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The wels catfish *Silurus glanis* Linnaeus, 1758 (Actinopterygii Siluriformes) in Italian waters: a review with first report in the Bolsena lake (Italy)

Emanuele Mancini[1,2], Francesco Tiralongo[2,3], Fabio Collepardo Coccia[4], Daniele Pieracci[2], Enea Tentoni[2], Massimo Ceci[5] & Stefano Cerioni[6]

[1]Italian Fishery Research and Studies Center, Rome 00184, Italy
[2]Ente Fauna Marina Mediterranea, Scientific Organization for Research and Conservation of Marine Biodiversity, Avola, Italy
[3]Department of Biological, Geological and Environmental Sciences, University of Catania, Catania, Italy.
[4]CURSA - University Consortium for Socioeconomic Research and the Environment, via Ravenna 8, 00161 Roma, Italy
[5]Laboratory of Systematic Zoology and Taxonomy - DIBAF-University of Tuscia, Viterbo, Italy
[6]Fishery Local Action Group "Lago di Bolsena", Marta 01010, Viterbo, Italy
*Corresponding author, e-mail: mancini.e@cirspe.it

ABSTRACT The wels catfish *Silurus glanis* Linnaeus, 1758 (Actinopterygii Siluriformes) is the largest freshwater fish in the European waters and is considered a generalist predator capable of rapidly adapting both to new habitat and to new prey sources. This alloctonous species affects various ecological groups and its presence can generate adverse effects on native fish communities. In Italian waters, *S. glanis* was introduced since the first decades of the XX century and to date is reported in several rivers and within some lakes. In August 2020, a single specimen of *S. glanis* was caught by trammel net off Bolsena lake by professional fishermen; the specimen has been donated to the C.I.R.S.Pe. (Italian Fishery Research and Studies Center). In laboratory the individual was identified, photographed, and the stomach content was analyzed. In this work, we report the presence of *S. glanis* in the Bolsena lake, the largest volcanic lake in Europe and besides we provide a systematic review on the presence of the species in the Italian freshwater.

KEY WORDS Invasive species; freshwater; lakes; biological invasions; Italian waters.

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INTRODUCTION

The wels catfish *Silurus glanis* Linnaeus, 1758 (Actinopterygii Siluriformes) is known to be the largest freshwater fish species in the European waters (maximum total length 2.7 m for a weight of 130 kg) and one of the 20 largest freshwater fish species worldwide (Stone, 2007; Boulêtreau & Santoul, 2016). In nature, the species has a potential life span of 60 years (Ladiges & Vogt, 1979).

The wels catfish inhabits large rivers, lakes and coastal brackish waters (salinity <15‰) and its most suitable habitat is still waters, with a preference for deeper traits (Wheeler, 1969; Greenhalgh, 1999; Copp et al., 2009; Cucherousset et al., 2018). The predatory activity, due to the scarcely developed eyesight (Bruton, 1996), is carried out by relying mainly on the sense organs of touch and taste (long sensory barbels) (Mihalik, 1995). This feature allows wels catfish to hunt effectively even in poor visibility conditions. Despite the opportunistic and variable diet (Copp et al., 2009), the species can be considered predominantly piscivorous, a feeding behavior adopted by this catfish once it exceeds 30 cm in length (Rossi et al., 1991). Mainly active at night and for short periods of time, wels catfish demonstrates a prevailing sedentary lifestyle (Slavik et al., 2007; Brevé et al., 2014; Slavik et al., 2014). However, it can vary its feeding strategies based on seasonal variations of the enviromental factors such as water turbidity and temperature, resulting more active during warm water periods (Capra et al., 2014) and showing a thermal optimum of 25–27°C (Copp et al., 2009). During the cold months, this species hibernates inside holes and cavities located in river beds; in lakes, *S. glanis* inhabit muddy substrates and is generally present in the lower third of the water column (Lelek et al., 1964; Lelek, 1987). In its native range, reproduction takes place in late spring-early summer, when the water temperature reaches 18–22 °C (Mohr, 1957; Lever, 1977; Shikhshabekov, 1978). The reproduction phase is preceded by an up-stream migration to the spawing sites wich are mainly represented by shallow vegetated river areas, lake shores or flood plais (Berg, 1949; Wheeler, 1969). Both males and females become sexually mature at the age of 3–4 years and they pair up during the migration phase (Copp et al., 2009). The spawing, that generally occours at nigth, is carried out on a nest previously realized by the male (Mihalik, 1982). Females exhibit high fecundity, laying up to 33.000 eggs/kg of body weight (Lever, 1977) and the males carry out parental care (Maitland & Campbell, 1992). This catfish affects various ecological groups with its presence, and it is known to be a generalist predator that is capable of rapidly adapting to new prey sources (Carol et al., 2009; Vejřík et al., 2017; Haubrock, 2021), with strong adverse effects on native fish communities (Copp et al., 2009). Moreover, it is highly tolerant to environmental factors, such as variations in oxygen concentrations (Mihálik, 1995), changes in water temperature (Hilge, 1985) and pollution (Lelek, 1987) and shows high invasive capabilities (Hilge, 1985; Copp et al., 2009).

In the European freshwater only two species of the family Siluridae are presents: *Silurus glanis* and *S. aristotelis* German, 1890, the latter is reported only in Greece. *Silurus glanis* is native to Eastern Europe and Western Asia (Lever, 1996) but in the last decades this species has undergone a rapid increase in population size and distribution in Western European water due to angling and aquaculture activities (Elvira & Almodovar, 2001; Keith & Allardi, 2001; Copp et al., 2009; Cunico & Vitule, 2014). Indeed, the species is a sport fish in some countries (e.g., France, Italy, Spain, UK) and considered a delicacy in others (e.g., Hungary, Poland, Slovakia, Lithuania), where it is exploited for its flesh (tender white meat), skin (for leather and glue production) and eggs (for caviar). *Silurus glanis* has been used in aquaculture for more than 100 years and the economic importance of this species has increased in recent years especially in many Central and Eastern European countries (Proteau et al., 1993; Paschos et al., 2004). The rise in commercial interests of wels catfish has led to a proliferation of scientific articles on its growth, feeding diets, reproduction, manipulation and management of the genome (Schlumberger et al., 1995; Adamek et al., 1999; Triantafyllidis et al., 2002; Alpe et al., 2004).

Thanks to these features, this invasive species has been introduced into a number of countries such as the UK, Spain, Cyprus, Algeria, Croatia, Syria, Kazakhstan, Tunisia and re-introduced after a long absence to previously native distributions in parts of Belgium, the Netherlands and France (The FAO Database of Introduced Aquatic Species - DIAS (FAO, 2013).

In Italian waters, it was introduced since the first decades of the XX century (Manfredi, 1957) and the first case of acclimatization was observed in the Po River (Gandolfi & Giannini, 1979). Subsequently this species spread throughout the Italian peninsula with diverse impacts on native and also newly introduced species (Castaldelli et al., 2013). To date, the presence of wels catfish in Italy is reported in several rivers and within some lakes: Adda river (Manfredi et al., 1957), Po river, Stella river, Isonzo river (Gandolfi & Giannini, 1979; Specchi & Pizzul, 1994), Sile river (Boldrin & Rallo, 1980; Mecatti, & Cecchi, 2010) Ticino river (Galli et al., 2003), Arno river (Nocita, 2002; Gualtieri & Mecatti, 2005), Po di Volano (Castadelli et al., 2013), Volturno river (De Bonis, 2015), Tiber river (Tancioni et al., 2009; Lorenzoni et al., 2010), Garda lake (Confortini et al., 1997), Scandarello lake (Gelosi et al., 1998; Gelosi & Colombari, 2004), Massaciuccoli lake (Baldaccini & Ercolini, 2006; Ercolini, 2015), Maggiore Lake (Volta & Jepsen, 2008).

In this work, we report the presence of *S. glanis* in the Bolsena lake, the largest volcanic lake in Europe and besides we provide a systematic review on the presence of the species in the Italian freshwater.

MATERIAL AND METHODS

Study area

The investigated area is located in Central Italy, Latium region, 50 km east of the Tyrrhenian Sea, in the geological Pleistocene Volsini volcanic district (age 0.8–0.09 million years). The Bolsena lake (Fig. 1) is one of the largest lakes in Italy and the largest lake of volcanic origin in Europe according to the total volume of the water body (9.2 km^3). This lake, which was formed within a volcanic caldera, covers an area of 448 km^2 and is located at a altitude of 305 m; its watershed has a mean height of 490 m a.s.l. and a maximum height of 690 m a.s.l. (Poggio Torrone). The lake has a circular shape, of almost uniform width all-round the lake. The length of the coastline is 48 km and the lake has a maximum depth of 226 m. The area of the lake is 113.9 km^2 draining a catchment area of 159 km^2 only. The Bolsena lake has no natural tributaries but one single outlet at the southern shoreline (Marta River). In fact, the lake is fed only by springs coming from the hydrographic basin and by two small ditches, the Arlena ditch and the Ponticello ditch, which are drained in the summer.

In the territory of the Bolsena lake, thanks to its valuable naturalistic characteristics, there are 5 Natura 2000 sites: 3 ZSC sites (ZSC Lago di Bolsena - IT60100007, ZSC Isola Bisentina and Martana - IT6010042, ZSC Fiume Marta - IT6010020); the SPS of Lago di Bolsena and isole di Bisentina e Martana (IT6010055) and the ZSC-ZPS Monti Vulsini - IT6010008).

The ichthyofauna of the lake is most represented by the species: European eel *Anguilla anguilla* (Linnaeus 1758), sand loach *Cobitis bilineata* Canestrini, 1865, common carp *Cyprinus carpio* Linnaeus, 1758, goldfish *Carassius* sp., black bullhead *Ameiurus melas* (Rafinesque, 1820), pike *Esox* spp. Linnaeus, 1758, European whitefish *Coregonus lavaretus* Linnaeus, 1758, eastern mosquitofish *Gambusia holbrooki* Girard, 1859, bigscale sand smelt *Atherina boyeri* Risso, 1810, threespine stickleback *Gasterosteus aculeatus* Cuvier, 1829, largemouth bass *Micropterus salmoides* (Lacèpede, 1802), tench *Tinca tinca* (Linnaeus, 1758), rudd *Scardinius erythrophthalmus* (Linnaeus, 1758), Italian chub *Squalius squalus* (Bonaparte, 1837), pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758), European perch *Perca fluviatilis* Linnaeus, 1758, grey mullet *Mugil cephalus* Linnaeus, 1758 and sand goby *Knipowitschia panizzae* (Verga, 1841). Historically in Lake Bolsena/River Marta catchment, other species native to the Tuscany-Latium district such as South European roach *Sarmarutilus rubilio* (Bonaparte, 1837), Tiber barbel *Barbus tyberinus* Bonaparte, 1839 and Arno goby *Neogobius nigricans* (Canestrini, 1867), are also recorded.

About 40 fishing boats are active in the lake, hosting 65 professional fishermen who use multiple fishing gears based on the target species: fly gillnets, circulating nets, trammel nets, bertovello, filaccioni and cocullo. The most fished and marketed target species are whitefish, eel, pike, carp, tench, smelt and perch.

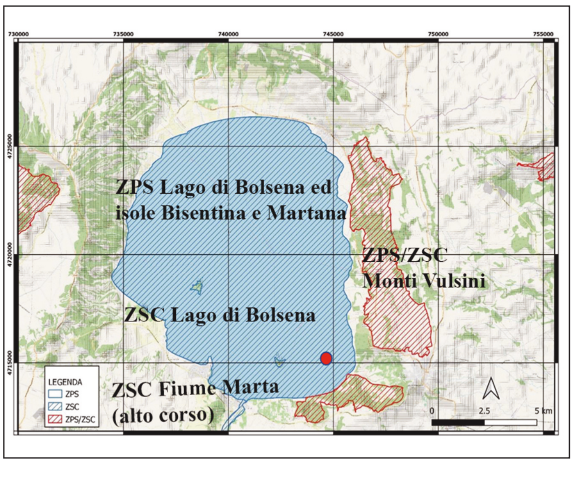

Figure 1. Map of Bolsena lake with location of fishing point (red point).

Samples

On 20th August 2020, a single female specimen of *S. glanis* was caught by trammel net, off Bolsena lake. The species was caught at depth of about 35 m in a locality named "Il Pinzale", an area located near the town of Monte Fiascone (42.55239N; 11.97354E) (Fig. 1). The specimen was photographed, preserved in 4% buffered formalin and deposited in the zoological collection of Ente Fauna Marina Mediterranea with code #EFMM-200920.

Stomach content was analyzed under a Leica APO 8 stereomicroscope. The entire content was sorted and identified to the finest taxonomic level possible (i.e., species), also depending on the level of digestion of the prey. All prey categories were enumerated, and their wet weight recorded to the nearest mg (0.001 g) after superficial drying with absorbing paper.

A systematic review on the main studies on the records of the species in Italian waters was performed (Table 1, Fig. 4). All the literature exanimated and reported in Tab. 1, overall summarizes all the records of *S. glanis* in Italian freshwaters.

RESULTS

The species, due to its morphology and meristics, was identified following Kottelat & Freyhof (2007). In particular, we analyzed the number of anal soft rays and the number of the flexible barbs, which protrude below the lower jaw. The number of flexible barbels is an essential recognition character because it allows to distinguish *S. glanis* (4 barbs) from the only other European species, the Aristotle's catfish *S. aristotelis* (2 barbs). The specimen analyzed was long 42.2 cm for a total weight of 504.7 g. Body elongate and laterally compressed (Fig. 2). Head broad with triangular shaped and characterized by the presence of small eyes and a large mouth (Figs. 3 , 4). Two long, slender and flexible cartilaginous barbs on the upper jaw and four short barbs which protrude below the lower jaw (Fig. 3 B). Pectoral fins (16 rays) sit directly behind the gill covers to the base of the ventral fins. Dorsal fin very small (5 rays, first hard and the other soft) and located in the first third of the body. Anal fin elongated, with 87 rays. Caudal fin short and rounded (Fig. 2). Body pigmentation dark along its back with marbled sides, with a greyish-white belly (Fig. 2).

The analysis of the stomach contents showed the exclusive presence of fishes. In total, 5 individuals were found (identified) for a total of 8.756 g weight: 2 juveniles individuals of *Lepomis gibbosus* Linnaeus, 1758, 1 juveniles individuals of *Micropterus salmoides* Lacépède, 1802 and 2 individuals of *Atherina* sp.

DISCUSSION AND CONCLUSIONS

Until now, *S. glanis* had never been reported in the Bolsena lake and its introduction could lead to an alteration of the trophic chains of the lake and a decrease in the local ichthyofauna with consequent damage to the fishing activities. The Bolsena lake, unlike other Italian lakes, is characterized by the presence of a very rich ichthyofauna. There are many native insectivorous and herbivorous species (i.e., *T. tinca*, *S. squalius*, *Scardinius* sp.) but there are also predators such as pike and eel. Other species have been introduced in the last few years for fishing interests (i.e., *Gambusia holbrooki*) while others have been accidentally introduced as in the case of *Lepomis macrochirus*, a voracious predator of eggs and fry (Mattioli et al., 2017). The wels catfish has adapted to living in acquatic enviroments with poor visibility (Bruton, 1996) and locates its prey thanks to multiple receptors and gustatory organs on its body surface (electro-receptor system, barbels, lips, skin of the body and head, etc.) and also uses complementary olfactory sacs which represent the main character used in research of food (Devitsina & Malyukina, 1977; Bretschneider, 1974). This fish has very small eyes but has developed a very efficient auditory sistem connected to the swim bladder and formed by vertebrae which developed together with the Weber apparatus (Copp et al., 2009; Mihalik, 1995). *Silurus glanis* exploits the smell of prey in its hunting actions, especially if they are stressed or injured (Malyukina & Martemyanov, 1981), and can detected their hydrodynamic and chemical traces (Pohlmann et al., 2001). Thanks to these characteristics, the wels catfish preys mainly at night and its predatory activity intensifies from sunset to dawn (Anthhouard et al., 1987). Wels catfish could in the future be a real threat to the ichthyofauna of Bolsena lake. In fact this

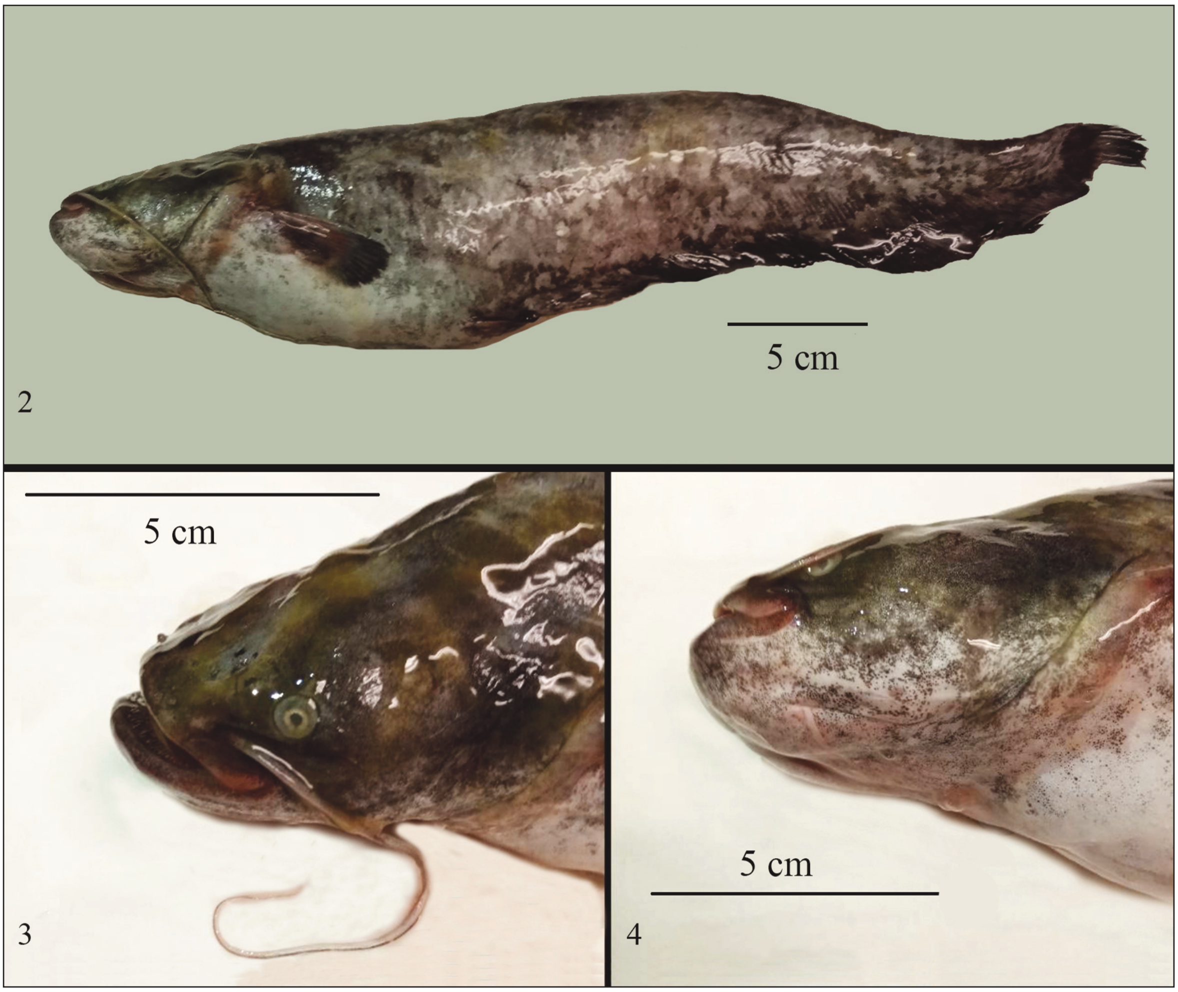

Figure 2. *Silurus glanis*. Lateral view of whole animal. Figure 3. *Silurus glanis*, dorsal view of head. Figure 4. *Silurus glanis*, latero-ventral view of head.

species is considered an omnivorous and opportunistic predator capable of adapting its diet to the species available in its hunting habitat (Omarov & Popova, 1985; Stolyarov, 1985). It was observed that specific diversity of *S. glanis* prey is greater than that of *Sander lucioperca* (Linnaeus, 1758) and *E. lucius*. Moreover, the wels catfish generally makes a more efficient but less selective exploitation of prey (Bekbergenov & Sagitov, 1984; Mihàlik, 1995). In addition, due to its large size, *S. glanis* is capable to bypass the size-refuge (Cucherousset et al., 2012) which normally prevent the predation of native prey such as tench or rudd, and could represent a future threat for local cyprinids populations (Gandolfi et al., 2017).

Silurus glanis also preys on relatively small fish species in relation to the width of its mouth (Wysujack and Mehner, 2005) and evident dietary variation has been observed based on its age classes and size. Among the most common prey of *S. glanis* (some of which are present in the Bolsena lake) can be counted: *A. anguilla*, *Abramis brama* (Linnaeus, 1758), *Barbus* spp., *Carassius* spp. (Linnaeus, 1758), *Cyprinus carpio* Linnaeus, 1758, *Chondrostoma* spp., *Rutilus* spp., *Alburnus alburnus* (Linnaeus, 1758), *T. tinca*, *S. lucioperca*, *Perca fluviatilis* Linnaeus, 1758, *Oncorhynchus mykiss* (Walbaum, 1792), *A. melas*, *Atherina* spp. and some species typical of brackish and transitional environments such as Mugilidae, *Neogobius* spp. and *Alosa* spp. (Copp et al., 2009). The fact that we have found in the stomach contents the presence of two species particular abundant in the lake and not previously observed in bibliography (*M. salmoides* and *L. gibbosus*) could suggest that the species has already adapted to prey on the local ichthyofauna. *Silurus glanis* varies its diet during its growth phases: the juveniles (4–34 mm) feed exclusively on invertebrates such as diptera, beetles, chironomids, hemiptera and mysida, cladocera, oligochetes, amphipods and copepods (Bruyneko, 1971; Benkbergenov & Sagitov, 1984; Orlova & Popova, 1987); once the length of 5–12 cm is reached,they begin to prey on ichthyofauna and vegetal debris (Theouov & Gousseva, 1977; Stoljarov 1985; Orlova & Popova, 1987); up to 30 cm they prey mainly on cyprinids and shrimps (Bruyenko, 1971; Orlova & Popova, 1987); exceeding 30 cm, as adults, they become unselective and begin to feed on shrimps and many species of fish and over 47 species have been observed in the stomach contents analyzed in previous work (Abdurakhmanov & Kasymov, 1962; Bruyenko, 1971; Orlova & Popova, 1976, 1987; Mukhamediyeva & Sal'nikov, 1980; Bekbergenov & Sagitov, 1984; Omarov & Popova, 1985; Stolyarov, 1985; Pouyet, 1987; Mamedov & Abbasov, 1990; Czarnecki et al., 2003; Bora & Gűl 2004; Wysujack & Mehner, 2005; Carol, 2007). In addition, exceptional preys are represented by small mammals and birds (Wheeler, 1969; Lever, 1977; Greenhalgh, 1999; Czarnecki et al., 2003).

In our specimen, which can be considered a small adult, the exclusive presence of local ichthyofauna was found, mainly represented by the Centrarchidae family, particularly abundant in Bolsena lake. This finding is in contrast with Copp et al. (2009) which found a great abundance of cyprinids. These observations would confirm that *S. glanis* is a non-selective predator which is adapted to prey on the most abundant local species (Copp et al., 2009). Before De Santis & Volta (2021), the trophic characteristics of this species had been mainly

Figure 5. Distribution of *Silurus glanis* in the main Italian lake and river basins (red circle: current work, Bolsena Lake).

analyzed in eutrophic basins and rivers; this work, carried out in the Lake Maggiore (considered an oligotrophic basin like the Bolsena Lake) showed that *S. glanis* can exploit both pelagic and coastal habitats using the trophic resources of both environments. Furthermore, this study highlighted that *S. glanis* exploit environmental resources according to the different age groups and according to the seasonal thermal variations of the lake. The wels catfish is a species that can be easily introduced with both voluntarily and accidentality ways (Arlinghaus & Mehner, 2003; Hickley & Chare, 2004; Clavero & García-Berthou, 2006; Valadou, 2007; Copp et al., 2009) and the causes of its arrival in Bolsena lake are still to be clarified and require further studies. Following its introduction, this large predator establishes itself very easily and previous studies have pointed out that it is favored in warmer climates (e.g., Mediterranean climate) (Crivelli, 1995),. This could lead to a future increase of individuals in the lake. Furthermore, the dispersion of the species is favored by hydrological events such as river floods (Slavìk et al., 2007) and this factor could represent both the cause of its introduction into the lake and the way in which *S. glanis* will expand its range in the environments adjacent to Bolsena lake. This species produces relatively few eggs in relation to its body mass (Kolar & Lodge, 2002) and its spread rate is still uncertain (Lelek & Libosvàrsky, 1960; Valadou, 2007; Copp et al., 2009) but it has been observed that its expansion is facilitated by the presence of artificial canals (Penil, 2004). Its natural dispersion is generaly slow and it is probably strictly dependent on both environmental characteristics of the introduction area and to the density of individuals (Copp et al., 2009). The Marta river represents one of the major concerns related to the expansion of the wel catfish in the areas adjacent to Lake Bolsena. Furthermore, this river has already undergone anthropogenic alterations and is characterized by a low number of indigenous predators (Ciccotti et al., 2014); the introduction of *S. glanis* in its waters could contribute to alter and compromise the integrity of their autochthonous fish populations, e.g., varione *Telestes muticellus* (Bonaparte, 1837), South European roach, Arno goby and Tiber barbel (Copp et al., 20009; Sarrocco et al., 2012). Being an opportunistic and not very selective predator, it has often proved to be dangerous or native species and its impact on the ecosystem is greater

Reference	River basin	Lake basin
Manfredi, 1957	Adda	
Gandolfi & Giannini, 1979	Po	
Specchi & Pizzul, 1994	Stella	
Specchi e Miccoli, 1970	Isonzo	
Boldrin & Rallo, 1980	Sile	
Confortini, 1997		Garda lake (VR)
Castaldelli et al. 2013	Po di Volano (FE)	
Gelosi et al., 1998; Gelosi & Colombari, 2004		Scandarello (RI)
Galli et al., 2003	Ticino	
Mancini et al., 2006		
Nocita, 2002; Gualtieri & Mecatti, 2005	Arno	
Baldaccini & Ercolini 2006; Ercolini 2015		Massacciucoli lake
De Bonis, 2015	Volturno	
De Santis & Volta, 2021	Reno	
De Santis & Volta, 2021	Serchio	
De Santis & Volta, 2021	Aterno-Pescara	
De Santis & Volta, 2021	Canalbianco	
De Santis & Volta, 2021	Ombrone	
Tancioni et al., 2009; Lorenzoni et al., 2010; De Santis & Volta, 2021	Tevere	
De Santis & Volta, 2021	Adige	
De Santis & Volta, 2021	Tagliamento	
Volta & Jepsen, 2008		Maggiore lake

Table 1. Presence of *Silurus glanis* in the main Italian lakes and basins.

in areas that have undergone alterations and anthropogenic impact (Copp et al., 2009). In addition, the wels catfish may represent a vector for the introduction of new pathogens and parasites (e.g., *Trichodina* sp., *Myxosporea myarii*, *Leptorhynchoides plagycephalus* and *Pseudotracheliastes stellifer*) which could adversely affect the health of local species (Bauer, 1991; Copp et al., 2009). It is important to underline, however, that some previous studies indicate that *S. glanis* is not to be only considered a voracious predator but also an opportunistic scavenger and that as such it does not always represent an insurmountable threat for the native ichthyofauna (Copp et al., 2005, 2009; Rodriguez-Labajos, 2006). Moreover, in some studies, this species is indicated as a good controller for some cyprinid species (Raat, 1990; Mehner et al., 2001; Valadou, 2007; Copp et al., 2009).

To date, this species is present in most of the major basins of northern and central Italy and its presence has been reported in some large rivers of southern Italy (De Santis & Volta, 2021) (Table 1; Fig. 4). This work represents the first report of *S. glanis* in Bolsena lake and indicates that this species is expanding in the freshwater environments of Latium. Furthermore, the fact that Lake Bolsena has no natural tributaries, but a single outlet, may favor the hypothesis that this report is linked to a case of voluntary introduction. The presence of *S. glanis* in the lake represents a potential threat for the lake biodiversity and could compromise in the future the conservation of local natural resources.

The continuous monitoring of the presence/increase of this species in the basin and new species management programs are essential in order to establish its effective settlement in the lake and also to limit its expansion in the neighboring areas.

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