect the organization, structure and processes of biotic communities in a long stretch of the river both upstream and downstream from the barrier. In many regulated river systems, modified flow regimes are associated to shifts in the thermal regime since dams release hypolimnetic (cold) or epilimnetic (warm) water from thermally stratified reservoirs. Water released from a deep stratum of a reservoir will be slightly warmer than the natural river in the winter, but it can become drastically cooler in the summer. Thermal impacts can be felt at relatively short or long distances downstream from the dam, depending on the exchange with the atmosphere, hydrologic inputs from tributaries and groundwater recharge and dam discharge (Palmer and O'Keeffe, 1989, 1990).

Some studies have showed that dam-induced thermal alterations have significant implications for stream productivity and the reproduction, growth, distribution and assemblage of organisms (Haxton and Findlay, 2008). Generally the biodiversity downstream of a dam is lower than in natural environments because of a reduced temporal heterogeneity in flow and temperature regime (Ward and Stanford, 1983; Jakob *et al.*, 2003). Since aquatic insects and fish use a combination of day length and temperature to synchronize many aspects of their biological cycles, the release of cooler water downstream from dams can influence the spawning of fish and the life history processes of invertebrates (Penaz and Jurayda, 1995). In the long term, the release of hypolimnetic water can cause the selective disappearance of more sensitive species from downstream stretches (Bunn and Arthington, 2002) and fish populations are forced to undergo changes in response to perturbations induced by damming. Dams can also produce a loss of sensitive and endemic species and alterations in dominant taxa (Poff and Zimmerman, 2010; Cibils Martina *et al*., 2013).

The Montedoglio Reservoir is a man-made lake located in Central Italy (Tuscany and Umbria regions) (Fig. 1) and situated about 33.5 km from the Tiber River source. This reservoir was planned in the early 1970s to create a water source for irrigation and drinking water. The construction of the dam was completed in 1993 with a planned volume of the reservoir of about 168 10^6 m^3 and an available volume of regulation of about 142.5 10^6 m^3 (Lorenzoni *et al*., 2004). The reservoir was also equipped with a valve, located about 3 m from the bottom of the dam, that allows water to return into the Tiber River to ensure the minimum vital flow. Since 2003, the reservoir has released about 7.7 10^6 m^3 of water per month into the Tiber River in order to exploit the hydroelectric potential of the water and to ensure a sufficient outflow of the river (Di Matteo *et al*., 2006).

The main aim of this research was to assess the changes in the composition of the fish community in the upper Tiber River Basin due to the construction of the Montedoglio Reservoir. A further aim was to compare the relative weight of the main fish species upstream and downstream from the dam to evaluate the potential effects of the dam on health of individuals.

Fig. 1. Study area and locations of the sampling sites.

METHODS

Study area

Data were collected in three different sampling sites (one upstream from the Montedoglio Reservoir and two downstream) (Fig. 1) along the Tiber River, which is the third-longest (405 km) river in Italy. The first sampling site (Pieve S. Stefano) was located 23 km downstream from the Tiber River source and about 7 km upstream from the Montedoglio Reservoir. In this location the Tiber River was 5.7 m wide, 0.25 m depth and a stretch of 62.10 m was sampled. The second sampling site (Anghiari) was the closest to Montedoglio Reservoir being localized about 1.5 km downstream from the dam and 35 km from the river source. In this site the Tiber had a deep of 0.45 m, a wide of 21.2 m and a stretch of 96.20 m was sampled. The third sampling site (S. Giustino) was located about 43 km from the Tiber River source and 10 km downstream from the dam. Here the river had a width of 17.5 m, a deep of 0.45 m and a stretch 113 m long was sampled.

Data collection

Data were collected in October 2010 and compared with those recorded during previous studies conducted in 1992 in the same month (Lorenzoni *et al*., 1994; Santucci *et al*., 1994), when the dam was still under construction.

In both periods the census of fish fauna was carried out by electrofishing by wading the river from downstream to upstream during daylight, using the removal method (Moran, 1951; Zippin, 1956). Immediately after capture, all specimens were identified at the species level, counted, measured for total length to the nearest 1 mm and weighed to the nearest 0.1 g. The estimated number of fish at each sampling site was calculated using the Moran-Zippin method (Moran, 1951; Zippin, 1956, 1958): the number of fish was estimated on the basis of specimens captured in two consecutive steps (Marconato, 1991). The density (specimens m^{-2}) was calculated by dividing the estimated number by the surface areas of the sampling sites. In order to identify changes in the composition of the fish community from 1992 to 2010, the fish species were divided into categories according to Huet (1954) who grouped the fish species on the basis of their ecological requirements (Mearelli *et al.*, 1995) (Tab. 1). However, in addition to the 4 categories suggested by Huet (1954) (rheophilic cyprinids, limnophilic cyprinids, predators and salmonids), to further illustrate the degree of change that occurred after the damming, another 2 categories were created: first, the species not belonging to the family of Cyprinids (*Cobitis bilineata, Padogobius nigrigans and Padogobius bonelli*) but inhabiting the same river stretches as the rheophilic cyprinids species (Lorenzoni *et al*., 2010) and showing ecological requirements similar to them (Giannetto *et al*., 2013) were grouped as *other species* (Carosi *et al*., 2006); second, *Telestes muticellus*, was not grouped together with other rheophilic cyprinid (because when compared with such species, it is better adapted to colder water and it can inhabit the same river stretches as salmonids) but considered alone in the category *Italian raffle dace* (Tab. 1).

Estimation of fish condition

Relative weight (W_r) (Wege and Anderson, 1978) was used to evaluate the condition of fish specimens belonging to five species: *Barbus tyberinus* Bonaparte 1839; *Squalius squalus* (Bonaparte 1837); *Rutilus rubilio* (Bonaparte 1837); *Telestes muticellus* (Bonaparte 1837) and *Salmo trutta* (Linnaeus 1758). For each specimens of the selected 5 species, W_r was calculated using the following equation:

$$W_r=(W/W_s)\ 100$$

where W is body weight (g) and W_s is the standard weight determined on the basis of a standard weight equation proposed for each species (Angeli *et al*., 2010; Giannetto *et al*., 2011a, 2011b). For these species for the sampling sites of Pieve S. Stefano and S. Giustino, *t*-Student test was used to test the difference in W_r values between 1992 and 2010. Before to apply the *t*-test, the normality of data distribution was assessed by means of the Wilk-Shapiro test.

The Anghiari sampling site was not considered since only salmonids and no cyprinid species were collected in 2010; subsequently, no comparison with the data collected

Tab. 1. Species composition of the ecological categories used in the research.

Ecological category	Species
Rheophilic cyprinids	*Barbus barbus* (Linnaeus, 1758); *Barbus tyberinus* Bonaparte, 1839; *Protochondrostoma genei* (Bonaparte, 1839); *Squalius squalus* (Bonaparte, 1837); *Rutilus rubilio* (Bonaparte, 1837).
Limnophilic cyprinids	*Cyprinus carpio* Linnaeus 1758*; Scardinius erythrophthalmus* (Linnaeus, 1758).
Predators	*Anguilla anguilla* (Linnaeus, 1758); *Ameiurus melas* (Rafinesque, 1820)*; Perca fluviatilis* Linnaeus, 1758.
Salmonids	*Salmo trutta* Linnaeus, 1758*; Thymallus thymallus* (Linnaeus, 1758).
Italian raffle dace	*Telestes muticellus* (Bonaparte, 1837).
Other species	*Padogobius bonelli* (Bonaparte, 1846); *Padogobius nigricans* (Canestrini, 1867)*; Cobitis bilineata* Canestrini, 1865.

in 1992 or with the fish communities found in the other sampling sites was possible.

Water temperature analysis

To analyse the change that occurred over time in thermal conditions downstream from the dam, due to the release of water from the reservoir, water temperature measured in the two different periods (1992 and 2010) was also compared. In both years, in the month of October, the temperature was measured in the two sampling sites downstream from the dam (Anghiari and S. Giustino) and in two additional localities further downstream from the dam (localized 21 km and 76 km from the Montedoglio Reservoir) (one measurement each sampling sites). The values of temperature were plotted in function of the distance (in km) from the source.

RESULTS

Comparing the values of density of the species calculated in the two different periods (1992 and 2010), the fish community upstream of the dam (Pieve S. Stefano) showed very little changes from 1992 to 2010 (Fig. 2); in

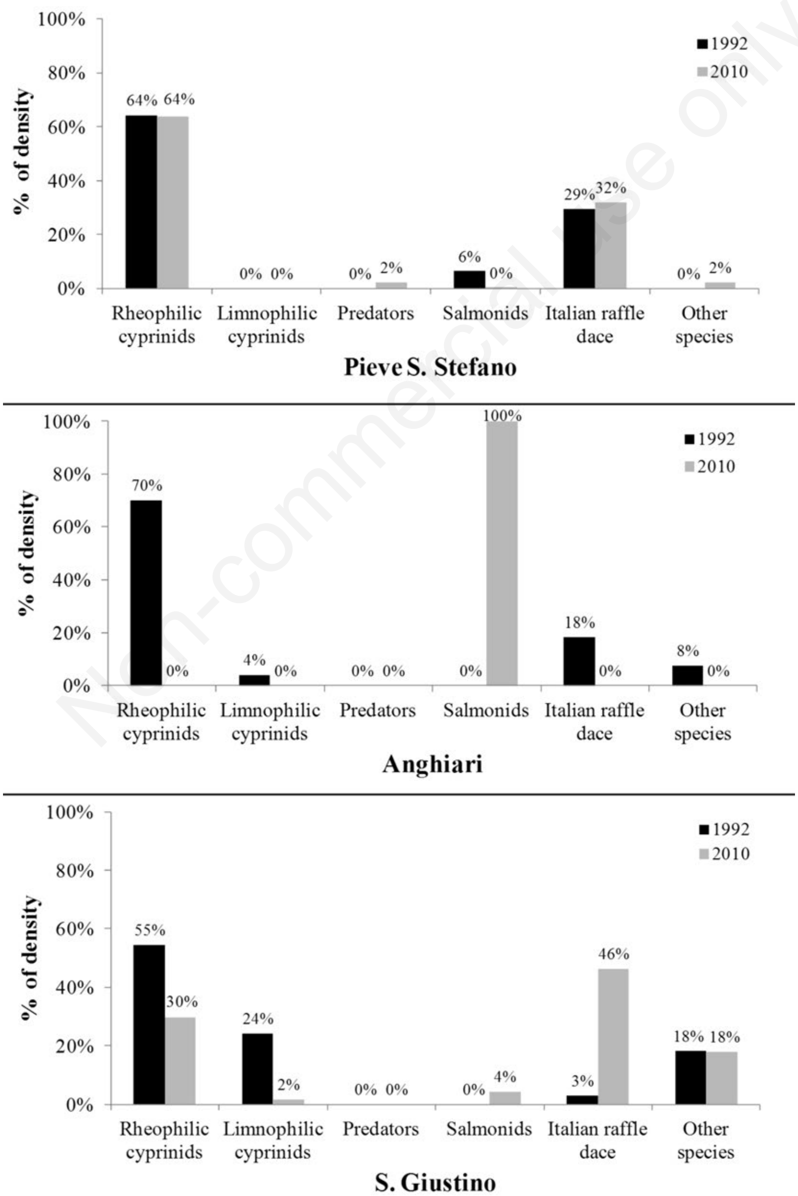

Fig. 2. Comparison of the composition of fish community (expressed as percentage of density for each fish category) found in the three sampling sites before (1992) and after (2010) the construction of the dam.

both years, the dominant category was rheophilic cyprinids. In contrast, in the sampling sites immediately downstream from the dam (Anghiari) a fundamental change in the fish communities was observed: while in 1992 the fish community was dominated by rheophilic cyprinids (70%), in 2010 this group was totally replaced by salmonids (100%) (Fig. 2). In the last sampling site, localized 10 km downstream from the dam (S. Giustino), the changes were less marked but the effects of the reservoir were still evident with a decrease in the limnophilic and rheophilic cyprinids and a consequential increase in the dominance of *Telestes muticellus* (Fig. 2).

Fish condition

According to the Wilk-Shapiro test, a normal distribution of fish condition data resulted for all the 4 species considered (W=0.987, P=0.174 for *Barbus tyberinus*; W=0.954, P=0.071 for *Rutilus rubilio*; W=0.927, P=0.085 for *Squalus squalus*; W=0.992, P=0.166 for *Telestes muticellus*) and this validate the use of *t*-test to compare the change in condition between the two period. At Pieve S. Stefano, the mean W_r values of each species were very similar and not significantly different for *Barbus tyberinus* (*t*=3.677, P=0.056), *Rutilus rubilio* (*t*=1.415, P=0.237), *Squalus squalus* (*t*=2.271, P=0.134) and *Telestes muticellus* (*t*=0.045, P=0.831) (Tab. 2).

In contrast, in the site immediately downstream from the dam (S. Giustino), the W_r values were significantly higher in 2010 than in 1992 revealed a highly significant differences between the value of condition for *Barbus tyberinus* (*t*=20.882, P<0.001), *Squalus squalus* (*t*=39.172, P<0.001), and *Telestes muticellus* (*t*=8.465, P=0.005) while no significant differences were found for *Rutilus rubilio* (*t*=0.641, P=0.800) (Tab. 2). Moreover, the mean values of W_r calculated for these cyprinid species in 2010 were significantly higher in the sampling sites downstream from the dam (S. Giustino) for *Barbus tyberinus* (*t*=5.713, P=0.019), *Squalus squalus* (*t*=4.016, P<0.001) and *Telestes muticellus* (*t*=10.983, P=0.001) (Tab. 2). In the Anghiari sampling site, the mean W_r value for *Salmo trutta* resulted close to 100, 98.721 (Tab. 2).

Water temperature analysis

Analysis of water temperature revealed a generalized cooling of the upper stretch of the river, which became progressively more accentuated over time (Fig. 3). This reduction of water temperature was evident in 2010, when the reservoir reached its definitive level. The temperature drop was greatest in Anghiari, the sampling site immediately downstream of the reservoir (35 km from the Tiber River source), where a difference of up to 8.5°C between 1992 and 2010 was recorded. On moving further downstream, the variation was gradually attenuated (Fig. 3).

DISCUSSION

One of the most immediate effects of dam construction on a fish fauna is the introduction of obstacle to upstream migration. However, reservoirs can have also fundamental effects on the structure of fish communities by changing the habitat river downstream from the dam and this is particularly marked when deep reservoirs release hypolimnetic water (Lorenzoni *et al*., 2004). Habitat controls the natural longitudinal distribution of fish and changes in its characteristics result in alterations of the fish assemblage (Huet, 1949, 1954, 1962; Arunachalam, 2000; Bunn and Davies, 2000).

The results of the present study showed that the construction of the dam on the Tiber River had no apparent effect on fish community structure upstream of the reservoir, but, in contrast it has strongly influenced the community downstream. These results are in line with those of studies of other reservoirs (Lelek *et al*., 1973; Petts,

Tab. 2. Descriptive statistics of relative weight for sampling sites and study periods.

Species	Sampling site	1992			2010		
		n	Mean W_r	SD	n	Mean W_r	SD
B. tyberinus	Pieve S. Stefano	316	92.397	11.686	73	95.216	9.557
	S. Giustino	176	90.141	9.358	15	101.511	7.768
S. squalus	Pieve S. Stefano	108	98.888	12.043	78	96.304	10.803
	S. Giustino	313	88.977	14.259	36	104.278	10.039
R. rutilus	Pieve S. Stefano	22	94.480	12.164	65	99.723	19.372
	S. Giustino	316	91.374	19.213	7	93.232	18.957
T. muticellus	Pieve S. Stefano	132	97.977	14.712	56	98.457	12.586
	S. Giustino	10	89.581	22.641	82	107.702	18.088
S. trutta	Anghiari	-	-	-	82	98.721	13.140

N, sample size; W_r*, relative weight; SD, standard deviation.*

1988; de Mèrona *et al*., 2001). More specifically, in the present study, in 1992, in the sampling site located immediately downstream from the dam, the fish community was dominated by the rheophilic cyprinids species typical of the mid-upper reaches of the Tiber River (*B. tyberinus*, *P. genei*, *R. rutilus* and *S. squalus)* (Lorenzoni *et al*., 2006); in contrast, in 2010, the fish community of Anghiari was constituted entirely of salmonids and the only species sampled were *S. trutta* and *T. thymallus*. A similar pattern was also observed in the Colorado River (USA) where the construction of dam had resulted in a decline of native fish community and its replacement by *Salmo spp.* (Holden and Stalnaker, 1975). In Central Italy, *S. trutta* typically inhabits the small tributaries of the Tiber River localized in mountain because this species is a frigo-stenothermal stenoxybiont and less adapted to the environmental characteristics of the main stretch of the Tiber River (Lorenzoni *et al*., 2006). This species probably benefitted from the recent decrease of water temperature that occurred downstream from the Montedoglio Reservoir as demonstrated by the mean values of relative weight calculated for this species that reflected a good status of condition (Anderson, 1980). The same increasing of condition for the fish populations downstream from the dam, observed in the present study, were also reported by Crisp *et al*. (1983) for the Tees River (UK) after the construction of the Cow Green Reservoir. In that case, quantitative changes in the composition of fish stomach contents also occurred after the construction of the dam (Crisp *et al*., 1978, 1984). With regard to *T. thymallus*, its distribution is actually limited to the watercourses of North Italy (Zerunian, 2002) and the presence of this species in the Tiber River was due to recent introduction. In the past, several efforts to introduce this species into other waterways have been attempted but without success; the presence of the *T. thymallus* in the Tiber River was surely facilitated by the change in its environmental conditions due to the reservoir. In the other sampling site downstream from the dam (S. Giustino) the fish community also proved to have been modified since 1992 with a drastic decrease of the dominance of rheophilic and limnophilic cyprinids and a high increase in Italian ruffle dace. This species benefitted from the changes induced by the reservoir, probably because, among all the cyprinids present, it is the one that adapts best to cold water (Bianco, 1996).

Water temperature is one of the environmental factors that most strongly influences the distribution of fish fauna (Martinez *et al*., 1994); changes in the thermal regime and in the water quality result in changes in primary produc-

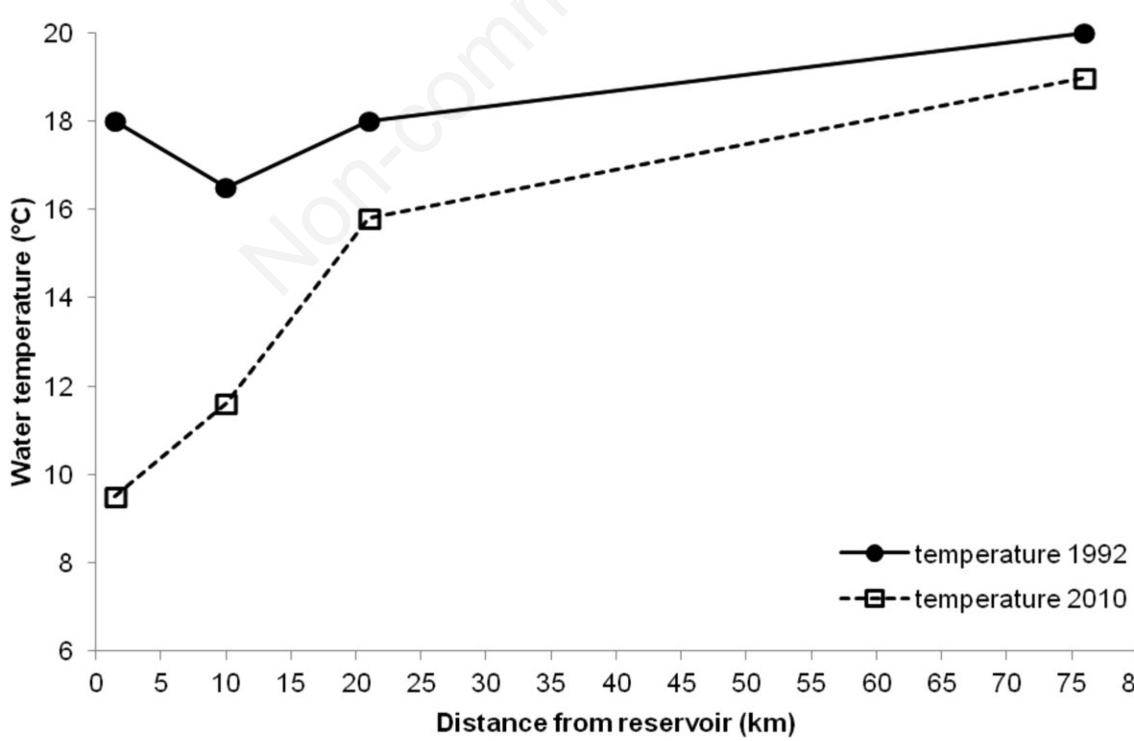

Fig. 3. Comparison between water temperature (°C) in the Tiber River in 1992 and 2010 in relation to the distance from the reservoir of the sampling sites.

tion, with long-term implications for the fish community and other organisms at the top of the food chain (McCartney *et al*., 2001). For example, a substantial number of large dams have intentionally been used to manage thermal regimes through the selective release of cold water from deep reservoirs, in order to promote fishing opportunities for some species of salmonids (Olden and Naiman, 2010). Similarly, the radical change in the distribution of fish fauna observed in the Tiber River downstream of the Montedoglio Reservoir can be attributed to the decrease of the water temperature due to the release of cold water from the hypolimnion. Immediately downstream from the Montedoglio Reservoir, the variation in the water temperature led to the loss of optimal conditions for the survival of rheophilic cyprinids (Huet, 1949, 1954, 1962; Mearelli *et al*., 1995) and facilitated colonization by salmonids.

Upstream from the dam (Pieve S. Stefano), the condition of the species investigated remained unchanged between 1992 and 2010. On the contrary downstream of the dam (S. Giustino) an increase in condition was observed when compared with the populations inhabiting areas upstream from the dam and with the state before the construction of the reservoir. The same scenario was reported by McCartney *et al*. (2001) who observed that fish populations increased in the tailwaters of some dams because the regulated thermal regime raises the local primary production (*i.e*., plankton) and observed lower turbidity was favourable for some fish species (*e.g*., salmonids).

CONCLUSIONS

The modification of thermal conditions of rivers due to the release of hypolimnetic water from reservoirs has a marked impact on river because it interrupts the natural fish zonation (Huet, 1949; Mearelli *et al*., 1995). In this way, species traditionally inhabiting the upper stretches of the river (*e.g*., salmonids) may colonize the downstream sectors disadvantaging the species typical of the barbel zone. Moreover, the increase of condition in fish downstream from the dam could easily be attributed to an increase in the availability of nutrients as a result of the decomposition and mineralization of organic substances inside the reservoir.

The original fish community of the upper part of Tiber River consists of species with a high conservation value (Lorenzoni *et al*., 2006) comprising many of the endemics of the Tuscany and Lazio district (Bianco, 1996) and already threatened by various human pressures (IUCN, 2011). In this context, the construction of the Montedoglio Reservoir raises another potential threat for these species: in absence of careful management, the reservoir may represent a source of diffusion of various exotic species in the downstream river stretches (Lorenzoni *et al*., 2004) potentially raising the already high level of zoogeographic pollution that now characterises the Tiber River (Bianco, 1990; Lorenzoni *et al*., 2006, Giannetto *et al*., 2012).

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