

Non-indigenous invertebrates, fish and macrophytes in Lake Garda (Italy)

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ABSTRACT

As observed in many countries, lakes are involved in an important process of colonization by non-indigenous species (NIS). Since 1725, 37 species of non-indigenous fish, invertebrates and macrophytes have been recorded in Lake Garda, the largest Italian lake. This phenomenon is particularly important for invertebrates and macrophytes, as their pathways of introduction are accidental. Recently among the 100 Worst Invasive Alien Species in Europe, the invertebrates *Corbicula fluminea*, *Dikerogammarus villosus* and *Procambarus clarkii*, and the macrophytes *Lagarosiphon major*, *Elodea nuttallii* and *Elodea canadensis* have been recorded in Lake Garda. In order to define the present status of non-indigenous species in Lake Garda, published and unpublished data were reviewed.

Key words: invasive species, lakes, xenodiversity

1. INTRODUCTION

There is a large consensus today that invasive non-indigenous species are one of the most important direct drivers of biodiversity loss and change in ecosystem services (i.e. provision of water, recreational benefits and nutrient cycling), together with habitat change, climate change, overexploitation of species and pollution (Millennium Ecosystem Assessment 2005).

Biotic exchange is relatively more important for aquatic (especially lakes) than for terrestrial ecosystems because of extensive intentional (e.g., fish stocking) and unintentional (e.g., ballast water) release of organisms (Sala *et al.* 2000; Beeton 2002). As observed in many countries, lakes in particular are involved in an important process of colonization by non-indigenous species, which seldom show invasive behaviour.

Lake Garda, the largest Italian lake (volume = 49 km³, surface = 368 km² and maximum depth = 350 m) is one of the deep Insubrian lakes south of the Alps along with lakes Iseo, Como, Lugano and Maggiore. The lake is included in theILTER network (Italian Long Term Ecological Research) and its trophic condition ranges from oligotrophy to mesotrophy (Salmaso 2005; Salmaso *et al.* 2009).

In this paper we reviewed both the scientific and grey literature together with our own unpublished data, in order to define the present status of non-indigenous species in Lake Garda.

2. RESULTS

No comprehensive studies have been conducted on Lake Garda invertebrates; only specific studies related

to Bivalves and Gastropods are available (Giusti & Oppi 1972; Mariani *et al.* 1980). Most macrophyte studies are outdated or related to specific lake areas (Bianchini *et al.* 1974; Autorità di Bacino del Fiume Po 2000; Ludovisi *et al.* 2004); a recent study however, related the optical characteristics of the lake bottom with the presence/absence and degree of macrophyte coverage using remote sensing (Fazioli 2006). For fish fauna only data provided by fishermen are available.

Generally data tend to be qualitative, and only some studies were based on quantitative samplings (Bianchini *et al.* 1974; Franchini 1978; Mariani *et al.* 1980; Autorità di Bacino del Fiume Po 2000; Nardi & Braccia 2004; Casellato *et al.* 2006).

The bibliographic review and our recent records showed that since 1725, 19 non-indigenous fish (including 3 non-acclimatized species), 15 invertebrates and 3 macrophytes species have been observed in the lake, for a total of 37 species (Tab. 1). Since 2000, eleven new species have arrived in the lake, showing an increasing trend of introduction (Fig. 1).

The mode of introduction differs between organisms: for fish fauna and macrophytes it is mainly intentional, while for invertebrates introduction is unintentional (Fig. 2). According to Gherardi *et al.* (2008) the main vector of fish introduction is release, while for macroinvertebrates it is transport. For macrophytes introduction is mainly a consequence of imported ornamental plants for aquaria and ponds. Aquatic plants are in general less frequently released deliberately but more often escape unintentionally or are stowaways attached to river/canal traffic (Hulme *et al.* 2008).

Tab. 1. Non-indigenous fish, invertebrates and macrophytes recorded in Lake Garda since 1725. The year of first record, reference and inclusion in the List of 100 worst invasive species for Europe (DAISIE, 2009) (D) and for the world (IUCN; Lowe *et al.* 2000) (I) are reported. * Atlantic lineage; ** In Varone Stream mouth (Lake Garda's tributary).

Phylum (Division)/Class	Family	Species	D	I	Year	Reference	Presence
Fish							
Chordata/Osteichthyes	Centrarchidae	<i>Micropterus salmoides</i> Lacépède, 1802		x	1920	Malfer 1927	present
Chordata/Osteichthyes	Centrarchidae	<i>Lepomis gibbosus</i> (Linnaeus, 1758)			1917	Malfer 1927	present
Chordata/Osteichthyes	Clariidae	<i>Clarias anguillaris</i> (Linnaeus, 1758)			1992	Confortini 1997	occasional
Chordata/Osteichthyes	Cyprinidae	<i>Ctenopharyngodon idellus</i> (Valenciennes, 1844)			1993	Confortini 1997	occasional
Chordata/Osteichthyes	Cyprinidae	<i>Carassius auratus</i> (Linnaeus, 1758)			1950s	Malesani 1973	present
Chordata/Osteichthyes	Cyprinidae	<i>Cyprinus carpio</i> Linnaeus, 1758		x	1725	Marsili 1725	present
Chordata/Osteichthyes	Cyprinidae	<i>Rhodeus sericeus</i> (Pallas, 1776)			2000	Personal unpublished data	present
Chordata/Osteichthyes	Cyprinidae	<i>Pseudorasbora parva</i> (Schlegel, 1842)		x	1996	Confortini 1997	present
Chordata/Osteichthyes	Cyprinidae	<i>Rutilus rutilus</i> (Pallas, 1776)			2005	Personal unpublished data	occasional
Chordata/Osteichthyes	Ictaluridae	<i>Ictalurus melas</i> (Rafinesque, 1820)			1930	Malesani 1973	present
Chordata/Osteichthyes	Percidae	<i>Stizostedion lucioperca</i> (Linnaeus, 1758)			1970s	Confortini 1997	occasional
Chordata/Osteichthyes	Percidae	<i>Gymnocephalus cernuus</i> (Linnaeus, 1758)			1995	Confortini 1997	occasional
Chordata/Osteichthyes	Poeciliidae	<i>Gambusia holbrooki</i> Girard, 1859			1965	Malesani 1973	occasional
Chordata/Osteichthyes	Salmonidae	<i>Oncorhynchus mykiss</i> (Walbaum, 1792)			1891	Tomasi 1963	now disappeared
Chordata/Osteichthyes	Salmonidae	<i>Oncorhynchus kisutch</i> (Walbaum, 1792)			1975	Oppi 1988	now disappeared
Chordata/Osteichthyes	Salmonidae	<i>Salmo (trutta) trutta</i> Linnaeus, 1758*			1970s	Oppi 1974	abundant
Chordata/Osteichthyes	Salmonidae	<i>Coregonus lavaretus</i> (Linnaeus, 1758)			1918	Malfer 1927	abundant/invasive
Chordata/Osteichthyes	Salmonidae	<i>Salvelinus fontinalis</i> (Mitchill, 1814)		x	1950s	Oppi 1988	now disappeared
Chordata/Osteichthyes	Siluridae	<i>Silurus glanis</i> Linnaeus, 1758			1988	Confortini 1997	present
Invertebrates							
Cnidaria	Olindiidae	<i>Craspedacusta sowerbyi</i> Lankester, 1880			2008	Personal unpublished data	present
Platyhelminthes/Turbellaria	Dugesidae	<i>Dugesia tigrina</i> (Giard, 1985)			1971	Bonomi 1974	present
Nematoda/Secernentea	Anguillicolae	<i>Anguillicola crassus</i> Kuwahara, Niimi & Itagaki, 1794	x		1995	Confortini 1997	present
Anellida/Oligochaeta	Tubificidae	<i>Branchiura sowerbyi</i> Bebbard, 1892			1970	Bonomi 1974	present
Anellida/Hirudinea	Piscicolidae	<i>Piscicola geometra</i> (Linnaeus, 1758)			1894	Garbini 1895	present
Mollusca/Gastropoda	Ancylidae	<i>Ferrissia wautieri</i> (Mirrolli, 1960)			2007	Cianfanelli <i>et al.</i> 2007	present
Mollusca/Gastropoda	Hydrobiidae	<i>Potamopyrgus antipodarum</i> (J.E. Gray, 1843)**			1990	Ferrieri 2000	present
Mollusca/Gastropoda	Physidae	<i>Haitia acuta</i> Draparnaud, 1805			2002	Nardi and Braccia 2004	abundant
Mollusca/Bivalvia	Dreissenidae	<i>Dreissena polymorpha</i> (Pallas, 1771)	x	x	1970	Giusti and Oppi 1972	present
Mollusca/Bivalvia	Unionidae	<i>Sinanodonta woodiana</i> (Lea, 1834)			2009	Cappelletti <i>et al.</i> 2009	abundant/invasive
Mollusca/Bivalvia	Corbiculidae	<i>Corbicula fluminea</i> (O. F. Müller, 1774)	x		2002	Nardi and Braccia 2004	present
Mollusca/Bivalvia	Corbiculidae	<i>Corbicula fluminalis</i> (O. F. Müller, 1774)			2008	Ciutti and Cappelletti 2009	abundant/invasive
Arthropoda/Crustacea/Amphipoda	Gammaridae	<i>Dikerogammarus villosus</i> (Sowinsky, 1894)		x	2003	Casellato <i>et al.</i> 2006	abundant/invasive
Arthropoda/Crustacea/Decapoda	Cambaridae	<i>Orconectes limosus</i> Rafinesque 1817			1998	Zanini 1999	abundant/invasive
Arthropoda/Crustacea/Decapoda	Cambaridae	<i>Procambarus clarkii</i> (Girard, 1852)		x	2003	Zanini unpublished data	present
Macrophytes							
Magnoliophyta/Liliopsida	Hydrocharitaceae	<i>Elodea canadensis</i> Michx.	x		1892	Pignatti 1982	unknown
Magnoliophyta/Liliopsida	Hydrocharitaceae	<i>Elodea nuttallii</i> (Planch.) H.St. John			2001	Zanini 2001	present
Magnoliophyta/Liliopsida	Hydrocharitaceae	<i>Lagarosiphon major</i> (Ridley) Moss			1969-71	Bianchini <i>et al.</i> 1974	abundant

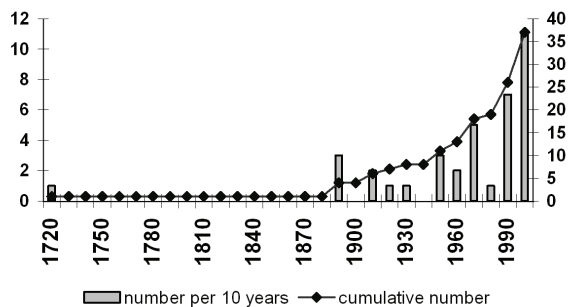


Fig. 1. Number of records of non-indigenous species (NIS) per decade in Lake Garda and cumulative number of NIS.

2.1. Invertebrates

Among invertebrates, most invasive species are bivalves or crustaceans. Lake Garda was the first Italian lake (1970) where the bivalve *Dreissena polymorpha* (Pallas, 1771) was recorded. Six years later its density ranged from 756 ind m⁻² at Sirmione to 24,756 ind m⁻² at Bardolino, two Garda localities (Mariani *et al.* 1980). Now it covers all submerged substrates. Giusti & Oppi

(1972) suggested boats coming from Germany as a possible pathway of introduction. Quaglia *et al.* (2008) confirmed the German origin of the species by means of molecular markers. Spread dynamics of *D. polymorpha* from Lake Garda to other lakes has been studied by Cianfanelli *et al.* (2010).

The Asian clam *Corbicula fluminea* (O.F. Müller, 1774) was first recorded in 2002, on sandy substrates in a very localized littoral area (200 m long) at Manerba, with a maximum density of about 50 ind m⁻² (Nardi & Braccia 2004). Since then, the species has been found in other sites; observations in 2003 revealed the presence of large numbers of dead specimens, with a mean and maximum height of 13.18 and 23.13 mm respectively (Ciutti *et al.* 2007). Shells of another non-indigenous bivalve *Corbicula fluminalis* (O.F. Müller, 1774) were found in July 2008 on the lake shore at Castelnuovo del Garda and Lazise. In Castelnuovo del Garda two distinct shell deposits along the shore were observed, resulting in an impressive scene: an larger outer deposit from 1 to 4 meters from the water line, with high numbers of *C. fluminea* shells, and an inner deposit in the area pounded by waves where *C. fluminea* was mixed

with *C. fluminalis*; in Lazise *C. fluminalis* shells were dominant in the area pounded by waves, but *C. fluminea* was also present (Ciutti & Cappelletti 2009).

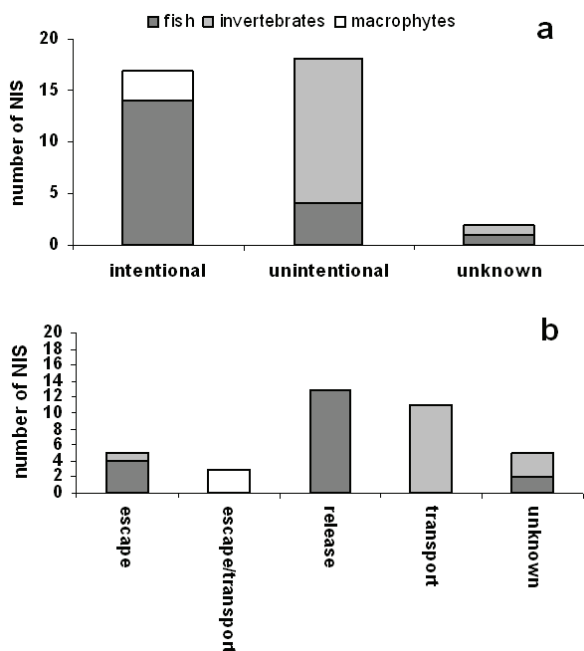


Fig. 2. Mode of arrival (a) and vectors (b) for non-indigenous species (NIS) of fish, invertebrates and macrophytes in Lake Garda according to Gherardi *et al.* 2008.

Among freshwater bivalve species recently introduced in Italy, the Chinese pond mussel *Sinanodonta woodiana* (Lea, 1834) is the most rapidly spreading and since its first recording in Italy in 1996 (Manganelli *et al.* 1998), it has rapidly colonized eight Italian regions, mainly related to the hydrographical basins of the rivers Po, Adige, Piave, Reno, Arno, and Tiber (Cianfanelli *et al.* 2007). Shells have been observed in February 2009 along the south-eastern shore of Lake Garda. The presence of different length classes of valves allows us to assume that the species is probably present in the lake with a stable and naturalized population, but the lack of a specific study makes it impossible to define population density (Cappelletti *et al.* 2009).

Among non-indigenous crustaceans, the killer shrimp *Dikerogammarus villosus* (Sowinsky, 1894) has been reported in Northern Italy (Lake Garda, Po and Mincio rivers) since 2003 and has been recently observed in Tuscany (Tricarico *et al.* 2010). In Lake Garda it showed invasive behaviour and a dramatic impact on the indigenous amphipod *Echinogammarus stammeri* (S. Karaman, 1931). A study conducted from June 2003 to April 2004 at eight stations revealed that in both the western and eastern areas of the southern basin, *D. villosus* was almost the only species found, while in the northern part of the lake *E. stammeri* was still present (Casellato *et al.* 2006; Casellato *et al.* 2008). Specimens of *D. villosus* collected from Garda were also used for

laboratory experiments to study their predatory behaviour on fish eggs and larval stages (Casellato *et al.* 2007).

Two decapod crustaceans, *Orconectes limosus* (Rafinesque, 1817) and *Procambarus clarkii* (Girard, 1852), were recorded in the lake respectively in 1998 and 2003 (Zanini 1999; Zanini unpublished data).

2.2. Fishes

A total of 34 fish species are present in the lake, 16 of which are non-indigenous (47%), intentionally introduced by stocking for angling and fisheries. This value reflects the critical situation of the freshwater fish fauna in Italy, where the 44% are non-indigenous species (Nocita & Zerunian 2007).

Moreover, three stocked species, *Oncorhynchus mykiss* (Walbaum, 1792), *O. kisutch* (Walbaum, 1792) and *Salvelinus fontinalis* (Mitchill, 1814) did not find suitable areas of reproduction and disappeared.

Among non-indigenous species, the whitefish *Coregonus lavaretus* (Linnaeus, 1758) was purposely introduced in 1918 and is now well established, with an abundant population. It actually represents one of the most important economic resources for fishery, together with twaite shad *Alosa fallax* (Lacépède, 1803), with about 58 and 149 tons respectively caught in 2008 (personal unpublished data) (Fig. 3). The population of *C. lavaretus* is sustained by local authorities by restocking programs. Lake Garda is also the habitat for the endemic salmonid "carpione" *Salmo carpio* (Linnaeus, 1758), which is included in the IUCN red list (2010) as critically endangered, also because of the competition with non-indigenous species, i.e. *C. lavaretus* (Ciutti *et al.* 2010).

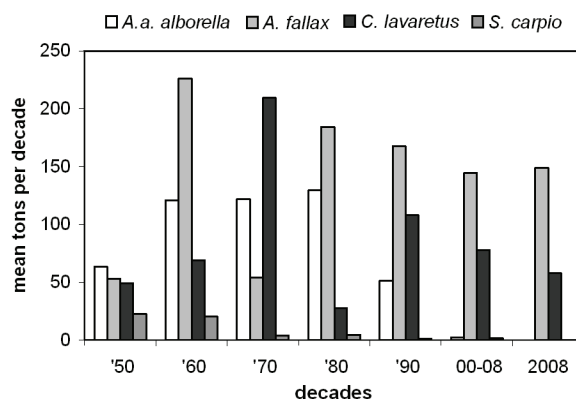


Fig. 3. Mean tons per decade of planktivorous fish caught by fishermen: *Alburnus alburnus alborella*, *Alosa fallax*, *Coregonus lavaretus*, *Salmo carpio*.

The Gadidae burbot *Lota lota* (Linnaeus, 1758) has been present in the lake since 1858, but was not included in the list of non-indigenous fish because its "cryptogenic" status (*sensu* Carlton 1996) has not been fully solved (Gherardi *et al.* 2008).

2.3. Macrophytes

Currently a distribution map of macrophytes in Lake Garda does not exist. *Lagarosiphon major* (Ridley) Moss and *Elodea nuttallii* (Planch.) St. John have been present in the lake since the early 70's and 2001 respectively (Bianchini *et al.* 1974; Zanini 2001). Since its first record, *L. major* continues spreading to the detriment of native species. Its widespread invasion in the northern area of the lake is believed to have been the main cause of the disappearance of *Ranunculus circinatus* Sibth. from the only surviving location in Trentino, where it was present until 1992 (Blasi *et al.* 2010). *E. nuttallii* seems to have a smaller diffusion: after the first record along the eastern lake shore at Brenzone, it was recently recorded in the harbours located along the northern shore of lake (Bertolli *et al.* 2009).

Elodea canadensis Michx., considered among the 100 worst invasive species for Europe (DAISIE), was definitely present up to 1974, but there are no recent data on its persistence.

3. DISCUSSION

Recent records of freshwater invasive species give an idea of the vulnerability of Lake Garda to biological invasions. While further fish fauna introductions could in theory be managed, because of their intentionality, more difficult is the control of invertebrates, as their pathways of introduction are mainly accidental.

Among new records, three species, *C. fluminea*, *D. villosus* and *P. clarkii*, are included in the 100 of the Worst Invasive Alien Species in Europe (DAISIE 2009). Remarkably, records of *D. polymorpha* and *D. villosus* in Lake Garda represent the first observations of these species for Italy.

An extensive study of the benthic communities (invertebrate and macrophytes) and fish fauna in Lake Garda is advisable, in order to identify both the actual consistency of populations of recently introduced species described above, identify short and long term trends and assess the relationships between introduction of invasive species, biodiversity and changes in ecosystem services. For fish fauna new studies are needed to identify possible negative effects of alien fish *C. lavaretus* on the endemic planktivorous *S. carpio*, as suggested in the IUCN Red List (2010), but also on trends of colonization of *Rutilus rutilus* (Pallas, 1776), which is a rapidly spreading species in Italy and is invasive in other sub-alpine lakes, i.e. Lake Lugano (Switzerland) and Lake Como (Italy) (CISPP 2005; Porrini & Ippoliti 2006).

Current distribution of non-indigenous macrophytes should also be studied and mapped. In particular *L. major* is currently classified as locally invasive, because of restricted distribution in Italy. In general, local invasive species might be harmful invaders; implications may be relevant for invasion management and they should be major targets of invasion control (Celesti-Gradow *et al.* 2009). In fact, *L. major* under favourable

conditions can build dense floating mats that prevent light from reaching the layers below, thus competing with other species and threatening the survival of aquatic invertebrates (Global Invasive Species Database 2005).

Other phenomena seem to affect the local aquatic flora and fauna of Lake Garda. At the end of July 2004, a "black bloom" appeared in the western portion of the lake. Using morphological and molecular analysis, Pucciarelli *et al.* (2008) characterized the protozoan *Stentor amethystinus* Leidy, 1880 as the cause of this bloom. It is an open question if this species was recently introduced in Lake Garda by anthropogenic activities, or if it was already a member of the zooplankton community, but at a very low densities.

Many authors consider that transport by recreational boating is the main factor influencing the local diffusion of freshwater alien species in lakes at a local scale (Johnson *et al.* 2001; Leung *et al.* 2006; Karatayev *et al.* 2007; Horvath 2008). At the same time, prevention is the main step in combatting invasive species and, in particular, prevention towards unintentional introductions goes through the implementation of boat inspection and washing programs, as reported for *D. polymorpha* by Horvath (2008). Nevertheless, this could hardly be applied to Lake Garda, as many tourist harbours are present and because of the administrative fragmentation of the lake, divided among three provinces belonging to three different regions (Trento, Trentino-Alto Adige Region; Verona, Veneto Region; Brescia, Lombardia Region).

The regulation and management of fish stocking is also advisable, in order to avoid introduction of new non-indigenous fish and Unionids.

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