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INFLUENZA DELL'INVASO DI MONTEDOGLIO SULLA FAUNA ITTICA DELL'ALTO TEVERE

INFLUENCE OF THE MONTEDOGLIO RESERVOIR ON FISH FAUNA IN THE UPPER TIBER

E. FRANCHI[1*], A. CAROSI[1], L. GHETTI[2], D. GIANNETTO[1], G. LA PORTA[1], L. POMPEI[1], G. PEDICILLO[1], M. LORENZONI[1]

[1]*Dipartimento di Biologia Cellulare e Ambientale - Università di Perugia, Via Elce di Sotto 06123, Perugia Italy.*
[2]*Regione dell'Umbria, Servizio Programmazione Forestale, Faunistico-Venatoria ed Economia Montana.*
*elifra81@gmail.com

Riassunto
Dighe e sbarramenti interrompono il continuum fluviale ed hanno un impatto sul regime idrologico, sul regime termico e sulla sedimentazione del fiume; a loro volta le variazioni delle condizioni fisiche influenzano organizzazione, struttura e processi delle comunità biotiche di un ampio tratto a monte e a valle dello sbarramento.
Scopo della ricerca è indagare gli effetti della costruzione dell'invaso di Montedoglio sulla composizione della comunità ittica del corso medio-alto del fiume Tevere.
Tre serie di dati sono state esaminate al fine di confrontare la situazione odierna (2010) con quella preesistente alla creazione dell'invaso (1992) e una fase intermedia fra le due (2004). Per ogni stazione di campionamento è stata censita la comunità ittica presente mediante un elettrostorditore di 4500 W di potenza ed è stata applicata la tecnica delle passate successive, per stimare l'abbondanza di ciascuna specie ittica. Per l'analisi dei risultati le specie censite sono state suddivise in base alle loro preferenze ecologiche: salmonidi ciprinidi reofili, ciprinidi limnofili, vairone, predatori ed altri.
Il confront0 tra i dati raccolti nei vari anni ha mostrato come la struttura delle comunità a valle dell'invaso sia stata profondamente modificata: le stazioni immediatamente a ridosso della diga hanno subito cambiamenti più radicali, ma ancora a 43 km più a valle è possibile notare un'influenza sulle comunità ittiche.
Tali cambiamenti sono la conseguenza del rilascio di acqua ipolimnica fredda dall'invaso di Montedoglio che ha causato nel tempo un progressivo abbassamento della temperatura dell'acqua del fiume Tevere, con variazioni anche di 8 °C nelle stazioni immediatamente a valle della diga.

Summary
Dams and barriers interrupt the continuity of rivers and have an impact on their hydrological and thermal regimes and on sedimentation. 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 of the barrier.
The downstream effects of the Montedoglio Reservoir on fish communities were examined by comparing the composition of the fish community in the mid-upper River Tiber before and after the creation of this impoundment.
Three sampling sites were selected, one above and two below the dam, and three series of data (1992, 2004, 2010) were examined in order to trace the temporal evolution of the fish populations in these stretches of the river. At each sampling site, a census of the fish

community was conducted and the density and standing crop of each fish species were estimated.
Comparison of the data collected in the various years showed that the structure of the communities downstream of the reservoir had changed radically; the sites immediately below the dam were seen to have undergone the most marked changes, while the variations observed in the stretch of water upstream of the dam were very slight.
These changes are the result of the release of hypolimnetic cold water from the reservoir; over time, this has caused a progressive lowering of the temperature of the water of the River Tiber, with variations of as much as 8°C in 2010 at the sites immediately downstream of the reservoir.

Keywords: River Tiber; dam effect; fish community; relative weight; temperature.

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 both the upstream and downstream aquatic ecosystems (Mérona, et al. 2001; Lorenzoni et al., 2004). By changing the flow of water, sediment, nutrients, energy and biota, dams interrupt and alter most of the river's important ecological processes (Ligon et al., 1995).
In many regulated river systems, modified flow regimes are accompanied by shifts in the thermal regime because 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 slightly cooler in the summer. Thermal impacts can be felt at relatively short or extremely long distances downstream of the dam, depending on heat exchange with the atmosphere, hydrologic inputs from tributaries and groundwater recharge, and dam discharge (Palmer and O'Keeffe, 1989, 1990).
Some studies have shown that dam-induced thermal alterations have significant implications for stream productivity and the reproduction, growth, distribution and assemblage of organisms (Haxton and Findlay, 2008). Since aquatic insects and fish use a combination of day length and temperature to synchronize many aspects of their biological cycle, the release of cooler water downstream of impoundments can influence the spawning behavior of fish and the life history processes of invertebrates (Penaz and Juraida, 1995). In the long term, the release of hypolimnetic water can cause the selective disappearance of susceptible species from downstream reaches (Bunn and Arthington, 2002).
In order to survive perturbations induced by damming, fish populations face numerous challenges; in this context, the present study aimed to gain a better understanding of variations in the composition of the fish community in the mid-upper River Tiber caused by the construction of the Montedoglio Reservoir.

Materials and methods

Study area

The Montedoglio Reservoir is a man-made lake located in the northern part of the Central Apennines (latitude: 43° 35' 55.68'' N; longitude: 12° 03' 53.64'' E) (Figure 1). The dam is situated about 33.5 km from the source of the Tiber in the towns of Pieve Santo Stefano, Anghiari and Sansepolcro, in the province of Arezzo (Tuscany). In addition to the River Tiber, the reservoir has two other tributaries: the Tignana and Singerna streams.
The reservoir was planned in the early 1970s to create a water source for irrigation in the Chiana Valley, Tiber Valley and Lake Trasimeno, in addition to providing drinking water for

many municipalities in Umbria and Tuscany. Construction of the dam was terminated in 1993 and in 1990 experimental filling operations began, which led to an annual accumulation of about 10 10^6 m^3 of water; subsequently, the first operations to restore water to the river began. The surface area of the catchment basin is about 275.8 km^2, and that of the lake about 7.66 km^2. The planned volume of the reservoir was about 168 10^6 m^3 and the available volume of regulation about 142.5 10^6 m^3 (Lorenzoni et al., 2004). However, only in 2010 did the reservoir reach its full capacity, creating conditions that can be considered close to definitive.
The reservoir is equipped with a valve, located about 3 m from the bottom of the dam, through which water returns into the River Tiber in order to ensure the minimum vital outflow. Since May 2003, in order to exploit the hydroelectric potential of the water released and to ensure a sufficient outflow into the River Tiber, about 7.7 10^6 m^3 of water per month is released from the reservoir (Di Matteo et al., 2006).

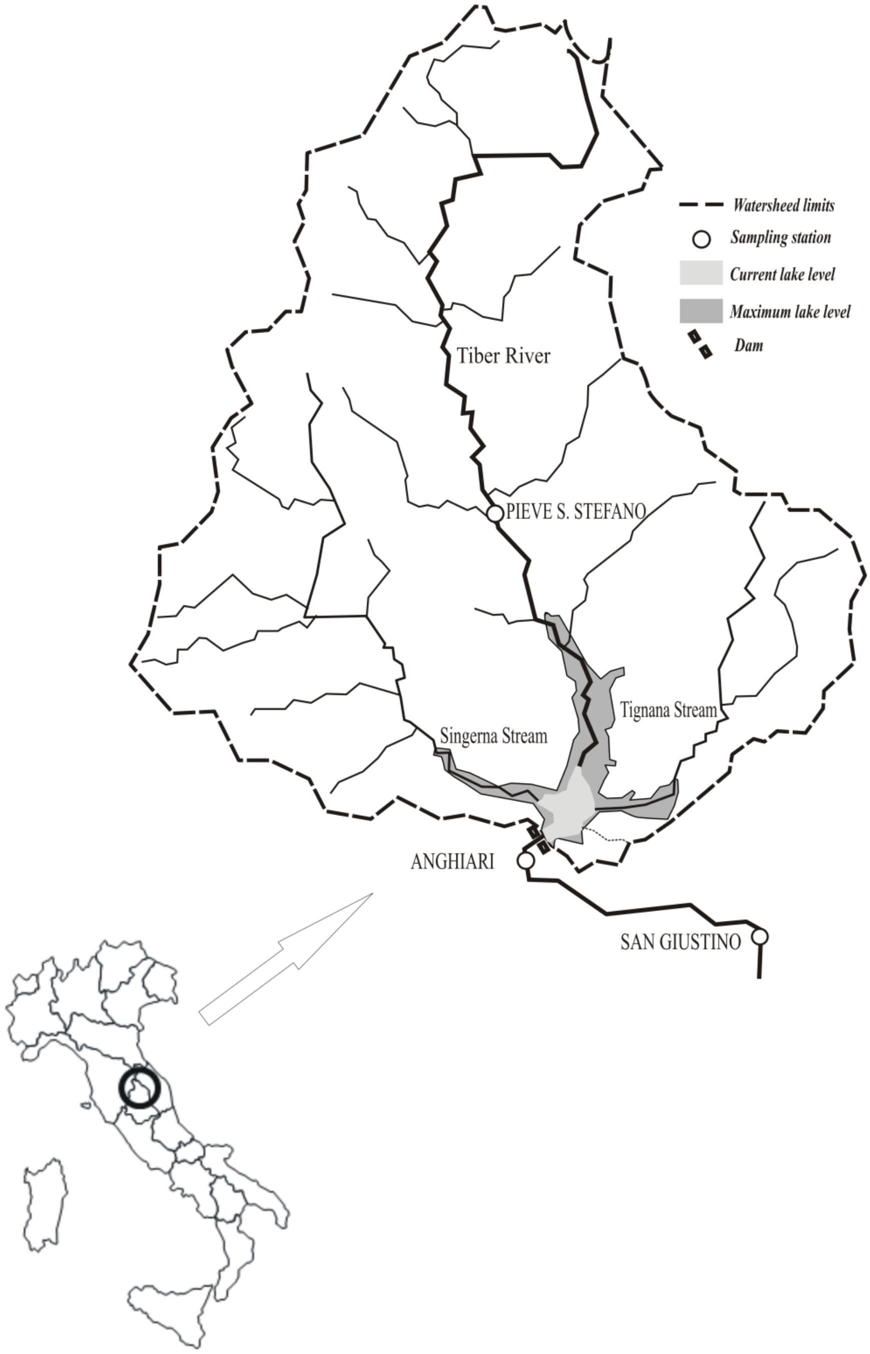

Figure 1: Study area and locations of the sampling sites

Methods

Sampling was undertaken at three sites along the Tiber River. One site was located about 7 km upstream of the dam, in the municipality of Pieve S. Stefano (N 43 38.890; E 12 03.221); the other sites were located 35 km and 43 km downstream of the dam, in the municipalities of Anghiari (N 43 34.740; E 12 03.330) and San Giustino (N 43 31.668; E 12 09.422), respectively (Figure 1).

Sampling was carried out by means of electrofishing in September 2010. Immediately after capture, 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 (Anderson and Neumann, 1996).

The age of the fish was determined by means of the microscopic scalimetric method (DeVries and Frie, 1996): scales were removed from the left side of the fish, above the lateral line, near the first dorsal fin, and stored in ethanol (33%). Age determination by means of scale analysis was confirmed and integrated by applying Petersen's length-frequency method (Bagenal and Tesch, 1978).

The probable number and biomass of fish at each sampling site were calculated by using the Moran-Zippin method (Moran, 1951; Zippin, 1956, 1958). In accordance with the methodologies used, the probable number and biomass were estimated on the basis of specimens captured in two consecutive steps.

Abundance was estimated by breaking down the whole sample into homogeneous age-classes. The probable biomass was calculated by multiplying the probable number by the average weight of the individuals caught (Marconato, 1991). The density (specimens m^{-2}) and standing crop (g m^{-2}) were calculated by dividing the probable number and biomass by the surface areas of the sampling sites.

The data collected in 2010 at the three sampling sites were compared with those recorded during a study conducted in 1992 at the same sites (Lorenzoni et al., 1994; Santucci et al., 1994). In addition, with regard to the sampling site located in the municipality of S. Giustino, we also used the data acquired in 2004 during a some sampling campaigns carried out for the compilation of the Regional Fish Chart (Lorenzoni et al., 2007).

In order to identify changes in the composition of the fish community from 1992, when the dam was still under construction, to 2010, the species present were grouped into six categories according to their ecological requirements (Table 1) (Huet, 1949; Mearelli et al., 1995; Carosi et al., 2006). We used ecological categories rather than individual species because, between 1992 and 2010, a variation occurred in the species present in the River Tiber as a result of the recent introduction of some allochthonous species, such as, for example, *Barbus barbus* (Linnaeus, 1758), *Padogobius bonelli* (Bonaparte, 1846) and *Thymallus thymallus* (Linnaeus, 1758) (Lorenzoni et al., 2006).

Table 1: Species composition of the ecological categories.

Category	Species
Rheophilic cyprinids	*Barbus barbus*; *Barbus tyberinus*; *Protochondrostoma genei*; *Squalius squalus*; *Rutilus rubilio*
Limnophilic cyprinids	*Cyprinus carpio; Scardinius erythrophthalmus*
Predators	*Anguilla anguilla*; *Ameiurus melas; Perca fluviatilis*
Salmonids	*Salmo (trutta) trutta; Thymallus thymallus*
Italian raffle dace	*Telestes muticellus*
Others	*Padogobius bonelli*; *Padogobius nigricans; Cobitis bilineata*

Relative weight (W_r) (Wege and Anderson, 1978) was used to evaluate the condition of individual fish belonging to five species: *Barbus tyberinus* Bonaparte, 1839; *Squalius squalus* (Bonaparte, 1837); *Rutilus rubilio* (Bonaparte, 1837); *Telestes muticellus* (Bonaparte, 1837) and *Salmo (trutta) trutta* (Linneus, 1758). This was calculated as follows: $W_r = (W/W_s)\ 100$, 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 for the Tiber River basin (Angeli et al., 2010; Giannetto in press). For each species, the differences in condition between the sampling sites and periods of study were tested by means of ANOVA; moreover, for each sampling site, one-way ANOVA was used to test the difference in W_r value between 1992 and 2010 for each species. The Anghiari sampling site was excluded from the statistical analyses because, in 2010, the only species found there was the brown trout; moreover, it was not possible to perform the ANOVA test on the brown trout because a sufficient number of specimens were caught only in 2010 and only at the Anghiari sampling site.
The water temperature was measured at each sampling site. The temperature in September 2010 was compared with that recorded in the same month in 1992 and 2004 at seven sampling sites, at increasing distances up to 123 km downstream of the reservoir. In order to analyze the trend in temperature both over time and as a function of the distance from the reservoir a linear regression between the temperature of the water and the distance from the reservoir was carried out for each of the years considered.

Results

A total of 1163 specimens belonging to 16 fish species were caught at the three sampling sites; Table 2 lists the species caught and their values of density (specimens m^{-2}) and standing crop (g m^{-2}). At the sampling site upstream of the dam (Pieve S. Stefano), 10 species were caught. The highest density values were recorded for *Padogobius nigricans* (Canestrini, 1867) (2.00 specimens m^{-2}), *T. muticellus* (1.424 specimens m^{-2}), *B. tyberinus* (1.119 specimens m^{-2}) and *R. rubilio* (1.073 specimens m^{-2}); with regard to the biomass measured per unit of surface area sampled, the highest values were registered for *S. squalus* (69.696 g m^{-2}), *B. tyberinus* (24.915 g m^{-2}) and *R. rubilio* (7.397 g m^{-2}). At the Anghiari sampling site, only two species were found, *S. trutta* and *T. thymallus*; their density and standing crop values were 0.051 specimens m^{-2} and 7.428 g m^{-2} for *S. trutta* and 0.001 specimens m^{-2} and 0.946 g m^{-2} for *T. thymallus*. At the San Giustino sampling site, the density of all the species present proved to be low; with the exception of the Italian raffle dace population, which displayed a density of 0.103 specimens m^{-2}, the other species had little impact on overall density. With regard to biomass, the highest values were recorded for the populations of chub (6.223 g m^{-2}), carp (5.440 g m^{-2}) and brown trout (2.145 g m^{-2}).
In terms of species, the composition of the fish community at the Pieve S. Stefano sampling site was seen to have changed very little from 1992 to 2010 (Figure 2); in both years, the dominant category was that of rheophilic cyprinids. Downstream of the dam, however, a different situation emerged; at the Anghiari sampling site, a community chiefly constituted by rheophilic cyprinids (70%) was seen to have given way to a community made up entirely of salmonids (100%) (Figure 3). At the San Giustino site, the changes were less marked than in the stretches closer to the dam. Nevertheless, the effects of the presence of the reservoir were evident; indeed, limnophilic cyprinids and rheophilic cyprinids were seen to have diminished markedly in favor of the Italian raffle dace (Figure 4).
The mean W_r values of the fish species in the sample, when broken down by sampling site and year, are reported in Table 3. At the Pieve S. Stefano site, the mean W_r values of each species proved to be very similar in the two years considered; on the ANOVA test, the differences in condition were not statistically significant: *S. squalus* ($F = 2.271$, $p = 0.134$), *B. tyberinus* ($F = 3.677$, $p = 0.056$), *T. muticellus* ($F = 0.045$, $p = 0.831$) and *R. rubilio* (F =

1.415, $p = 0.237$). By contrast, downstream of the dam (San Giustino), all the W_r values proved to be higher in 2010 than in 1992, and the ANOVA test revealed highly significant differences with regard to *S. squalus* ($F = 39.172$, $p = 0.000$), *B. tyberinus* ($F = 20.882$, $p = 0.000$) and *T. muticellus* ($F = 8.465$, $p = 0.005$), while no significant differences were found for *R. rubilio* ($F = 0.641$, $p = 0.800$).

For these four fish species, the differences between the mean relative weight of the populations present in 2010, both upstream and downstream of the dam, were tested by means of ANOVA. The mean values always proved to be higher at the sampling sites downstream of the dam (San Giustino) than at the site situated upstream, and significant differences in mean W_r values were observed for *S. squalus* ($F = 14.016$, $p = 0.000$), *B. tyberinus* ($F = 5.713$, $p = 0.019$) and *T. muticellus* ($F = 10.983$, $p = 0.001$), while no significant differences were found for *R. rubilio* ($F = 0.712$, $p = 0.401$).

Figure 5 shows the linear regressions between the temperature of the water and the distance from the source of the River Tiber calculated for the three different periods of time considered. Analysis of these data revealed a generalized cooling of the upper stretch of the river, which became progressively more accentuated overtime. This temperature reduction was more evident in recent years, when the reservoir reached its definitive level of operation. The temperature drop was seen to be greatest immediately downstream of the reservoir (35 km from the 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, although it was still measurable at a distance of 123 km from the dam.

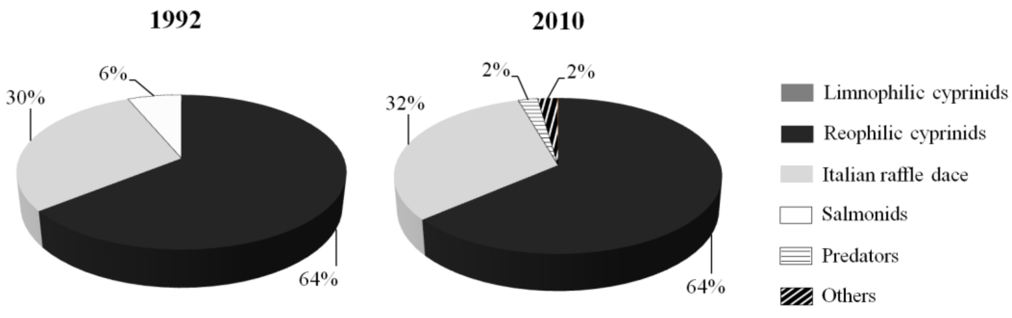

Figure 2: Composition of the fish community in the River Tiber at Pieve S. Stefano.

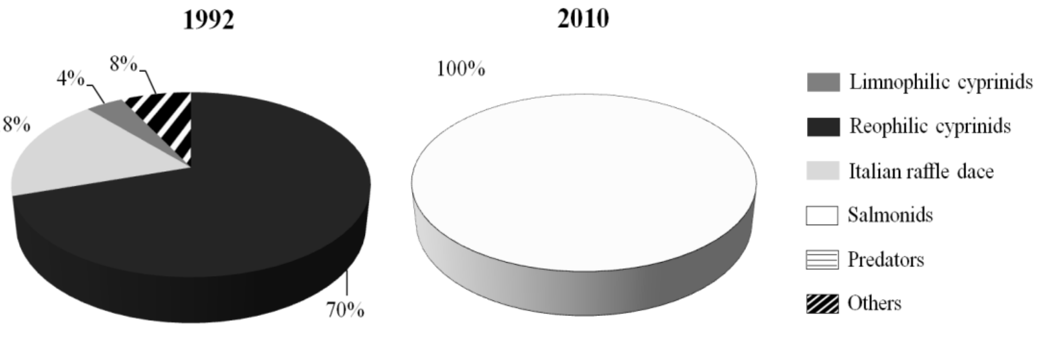

Figure 3: Composition of the fish community in the River Tiber at Anghiari.

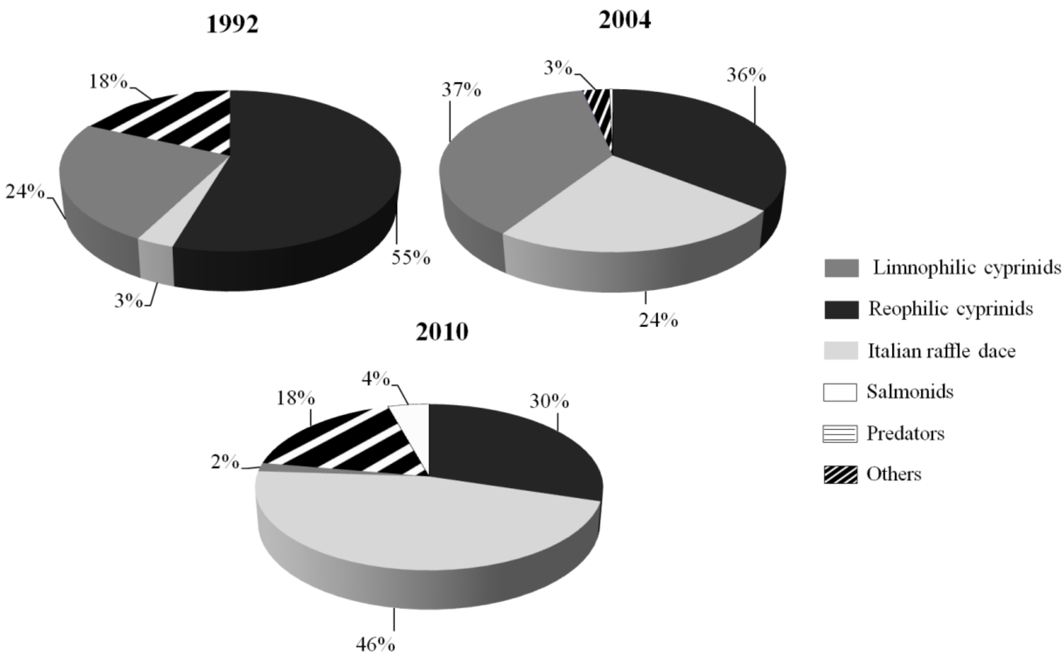

Figure 4: Composition of the fish community in the River Tiber at San Giustino.

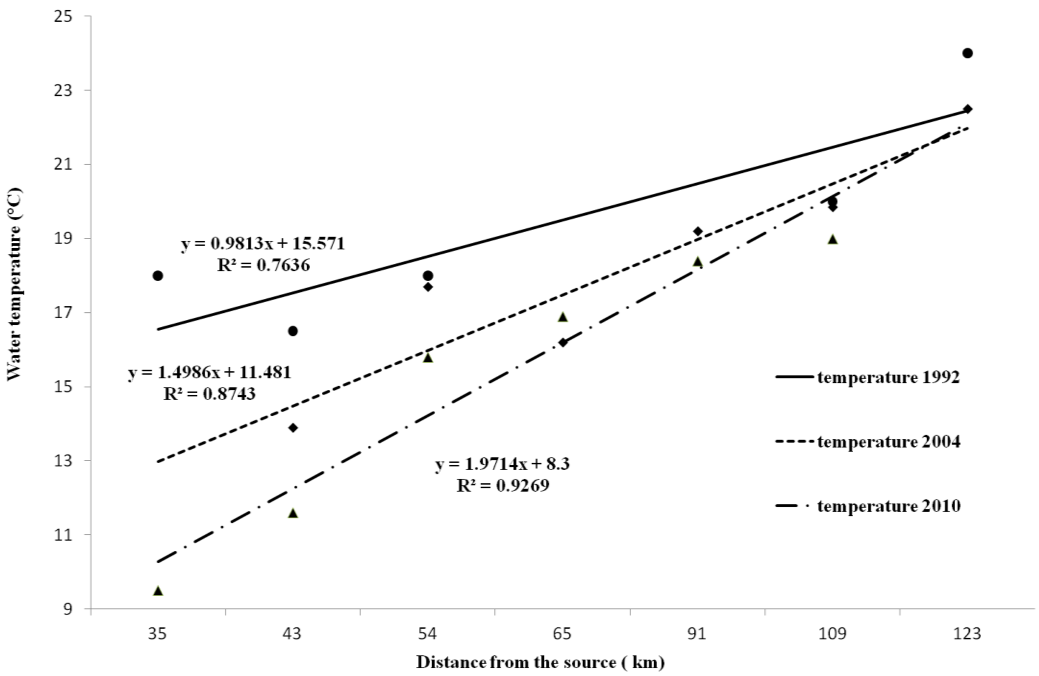

Figure 5: Relationship between temperature (°C) and distance from the source of the River Tiber in 1992, 2004 and 2010

Table 2: Abundance (specimens m^{-2}) and biomass (g m^{-2}) of fish species captured at the three sampling sites in 2010.

Species	Pieve S. Stefano		Anghiari		San Giustino	
	Density	Standing crop	Density	Standing crop	Density	Standing crop
Anguilla anguilla (Linnaeus, 1758)	0.003	1.173				
Rutilus rubilio (Bonaparte, 1837)	1.073	7.397			0.005	0.023
Squalius squalus (Bonaparte, 1837)	0.661	69.696			0.022	6.223
Telestes muticellus (Bonaparte, 1837)	1.424	4.468			0.103	1.07
Scardinius erythrophthalmus (Linnaeus, 1758)					0.001	0.042
Protochondrostoma genei (Bonaparte, 1839)					0.003	0.145
Barbus barbus (Linnaeus, 1758)	0.003	0.686				
Barbus tyberinus Bonaparte, 1839	1.119	24.915			0.037	1.905
Cyprinus carpio Linnaeus, 1758					0.003	5.44
Cobitis bilineata Canestrini, 1865					0.018	0.031
Ameiurus melas (Rafinesque, 1820)	0.084	4.65				
Salmo (trutta) trutta Linnaeus, 1758	0.003	0.349	0.051	7.428	0.005	2.145
Thymallus thymallus (Linnaeus, 1758)			0.001	0.946	0.005	1.439
Perca fluviatilis Linnaeus, 1758	0.011	0.071				
Padogobius bonelli (Bonaparte, 1846)					0.009	0.019
Padogobius nigricans (Canestrini, 1867)	2	6.89			0.013	0.04
Total	6.381	120.296	0.052	8.374	0.222	18.522

Table 3: Descriptive statistics of relative weight (W_r) for sampling sites and study periods; n: sample size; S.D.: standard deviation.

Species	**Sampling site**	**1992**			**2010**		
		n	**Wr medio**	**S.D.**	**n**	**Wr medio**	**S.D.**
Chub	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
Barbel	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
Italian raffle dace	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
Italian roach	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
Brown trout	Anghiari				82	98.721	13.140

Discussion

One of the most immediate effects of dam construction on ichthyofauna is the blockage of upstream migration. However, reservoirs have also proved to exert profound effects on the structure of fish communities by changing the fluvial habitat downstream, particularly when deep reservoirs release hypolimnetic water (Lorenzoni et al., 2004). This is because habitat controls the longitudinal distribution of fish, and changes in habitat characteristics are often associated with changes in the composition of the fish assemblage (Huet, 1949, 1954, 1962; Arunachalam, 2000; Bunn and Davies, 2000).

The construction of the dam on the Tiber River has had no effect on the community structure upstream of the reservoir, but has profoundly influenced the community downstream of the dam as the present study has showed. Indeed, at the sampling site closest to the dam (Anghiari), 70% of the species sampled in 1992 was constituted by rheophilic cyprinids typical of the mid-upper reaches of the River Tiber, such as the barbel, Italian nase, roach and chub (Lorenzoni et al., 2006); by contrast, the present fish community is made up entirely of salmonids, and the only species sampled were brown trout and European grayling. The brown trout is typically found in the mountain tributaries of the River Tiber, in that it is a frigo-stenothermal, stenoxybiont species which poorly adapts to the environmental characteristics of the main stretch of the river (Lorenzoni et al., 2006). This species has surely taken advantage of the recent drop in the temperature of the water of the Tiber; this is also demonstrated by the analysis of relative weight, the mean value of which proved to be 98.7. A W_r value above 95 is indicative of an ideal condition (Anderson, 1980). The distribution of the European grayling is limited to the watercourses of the Padana Plain (Zerunian, 2002), the presence of the species in the River Tiber being due to recent introduction. In the past, several attempts to introduce this species into other waterways have been made, though always without success; in the case of the Tiber, however, the presence of the European grayling has evidently been facilitated by the recent change in the environmental conditions of the river.

At the San Giustino site, too, the fish community proved to have been modified since 1992. Indeed, before the construction of the reservoir, rheophilic ciprinids (55%) and limnophilic ciprinids (24%) displayed the greatest abundance; in 2010, however, the Italian raffle dace alone accounted for 46% of the fish community (3% in 1992), while rheophilic cyprinids (30%) and, especially, limnophilic cyprinids (2%) were seen to have dwindled drastically. The Italian raffle dace is the species that has benefited most from the changes induced by the reservoir, probably because, among all the cyprinids present, it is the one which adapts best to cold water (Bianco, 1996).

The radical change in the distribution of fish fauna in the River Tiber downstream of the Montedoglio Reservoir can be attributed to the reduction in the temperature of the water caused by the release of cold water from the hypolimnion. Indeed, 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 quality of the water give rise to changes in primary production, which, in turn, has long-term implications for fish and other animals 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, such as trout or salmon (Olden and Naiman, 2010). Immediately downstream of the Montedoglio Reservoir, the temperature variation of the water has led to the loss of optimal conditions for the survival of rheophilic cyprinids (Huet 1949, 1954, 1962; Mearelli et al., 1995) and has facilitated colonization by the trout and the European grayling.

Our analysis of relative weight indicated that, upstream of the dam (Pieve S. Stefano site), the well-being of the species investigated had remained unchanged from 1992 to 2010; this finding shows that, predictably enough, the presence of the reservoir has not modified the

living conditions of the fish fauna in the upstream stretches of the river. Downstream of the dam (San Giustino site), however, the increase in relative weight that emerged from comparison, both with the populations present in the stretch upstream of the dam and with those present in the same sector of the river in the period prior to construction of the reservoir, reveals an evident improvement in the well-being of all the fish species investigated. This can easily be attributed to an increase in the availability of nutrients downstream of the dam as a result of the decomposition and mineralization of organic substances inside the reservoir. Regarding this aspect, some studies have shown that, in some temperate climates, fish populations increase in the tailwaters of some dams because the regulated thermal regime, increased primary production (i.e. plankton) and lower turbidity are favorable for some fish species (e.g. trout) (McCartney et al., 2001).
The mid-upper reaches of the River Tiber are populated by a community of species that are particularly important from the conservationist standpoint, many of which are endemic (Bianco, 1996). This community is the most representative of the fish fauna in the hydrographic network of Tuscany and Lazio (Bianco, 1996), the most important watercourse of which is precisely the River Tiber. It is, however, threatened by various types of human pressure (IUCN, 2011). To the various factors which impact on the original fish community in the Tiber (Lorenzoni et al., 2006), we must add the construction of the Montedoglio Reservoir. It had previously been hypothesized that, in the absence of careful management, the reservoir might become a source of the downstream diffusion of various exotic species (Lorenzoni et al., 2004), thereby raising the already high level of zoogeographic pollution in the Tiber (Bianco, 1990; Lorenzoni et al., 2006). This threat is compounded by the environmental change in the thermal conditions of the river induced by the release of hypolimnetic water from the reservoir. Indeed, as this research demonstrates, this cooler water has had a marked impact on the longitudinal evolution of the river, in that it has disrupted the normal sequence whereby less rheophilic and frigo-stenothermal species are found progressively downstream (Huet, 1949; Mearelli et al., 1995; Carosi et al., 2006), thus further penalizing the species typical of the barbel zone by depriving them of a considerable portion of their habitat.

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