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Fishery biology of the goldfish *Carassius auratus* (Linnaeus, 1758) in Lake Trasimeno (Umbria, Italy)

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ABSTRACT

Key-words: *gill-net selectivity, invasive species, electrofishing, CPUEs*

The fishery biology of the goldfish *Carassius auratus* was studied in Lake Trasimeno by analysing the selectivity of the equipment that can be used to control this invasive species. Sampling was conducted monthly from February 2003 to January 2004 by means of electrofishing, fyke-nets and gill-nets of different-sized mesh (22, 25, 28, 35, 40, 50, 70 and 80 mm). The average value of the CPUEs of goldfish caught was 10 175.48 $g \cdot 10^{-2} \cdot m^{-2}$ for gill-nets, 246.97 $g \cdot h^{-1}$ for fyke-nets and 606.50 $g \cdot min^{-1}$ for electrofishing. The efficiency of electrofishing was not uniform in all periods of the year, the mean CPUEs being highest in spring, when specimens of reproductive age were preferentially caught. Gill-nets yielded abundant catches of goldfish in all seasons, and displayed good sampling efficiency even in winter. With regard to the selectivity of gill-nets, estimated optimum selection lengths for each mesh size were: 11.92 cm, 13.55 cm, 15.18 cm, 18.97 cm, 21.68 cm, 27.10 cm, 37.94 cm and 43.36 cm. The results of this research demonstrate that the various fishing techniques can be effectively combined with the aim of controlling the goldfish population in Lake Trasimeno.

RÉSUMÉ

Biologie halieutique du carassin *Carassius auratus* (Linnaeus, 1758) dans le lac Trasimeno (Ombrie, Italie)

Mots-clés : *sélectivité des filets maillants, espèce invasive, pêche électrique, CPUE*

La biologie halieutique du carassin *Carassius auratus* a été étudiée dans le lac Trasimeno par analyse de sélectivité des équipements utilisables pour contrôler cette espèce invasive. L'échantillonnage a été conduit mensuellement de février 2003 à janvier 2004 par pêche électrique, verveux et filets maillants de différentes tailles de maille (22, 25, 28, 35, 40, 50, 70 and 80 mm). La valeur moyenne des CPUE de carassin était de 10 175,48 $g \cdot 10^{-2} \cdot m^{-2}$ pour les filets maillants, de 246,97 $g \cdot h^{-1}$ pour les verveux et de 606,50 $g \cdot min^{-1}$ pour la pêche électrique. L'efficacité de la pêche électrique n'est pas uniforme suivant les périodes de l'année, les CPUE moyennes sont plus fortes au printemps, quand les individus en âge de se reproduire sont principalement pêchés. Les captures de carassin par filet maillant sont abondantes en toute saison et montrent même une bonne efficacité en hiver. Compte tenu de la sélectivité des filets, les longueurs modales sélectionnées

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par chaque taille de maille sont : 11,92 cm, 13,55 cm, 15,18 cm, 18,97 cm, 21,68 cm, 27,10 cm, 37,94 cm et 43,36 cm. Les résultats de ces recherches montrent que les différentes techniques de pêche peuvent être efficaces en étant combinées pour contrôler la population de carassins du lac Trasimeno.

INTRODUCTION

In the last two centuries, non-indigenous fish species have been introduced into European freshwater systems for purposes of sport, aquaculture and ornament (Welcomme, 1988). Once established, many introduced species expand their geographical ranges within the region of introduction. Such biological invasions have received increasing attention because they have caused significant losses of biodiversity and altered the functioning of ecosystems (Mack *et al.*, 2000; Byers *et al.*, 2002). Introduced species can have both direct and indirect effects, and in some cases can cause major economic damage, irreversible ecological changes and significant public health concerns (Andersen *et al.*, 2004). The goldfish *Carassius auratus* (Linnaeus, 1758) is a cyprinid native to Eastern Asia (Lelek, 1987); as a consequence of human introduction, it is now widespread throughout Europe (Kottelat and Freyhof, 2007), North (Jenkins and Burkhead, 1994) and South America (Gomez *et al.*, 1997), New Zealand and Australia (Department of Fisheries of Western Australia, 2005). The distribution of *Carassius auratus* may, however, be overestimated owing to the erroneous inclusion of many populations of the Prussian carp *Carassius gibelio* (Bloch, 1792) (Kottelat and Freyhof, 2007). The two taxa are probably confused in Italy, too, where the checklist of fish species does not include the Prussian carp (Gandolfi *et al*., 1991).

The goldfish can spread spontaneously through the connections of hydrological networks and its range of distribution in Europe is currently expanding; it easily becomes one of the dominant species in stagnant and slow-running waters. Moreover, it is known as a hazardous species for native fish communities (Crivelli, 1995). The goldfish can change the flow of nutrients in the entire ecosystem by re-suspending nutrients (Richardson *et al.*, 1995), its bottom-sucking feeding methods increasing turbidity (Crivelli, 1995; Cowx, 1997), and can contribute to phytoplankton blooms; furthermore, it seems that the growth of cyanobacteria is stimulated when they pass through goldfish intestines (Kolmakov and Gladyshev, 2003). The principal threat to indigenous fish species, however, is probably competition for food and other resources. It has been reported that the goldfish introduced into Europe affect native fish, such as the carp *Cyprinus carpio* Linnaeus, crucian carp *Carassius carassius* (Linnaeus) and tench *Tinca tinca* (Linnaeus) (Halačka *et al.*, 2003); in addition, pike (*Esox lucius* Linnaeus) may decline in abundance as a result of increased water turbidity (Cowx, 1997).

The fish population in Lake Trasimeno, as in the rest of the River Tiber basin, is compromised by the presence of exotic species (Lorenzoni *et al.*, 2006), of which the goldfish is one of the most abundant. Although managing introduced species is often crucial to maintaining biodiversity and safeguarding the functioning of aquatic ecosystems (Byers *et al.*, 2002), relatively few investigations on the goldfish have been carried out in Italy (Lorenzoni *et al.*, 2007; Pedicillo *et al.*, 2007) and in Southern Europe in general (Tsoumani *et al.*, 2006). In Italy, the species is of no commercial interest and professional fishermen generally avoid catching it. Consequently, very little is known about the effectiveness of the different methods of capture on the individuals that make up the populations of this species. Since ecological factors affect the biological characteristics of fish species, catchability varies in different populations, environments and seasons. Determining the catch rates and selectivity of the various types of fishing equipment is of prime importance for the management of an invasive species in freshwater ecosystems (Louette and Declerk, 2006). The aim of our research was to collect information on the fishery biology of the goldfish, in order to facilitate the design of a plan to reduce the abundance of this species in Lake Trasimeno, as well as other similar environments.

> STUDY AREA

Lake Trasimeno is a lake of tectonic origin situated within the Tiber River basin in central Italy (43°9′11″ N and 12°15′ E). It is the fourth largest lake in Italy (124.3 km^2) and the largest in the Italian peninsula. It has a very modest depth (average depth: 4.72 m; max. depth: 6.3 m; theoretical turnover time: 24 years), so much so that it may be regarded as the largest laminar lake in Italy. The catchment basin displays low permeability and covers an area of 357.98 km^2, about three times greater than the lake surface (Mearelli *et al.*, 1990). Trasimeno is classified as an SPA of the Natura 2000 ecological network in Central Italy, according to BIOITALY (Biotopes Inventory of Italy, Italian ratification of the EU Directives HABITAT 92/43). A Mediterranean climate, with maximum rainfall in autumn and minimum in summer, characterizes this biotope. Its water is supplied by short intermittent streams which tend to dry up in the summer; the seasonal level of the lake is therefore quite variable. In recent years, in which mean rainfall values have been very low, the level of the lake has steadily fallen to more than 180 cm below the hydrometric zero, which is positioned at 257.33 m a.s.l. Owing to the morphologic characteristics of Lake Trasimeno, the water temperature is almost the same as the air temperature, exceeding 30 °C in the summer; thermal stratification is usually absent (Lorenzoni *et al.*, 1993). From a trophic point of view, Lake Trasimeno is classified as mesotrophic (Mearelli *et al.*, 1990). Aquatic macrophytes currently cover large areas of the lake, forming very dense masses, especially in shallow regions. Many phytophilic egg-layers, of which the goldfish is one, congregate in these areas in order to reproduce.

The fish fauna comprises 19 species and is dominated by cyprinids, including tench, carp and rudd *Scardinius erythrophthalmus* (Linnaeus); other common species are eel *Anguilla anguilla* (Linnaeus), European perch *Perca fluviatilis* Linnaeus and sandsmelt *Atherina boyeri* Risso. Today, fishing is still one of the main commercial activities of the local population and, despite a decline in recent years, the number of professional fishermen is still higher than on any other inland lake in Italy. Profound changes have occurred in the composition of the fish community owing to the introduction of exotic species. All the introduced species have adapted well, while the indigenous species have declined in abundance. The goldfish has been found in Lake Trasimeno since the 1990s. After a period of low population density, it gradually increased in number and is currently the dominant species; meanwhile, catches of species of commercial interest, such as tench, carp, pike and eel, have declined (Lorenzoni *et al.*, 2002).

It is not clear which factors have contributed to the success of the goldfish population in the lake. However, in similar ecosystems, environmental degradation has been identified as an important cause (Paschos *et al.*, 2004). Indeed, for some years the environmental condition of Lake Trasimeno has clearly worsened as a result of the progressive reduction in the depth of the water. Another factor which has surely given the goldfish an advantage over species of commercial interest is that it is shunned by professional fishermen.

MATERIALS AND METHODS

Sampling was conducted monthly, from February 2003 to January 2004. Specimens were caught by means of electrofishing and nets set along the perimeter of the lake. Two types of net were used: fyke-nets and gill-nets. The gill-nets were assembled from panels of different-sized mesh (22, 25, 28, 35, 40, 50, 70 and 80 mm, measured from knot to knot), each of which was 1 m high and 50 m long; these nets were positioned for one night near the bottom, perpendicular to the shore. The fyke-nets were positioned for one night in the vicinity of the gill-nets; each fyke-net had a total length of 8 m and a mesh of 20 mm (mouth width: 1.5 m).

Electrofishing was conducted monthly, except in April, when it was conducted weekly. Sampling was carried out from boats by means of 4.5 kW electric stunning devices (model EL63II GI); these devices supplied pulsating D.C. current. Electrofishing has been used to study fish populations in lotic wadable waters for some considerable time, but is seldom used in lentic systems, where it is effectively restricted to the littoral area (Cowx and Lamarque, 1990;

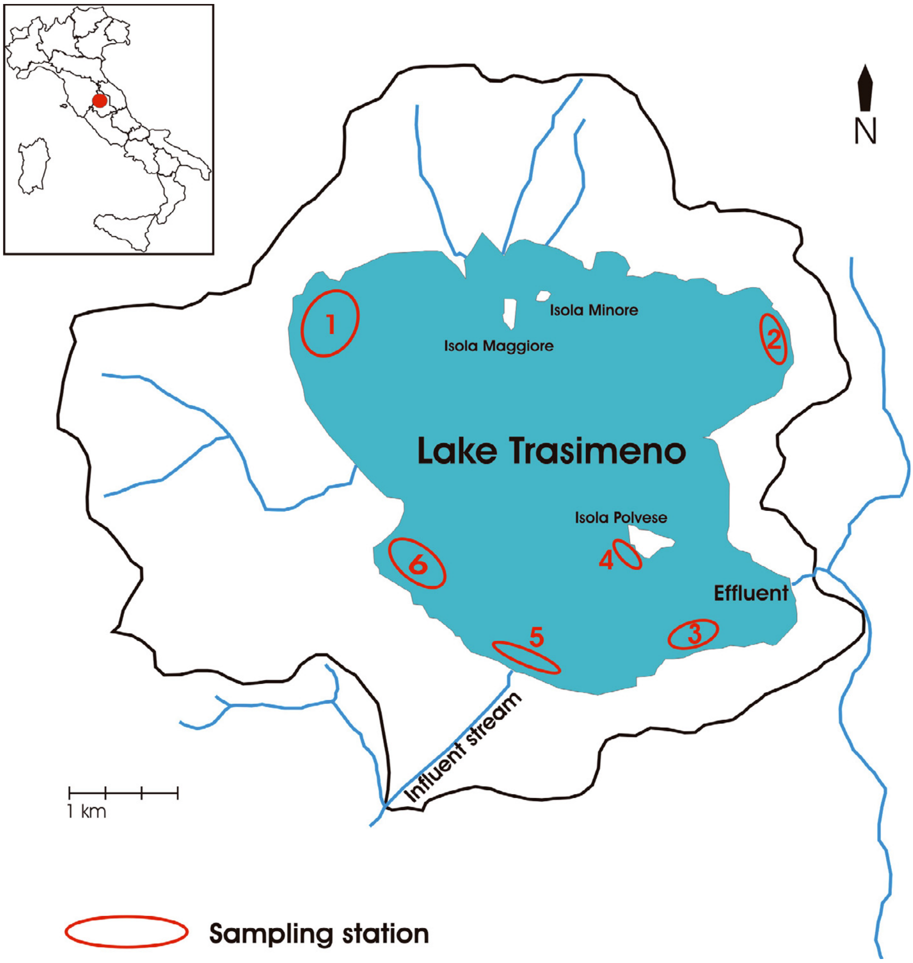

Figure 1
Study area and locations of sampling stations.

Figure 1
Carte du lac et position des stations d'échantillonnage.

Reynolds, 1996). In Lake Trasimeno, however, this technique is more efficient, as pointed out by a previous study (Mearelli *et al.*, 2004), in that the water is shallow in most of the lake. During each sampling session at each of the six stations, a variable number of transects of varying lengths were examined (Figure 1).

The fish caught (expressed as number of specimens and as biomass) were standardized with regard to the "fishing effort" (CPUE = catch per unit effort) (Degerman *et al.*, 1988; Wilderbuer and Kappenman, 1998). For fyke-nets, fishing effort was defined as the duration of sampling time, and CPUEs were expressed as $ind \cdot h^{-1}$ and as $g \cdot h^{-1}$; for gill-nets, fishing effort was calculated in terms of the area of nets (CPUEs = $ind \cdot 10^{-2} \cdot m^{-2}$ and $g \cdot 10^{-2} \cdot m^{-2}$); for electrofishing, fishing effort was the duration of sampling time (CPUEs = $ind \cdot min^{-1}$ and $g \cdot min^{-1}$). The lengths of the sampling areas were measured by a GPS meter.

Whenever necessary, the CPUEs were compared by means of the Kruskall-Wallis non-parametric test.

The size selectivity analyses used the indirect method, which is the most common method of fitting gill-net selectivity curves (Mahon *et al.*, 2000) when the size frequency of the study population is unknown. This method enables selectivity parameters to be estimated by comparing the proportion of fish caught by two different mesh sizes (m_a and m_b) for the same length class (L) (Sparre and Venema, 1992). The natural logarithms of the number of fish

caught per length-group (C_a and C_b) by two slightly different mesh sizes (m_a and m_b) are linearly related to the lengths of the specimens: $\ln (C_b/C_a) = a + b\,L$ where L is the mid-point of the length-class and *a* and *b* are the intercept and slope of linear regression, respectively.
The optimum lengths (Lm_a and Lm_b) for mesh sizes m_a and m_b, the selection factor (sf) and the standard deviation (sd) are then estimated from the following relationships (Sparre and Venema, 1992):

$$Lm_a = -2(am_a/b\,(m_a + m_b));\ Lm_b = -2(am_b/b\,(m_a + m_b));$$

$$sf = -2a/b\,(m_a + m_b);\ sd = (-2a\,(m_a + m_b)/b\,(m_a + m_b))^{1/2}.$$

The common selectivity factor was calculated by applying the following formula:

$$SF = -2\Sigma((a_i/b_i)(m_i + m_{i+1}))/\Sigma((m_i + m_{i+1})^2) \quad \text{for } i = 1 \text{ to } n-1.$$

The common standard deviation (SD) was calculated as the mean value of the single estimate for each consecutive pair of mesh sizes:

$$SD = (1/(n-1)\Sigma\,(2a_i\,(m_{i+1} - m_i))/(b^2(m_i + m_{i+1})))^{1/2}.$$

The optimum length for one mesh size corresponds to a 100% probability of retention and for each mesh size, m was determined from the relationship:

$$Lm = SFm.$$

The probability of capture (P) for a given length L in a gill-net with a mesh size m was determined from the following equation:

$$P = \exp -((L - Lm)^2/2SD^2).$$

The total lengths (TL) of the specimens were measured to the nearest 0.1 mm; individual total weight (W) was recorded to the nearest 0.1 g (Anderson and Neumann, 1996). The age of the fish was determined by means of the microscopic scalimetric method, and validated by means of length-frequency distribution (Bagenal, 1978; Britton *et al.*, 2004). The scales were removed from the left side of the fish, above the lateral line, near the dorsal fin (De Vries and Frie, 1996).
Specimens were assigned to age-classes on the basis of the number of winters that they had lived through before being caught. The date conventionally used as a cut-off between one age-class and the next was 31st December (De Vries and Frie, 1996).

RESULTS

The sample of goldfish was composed of 3111 specimens. The TL, W and age of the specimens analyzed varied between 4.30 and 40.60 cm, 1 and 1137 g, and 0.2 and 7.9 yr, respectively. Eight age-classes were found, with most specimens in the 2+ age-class.
During sampling, 13 species were caught; these are listed in Table I, together with the total number of individuals and biomass of each species. The electric stunning devices captured all 13 species present in the overall sample. With regard to the goldfish, 1673 specimens were caught, for a total biomass of 582.40 kg; goldfish accounted for 48.24% of all specimens caught and 62.63% of the total biomass.
The nets caught nine species of fish; unlike electrofishing, they could not catch top-mouth gudgeon *Pseudorasbora parva* (Schlegel), sandsmelt, carp and bleak *Alburnus alburnus alborella* (De Filippi). With the exception of the carp, these species are of a small size; the fact that they were not caught by the nets seems to justify the mesh sizes used. With regard to goldfish, a total of 1438 individuals were netted, for a total biomass of 476.17 kg; these accounted for 58.08% of all specimens and 73.23% of the total biomass of all nine species netted.

Table I
List of fish species, number (N) of specimens and biomass caught.

Tableau I
Liste des espèces de poisson, nombre (*N*) de spécimens et biomasse capturée.

	Species	*N*	Weight (g)
Goldfish	*Carassius auratus* (Linnaeus, 1758)	3111	1 058 570
Carp	*Cyprinus carpio* Linnaeus, 1758	94	218 203
Tench	*Tinca tinca* (Linnaeus, 1758)	285	112 265
Largemouth bass	*Micropterus salmoides* Lacépède, 1802	563	85 772
Rudd	*Scardinius erythrophthalmus* (Linnaeus, 1758)	487	66 580
Black bullhead	*Ameiurus melas* (Rafinesque, 1820)	166	11 816
Pike	*Esox lucius* Linnaeus, 1758	20	6926
European perch	*Perca fluviatilis* Linnaeus, 1758	133	6311
Eel	*Anguilla anguilla* (Linnaeus, 1758)	35	6042
Pumpkinseed	*Lepomis gibbosus* (Linnaeus, 1758)	184	5871
Sandsmelt	*Atherina boyeri* Risso, 1810	790	1052
Bleak	*Alburnus alburnus alborella* (De Filippi, 1844)	37	342
Top-mouth gudgeon	*Pseudorasbora parva* (Schlegel, 1842)	39	300

The average values of the CPUEs of the goldfish caught by gill-nets were 10 175.48 $g \cdot 10^{-2} \cdot m^{-2}$ and 35.81 $ind \cdot 10^{-2} \cdot m^{-2}$, in terms of biomass and number of individuals, respectively; the fyke nets displayed average CPUE values of 246.97 $g \cdot h^{-1}$ and 1.65 $ind \cdot h^{-1}$ (Table II). With regard to electrofishing, the number of transects was 97, while the average fishing effort (± SD) applied was 10.72 ± 6.17 min, for a length of 387.93 ± 233.31 m. Goldfish were also the species most frequently captured by electrofishing, the average values of the CPUEs, in terms of biomass and number of individuals, being 606.50 $g \cdot min^{-1}$ and 1.98 $ind \cdot min^{-1}$, respectively.

The efficiency of electrofishing was not uniform in all periods of the year. Few fish were caught in winter; specifically, none were caught in December or January, and the biomass caught in February was very low. Mean biomass CPUEs increased in spring, reaching a maximum in May; from June to August they declined and then increased again in autumn (Figure 2). The CPUEs expressed in terms of the number of individuals caught displayed a pattern which was very similar to that of the biomass until August; from September to November, however, the increase in catches in comparison with the previous months was much more marked, the highest mean value of the year being recorded in September. The Kruskall-Wallis non-parametric test showed that the differences in CPUEs among monthly median values were highly significant with regard to both the biomass ($\chi^2 = 26.05$, $p = 0.006$) and the number of individuals ($\chi^2 = 26.82$, $p = 0.004$). The differences between the patterns seen in CPUEs for the biomass and number of individuals are justified by the fact that the mean size of the specimens caught varies according to the sampling season. The characteristics of the specimens caught by means of electrofishing varied throughout the year (Figure 3); in the spring months, when reproduction takes place, older specimens (4+ and 5+) predominated, while in autumn a marked increase was seen in the abundance of younger specimens, including the young of the year (0+), which appeared in catches made by electrofishing from July onwards.

Gill-nets yielded abundant catches of goldfish in all seasons, with no great difference being recorded from one month to another (Figure 4); the average CPUEs reached their highest values in the period preceding reproduction and during reproduction itself. However, the nets also showed good sampling efficiency in winter. The Kruskall-Wallis non-parametric test showed that the differences in CPUEs among months were not significant with regard to either the biomass ($\chi^2 = 10.70$, $p = 0.469$) or the number of specimens caught ($\chi^2 = 18.71$, $p = 0.066$).

With regard to size selectivity, goldfish captured by electrofishing ranged from 4.30 to 40.60 cm TL, averaging (± SD) 23.77 ± 9.35 cm TL; all the age-classes were represented

Table II
Descriptive statistics of the CPUEs.

Tableau II
Description statistique des CPUE.

CPUEs (biomass)	Gill-nets ($g \cdot 10^{-2} \cdot m^{-2}$)			Fyke nets ($g \cdot h^{-1}$)			Electrofishing ($g \cdot min^{-1}$)		
	N values	Mean	SD	*N* values	Mean	SD	*N* values	Mean	SD
Goldfish	84	10 175.48	9733.86	12	246.97	202.88	97	606.5	931.89
Carp	84	0	0	12	0	0	97	253.63	709.63
Tench	84	1388.68	2899.12	12	13.54	20.5	97	45.62	89.35
Largemouth bass	84	520.32	1304.61	12	133.33	456.66	97	39.84	82.74
Rudd	84	2018.21	4319.34	12	1.39	4.81	97	17.13	51.2
Black bullhead	84	363.76	1205.45	12	16.04	15.83	97	3.1	15.32
Pike	84	80.05	648.55	12	0	0	97	3.98	17.24
European perch	84	275.25	1485.69	12	1.99	4.9	97	0.65	2.17
Eel	84	0	0	12	3.47	6.61	97	6.64	25.94
Pumpkinseed	84	214.39	1523.93	12	5.87	9.05	97	0.98	4.51
Sandsmelt	84	0	0	12	0	0	97	1.26	4.41
Bleak	84	0	0	12	0	0	97	0.1	0.63
Topmouth gudgeon	84	0	0	12	0	0	97	0.51	1.90

CPUEs (n. of specimens)	Gill-nets ($ind \cdot 10^{-2} \cdot m^{-2}$)			Fyke nets ($ind \cdot h^{-1}$)			Electrofishing ($ind \cdot min^{-1}$)		
	N values	Mean	SD	*N* values	Mean	SD	*N* values	Mean	SD
Goldfish	84	35.81	36.31	12	1.65	1.48	97	1.98	2.98
Carp	84	0	0	12	0	0	97	0.10	0.28
Tench	84	4.57	8.64	12	0.07	0.13	97	0.17	0.34
Largemouth bass	84	2.18	5.38	12	0.43	1.44	97	0.48	0.90
Rudd	84	15.77	33.58	12	0.01	0.05	97	0.12	0.32
Black bullhead	84	14.17	94.01	12	0.42	0.42	97	0.03	0.11
Pike	84	0.08	0.53	12	0	0	97	0.01	0.05
European perch	84	3.09	16.84	12	0.22	0.67	97	0.05	0.17
Eel	84	0	0	12	0.04	0.08	97	0.03	0.11
Pumpkinseed	84	3.80	22.16	12	0.49	0.80	97	0.04	0.11
Sandsmelt	84	0	0	12	0	0	97	0.75	2.34
Bleak	84	0	0	12	0	0	97	0.02	0.12
Topmouth gudgeon	84	0	0	12	0	0	97	0.05	0.13

in the catches (0+ = 6.21%; 1+ = 24.40%; 2+ = 15.14%; 3+ = 19.56%; 4+ = 16.50%; 5+ = 16.84%; $>$ 6+ = 1.37%).

The fish caught in fyke-nets ranged from 8.70 to 36.70 cm TL, averaging (± SD) 18.70 ± 7.33 cm TL; these nets caught more of the younger fish (1+ = 35.29%; 2+ = 44.12%).

For gill-nets, the length, and therefore the age, of the specimens caught increased with expanding mesh size: (22 mm: 1+ = 61.73%; 2+ = 20.99%) (25 mm: 1+ = 32.47%; 2+ = 45.45%) (28 mm: 1+ = 28.81%; 2+ = 44.07%) (35 mm: 2+ = 41.35%; 3+ = 23.08%) (40 mm: 2+ = 38.32%; 3+ = 29.34%) (50 mm: 3+ = 30.88%; 4+ = 41.18%) (70 mm: 4+ = 30.09%; 5+ = 34.85%) (80 mm: 4+ = 44.12%; 5+ = 55.88%).

The regression slope, intercept and coefficient of optimum length and selectivity parameters (selection factors and standard deviation) were assessed from length frequency distributions for each mesh size combination (Table III). The common selectivity factor (SF) and the common standard deviation (SD) were 5.42 and 5.71, respectively. Estimated optimum selection lengths were: 11.92 cm for 22 mm mesh, 13.55 cm for 25 mm mesh, 15.18 cm for 28 mm mesh, 18.97 cm for 35 mm mesh, 21.68 cm for 40 mm mesh, 27.10 cm for 50 mm mesh,

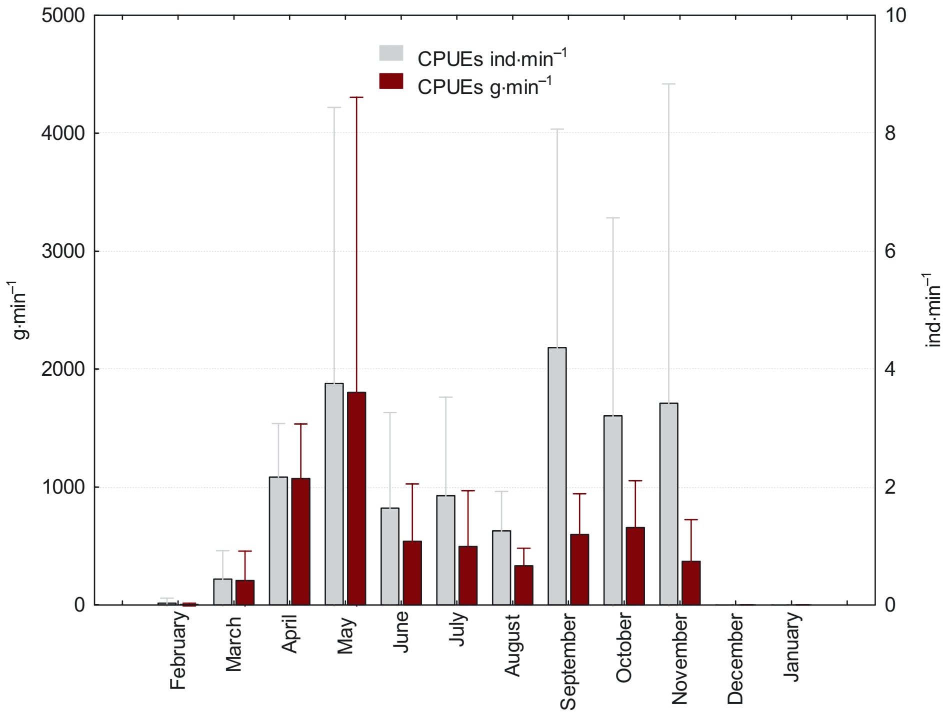

Figure 2
Monthly average values (with confidence limits) of the CPUEs of goldfish yielded by electrofishing.

Figure 2
Valeurs moyennes mensuelles (avec intervalle de confiance) des CPUE des carassins pêchés à l'électricité.

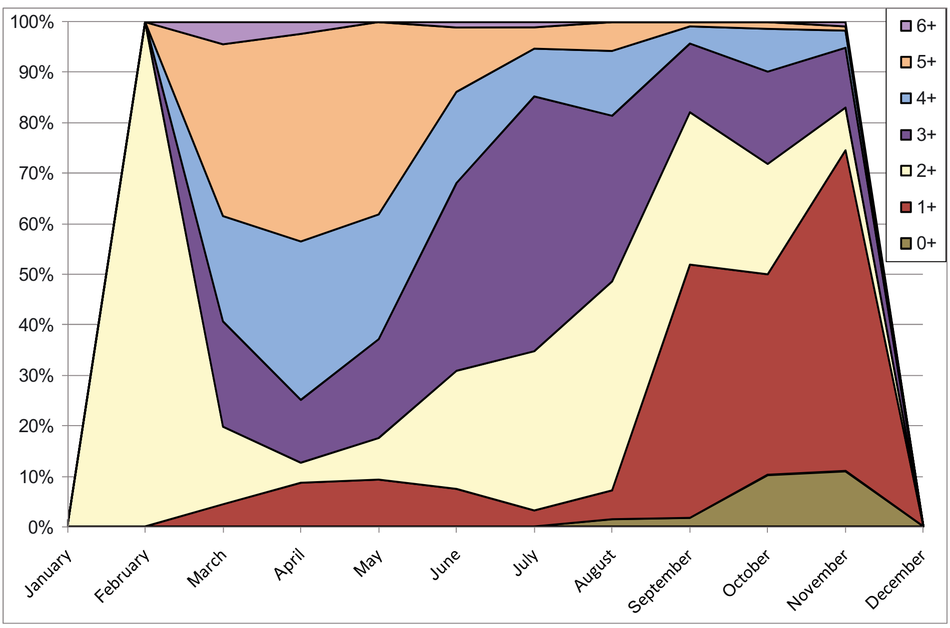

Figure 3
Monthly trend in catches of goldfish made by electrofishing, subdivided by age-class.

Figure 3
Tendances mensuelles dans les captures de carassin par pêche électrique subdivisées en classes d'âge.

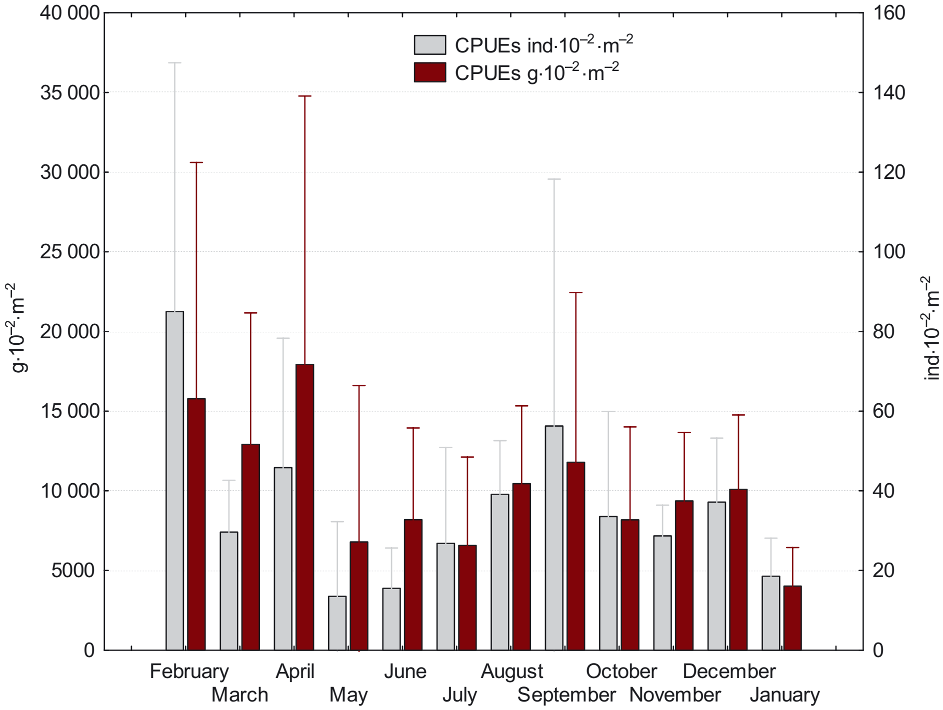

Figure 4
Monthly average values (with confidence limits) of the CPUEs of goldfish yielded by gills-net.

Figure 4
Valeurs moyennes mensuelles (avec intervalle de confiance) des CPUE des carassins pêchés aux filets maillants.

Table III
Selectivity parameters of gill-nets.

Tableau III
Paramètres de sélectivité des filets maillants.

Mesh size		Selectivity parameters						
m_a	m_b	a	b	R^2	Lm_a	Lm_b	sf	sd
22	**25**	–3.617	0.259	48.56%	13.25	15.06	5.94	6.88
25	**28**	–3.798	0.220	72.68%	16.26	18.21	6.51	8.88
28	**35**	–2.596	0.129	33.18%	17.92	18.97	6.40	34.78
35	**40**	–5.023	0.249	48.51%	18.85	21.54	5.39	4.59
40	**50**	–3.663	0.139	34.87%	23.44	27.10	5.86	42.20
50	**70**	–4.880	0.147	60.50%	27.68	38.76	5.54	75.38
70	**80**	–10.337	0.286	78.61%	33.79	38.62	4.83	16.91

37.94 cm for 70 mm mesh and 43.36 cm for 80 mm mesh. The selection curve of gill-nets yielded by the probability of capture (P) equation are shown in Figure 5.
A linear relationship can be seen between total length and the mesh size of the gill-net (m): TL = 11.6055 + 0.3292 m (R^2 = 0.478; p = 0.000).

DISCUSSION

In Lake Trasimeno the statistical records kept by commercial fishermen do not include catches of goldfish, as this species is not marketed. In the 1980s, the total commercial

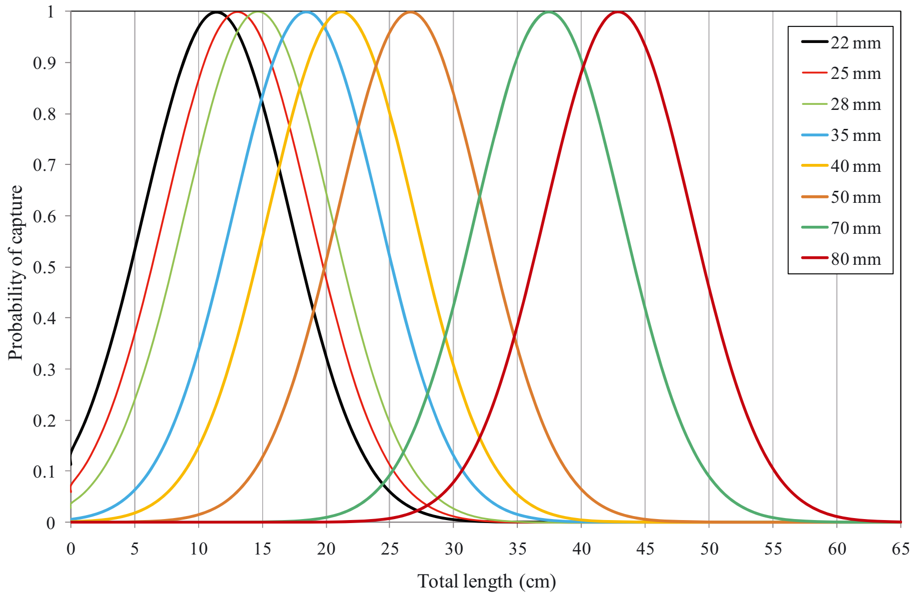

Figure 5
Selectivity curves of gillnets.

Figure 5
Courbes de sélectivité des filets maillants.

yield of the lake was 0.048 t·ha^{-1}·yr^{-1}; in more recent years (2002–2004), however, this value has practically been halved to 0.023 t·ha^{-1}·yr^{-1} (Lorenzoni *et al.*, 2007). At the end of the 1980s, only four species accounted for almost the entire catch: tench (31.05% of total yield), European perch (21.28%), sandsmelt (20.59%) and eel (13.46%). By 2002–2004, the situation had changed markedly: with the exception of the sandsmelt (29.76%), all the above species had dwindled. In those years, in addition to the sandsmelt, the species most frequently caught were, in descending order: tench (21.95%), largemouth bass *Micropterus salmoides* Lacepede (10.39%), eel (10.28%), carp (10.16%), and black bullhead *Ameiurus melas* (Rafinesque) (8.53%). European perch, one of the most valuable species from a commercial standpoint, were among the most heavily penalised species, reaching only 5.07% of the total yield in Lake Trasimeno.

Our data on the catches made by nets confirm that the goldfish population has markedly increased in the last few years. Goldfish were also the species most often captured by electrofishing, the average value of the CPUEs being 606.50 g·min^{-1}. In 1993, a similar monitoring campaign conducted by means of electrofishing did not result in the capture of any goldfish; this indicates that the species, though present in Lake Trasimeno at that time, had not yet reached considerable abundance (Lorenzoni *et al.*, 2007). In another study, conducted in 2001, the average value of the CPUEs of goldfish caught by electrofishing was seen to have reached 327.49 g·min^{-1} (Mearelli *et al.*, 2004).

One of the most important factors in fishery management is knowing the selectivity of the nets used (Louette and Declerk, 2006). Indeed, in the management of invasive species, this knowledge can help to direct efforts towards the capture of those specimens which contribute most to population recruitment. The common selectivity factor for the gill-nets used in the present research was 5.42; this parameter usually varies from 5 to 10 (Ozekinci *et al.*, 2007). The value calculated for the common standard deviation proved to be rather high: 5.71; this may be due to the fact that the goldfish, in addition to becoming entangled in the mesh of the net by the gills, as is usually the case, is also very often caught by the ossified and markedly serrated ribs of the dorsal and anal fins. Consequently, even nets with small meshes catch some large specimens, which would normally escape. Previous research has demonstrated that the goldfish population in Lake Trasimeno is made up almost exclusively of females, which reach sexual maturity after the second winter of life (2+ age-class) at a TL of about 17 cm (Lorenzoni *et al.*, in press). Nets with a 31 mm mesh have the greatest possibility of catching specimens of this length-class.

In managing an invasive species, eradication is obviously the favoured strategy and several studies have demonstrated that this can actually be achieved (Mack *et al.*, 2000; Myers *et al.*, 2000). The chances of successful eradication increase in the case of small, isolated biotopes, in which the possibility of re-colonisation is limited, or in the first stages of invasion (Zavaleta *et al.*, 2001). By contrast, in the case of r-strategist species like the goldfish, in which even a few specimens that escape can rapidly proliferate (Mueller, 2005), complete eradication is highly unlikely. In those cases in which eradication is difficult to achieve, it seems preferable to adopt a control programme (Mack *et al.*, 2000), which may be defined as management action aimed at reducing the density of pest species, in order to limit their impact on pre-existing biocenoses and on commercial activities. This is essentially a sustained-yield operation in localities where landings of unwanted species were formerly absent (Elvira, 2000).

Choosing the best strategy for the management of an invasive species often proves difficult, and in such cases it is necessary to weigh costs/benefits against the probability of success (Myers *et al.*, 2000). Generalization is difficult, as the choices vary according to several aspects, which also regard the economic and social context. Where commercial fishermen operate, a good strategy of control may be to encourage the harvesting of invasive populations, for example by offering financial incentives or encouraging the trade in fish or fish parts (*e.g.* eggs) (Lorenzoni *et al.*, 2007). A secondary aspect also concerns the practical possibilities of utilising mechanical means of control and the knowledge of their true effectiveness in the field (Koehn, 2003). Containment initiatives may also be facilitated by some ethological characteristics of unwanted species, such as, in the case of the goldfish, the tendency of sexually mature specimens to congregate in restricted areas (Paschos *et al.*, 2004). It is exactly because of this characteristic of the goldfish that electrofishing proved to be particularly effective against this species in Lake Trasimeno. Electrofishing is a specific sampling technique for shallow water, and habitat preference among life stages affects their vulnerability to it (Reynolds, 1996); in Lake Trasimeno its efficiency is conditioned by the age of the samples and varies throughout the year. Previous studies have shown that in Lake Trasimeno the reproductive period of the population covers a broad time-span which runs from March to June (Lorenzoni *et al.*, in press), but which reaches its peak in May. Indeed, it is precisely in the spring that electrofishing displays its greatest efficiency, enabling a very large number of specimens of reproductive age to be captured; moreover, its efficiency is enhanced by the tendency of the goldfish to move towards the shore in order to lay eggs and to congregate in large shoals. In subsequent months, overall catches decline and, especially in autumn, electric stunning devices act preferentially on younger individuals, which tend to remain in shallow waters and in the vicinity of vegetation. In winter, the efficacy of electrofishing is practically nil, as specimens move to deeper water and tend to become less active in cold periods.

With a view to managing the goldfish population in Lake Trasimeno, the results of the present study seem to be encouraging, in that they demonstrate that, in favourable situations, this sampling technique can be effectively combined with the use of nets in the containment of this invasive fish population. Electrofishing has some advantages over gill-nets; it causes little injury to the fish captured and exerts modest selectivity with regard to the size of the specimens. Unlike electrofishing, gill-nets can also be utilised in the deepest parts of the lake, and their efficacy remains high throughout the year; however, their use engenders major risks for non-target species (Closs *et al.*, 2003). Increased knowledge of the size and species selectivity exerted by meshes of different sizes, and extension of our analysis to other fish species present in Lake Trasimeno, will enable future goldfish catches to be optimised, thereby reducing the impact of this invader on other species.

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