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The invasion of Lake Orta (Italy) by the red swamp crayfish *Procambarus clarkii* (Girard, 1852): a new threat to an unstable environment

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Abstract

Procambarus clarkii is an invasive, prolific and aggressive species introduced into Italy for commercial use since the 1980s. In November 2010, this red swamp crayfish was detected in Lake Orta, a large, deep, Italian subalpine lake. Well-known for its 80-year heavy pollution by copper, Lake Orta has been gradually colonized by biota, after its chemical recovery in the 1980s. The lake is still far from being comparable to other subalpine lakes for taxa composition and seasonal dynamics. Lake Orta may be regarded as an unstable environment, in which the invasion by this voracious species deserves particular attention. After the present early detection, we plan to perform interventions to minimize negative impacts of *P. clarkii* to both the ecology and economy of the region. The latter may be particularly important in the case of the Lake Orta because of a persistence of heavy metals in the sediments.

Key words: alien species, aquatic environments, biomagnification, management

Introduction

The North-American red swamp crayfish *Procambarus clarkii* (Girard, 1852) was introduced into Spain in 1973 from its native range in Louisiana (USA). This introduction was aimed at revitalizing the crayfish market in Europe after the drastic decrease in European crayfish species stocks due to the "crayfish plague", a disease caused by *Aphanomyces astaci* (Schikora, 1906; Gherardi 2006). *P. clarkii* is one of the three North American crayfish species, the other being *Pacifastacus leniusculus* (Dana, 1852), *Orconectes limosus* (Rafinesque, 1817) which can carry the crayfish plague's fungus. Highly resistant to infection, *P. clarkii* can transfer the disease to other crayfish species and, under certain conditions, die from its own infection (Diéguez-Uribeondo and Söderhäll 1993).

Owing to its burrowing activity, *P. clarkii* causes heavy damage to agricultural areas (e.g. rice fields) and to rivers and lakes, where it destabilizes the banks (e.g. Fonseca et al. 1997). Increased water turbidity typically occurs after its introduction. *Procambarus* is an opportunistic omnivore species and is highly voracious, causing important changes in the food web of the invaded ecosystems (Salvi 1999), including the disappearance of endemic crayfish species. *P. clarkii* may often grow in waterbodies where blooms of toxic cyanobacteria (e.g. *Microcystis aeruginosa*; Kützing, 1846) are detected, being able to feed on the latter (Oliveira 1995). Consequently, they accumulate microcystins in their intestine and in the hepatopancreas, up to ca. 2.9 µg MCYST/g dry crayfish weight (Vasconcelos et al. 2001). Little is known, however, concerning the effects of the toxins accumulated in crayfish's organs and tissues (Tricarico et al. 2008) in terms of consumer health, including humans.

Procambarus has active dispersal capabilities (Barbaresi et al. 2004) and high adaptation plasticity for new habitats (Gutierrez-Yurrita and Montes 1999) and for those in which seasonal water level fluctuations are large (Barbaresi and Gherardi 2000). Highly resistant to adverse conditions, these organisms are able to spread even across dry lands (Gherardi et al. 2000), thus colonizing isolated water bodies.

P. clarkii was legally introduced into southern Spain in 1973, where it soon became an important commercial species. This success led

Figure 1. Picture of *Procambarus clarkii,* the red crayfish invasive species detected in Lake Orta in 2010. A reference scale for body length (cm) is also shown. Photograph by P. Volta.

to illegal introductions in France and Italy (1970s and 1980s) and to the colonization of southern Portugal and many island (Azores, Balearic Islands, Canary Islands, Cyprus, Sardinia and Sicily). Currently, the species is reported from 13 European countries/regions (Souty-Grosset et al. 2006) and, since 1990, also from the ponds and streams of northern and central Italy (Aquiloni et al. 2010).

Lake Orta is well-known for its history of pollution, recovery and biota colonization. This large (18.2 km^2), deep (maximum depth: 143 m) subalpine lake in the Piedmont region of northern Italy, was strongly polluted after a rayon factory was established at the southern end of its basin in 1926, discharging huge amounts of copper and ammonium sulphate into the water (Calderoni et al. 1991). The biochemical oxidation of N-NH_4 caused nitrate accumulation and a strong decrease in the pH of the lake, which was poorly buffered due to the geology of the catchment. Copper concentration in the water column increased to reach a maximum of 108 μg L^{-1} in 1958 (in-lake concentration value at the winter overturn). Copper started to be recovered from the factory effluent at the end of fifties. The ammonium discharge, however, continued until 1980 when the Italian Parliament passed a law regulating the discharge of industrial wastes into freshwaters. The response of the lake was rapid (Bonacina 2001) and was further accelerated by a liming intervention in 1989-1990 (Calderoni et al. 1991).

Zooplankton reacted promptly to the improvements in water quality. Rotifers were the first colonizers [*Brachionus calyciflorus* (Pallas, 176), *Brachionus urceolaris* (Müller, 1773), *Hexarthra fennica* (Levander, 1892), *Asplanchna brigthwellii* (Gosse, 1850)] followed by Cladocera. Most of the species which colonized the environment after the chemical restoration were non native, and often of a peculiar clone composition (Piscia et al. 2006; Bachiorri et al. 1989).

Material and methods

On November 17th 2010, during a night scuba diving, we observed the presence of many red crayfish on Lake Orta's bottom sediments (45°48′02″67N, 8°25′09″82E; Piscia and Volta, pers. obs.; Figure 1). Quantitative samples were collected using a square framework (0.25m^2) and stored into 10% formalin for taxonomic identification after which the specimens were attributed to the species following Souty-Grosset et al. (2006) identification key.

Attribution to the family Cambaridae was based on: 1) presence of a sharp spur on inferior margin of carpus below chela; 2) inferior margin of propodus shorter than dactylus; 3) presence of one pair of post-orbital ridges; 4) first abdominal segment with pleopods in both sexes. The ascription to the species was based on: 1) convergence of branchiocardiac grooves of both sides of carapace, leaving areola occluded; 2) very pronounced granulation on chelipeds forming spines; 3) chelipeds red on both surfaces (Souty-Grosset et al. 2006).

Results and discussion

A density of *ca*. 1 ind m^{-2} of *Procambarus clarkii* was estimated on Lake Orta's bottom sediments at *ca*. 4 m depth.

Being recently restored, Lake Orta may be regarded as a highly vulnerable aquatic environment, in which invasions of alien species are favoured (Ricciardi 2001). The success of *P. clarkii* in Lake Orta is likely enhanced by its high resistance to heavy metals (Del Ramo et al. 1987), which are still present in non-negligible concentrations even in the lake sediments, particularly in an area close to the old pollution site (e.g. Cu = 1.3 µg g^{-1} d.w.; Hg = 0.89 µ g^{-1} d.w.). Their ability to accumulate (especially in gills and hepatopancreas) nonessential metals (such as copper, cadmium, chromium and lead, all present in Lake Orta's sediments, as well as hydrocarbons), reflecting concentrations of these pollutants in the sediments (Anderson et al. 1997), justifies the use of these organisms as tracers of pollutants (Bollinger et al. 1997). As *P. clarkii* is highly valued for human consumption, the accumulation of these metals in its organs and tissues may represent an important vector of heavy metals to humans with subsequent implications for human health (Alcorlo et al. 2006).

The impact on biodiversity exerted by *P. clarkii* is generally severe and can occur across many levels of ecological organization (Gherardi 2007). After the present early detection, we plan to perform interventions for minimizing negative impacts of *P. clarkii* on both the ecology and economy of the region. The latter are likely further amplified by the persistence of heavy metals in Lake Orta's sediments.

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