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Managing the environment in a pinch: red swamp crayfish tells a cautionary tale of ecosystem based management in northeastern Italy

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ABSTRACT

Farmlands are globally widespread and their management should consider both human and environmental needs. In fact, these man-made ecosystems provide subsistence to the human population but are also habitats for plant and animal communities. The worldwide increase of exotic species has affected native communities, but also human activities or health. We used an exploited farmland in northern Italy, where many exotics are present, as a test case for identifying restoration measures based on an ecosystem approach. In particular, we focused on red swap crayfish for its ecosystem engineering capabilities, and examined the factors affecting its invasion success in order to attempt the definition of management strategies. We used multivariate and regression analysis to evaluate the relationships between the red swamp crayfish, water quality, macrophytes abundance, watercourse hydraulics and the fish community. All analyses indicated that red swamp crayfish was less likely to establish in large, deeper and fast flowing waterways, especially when these are deprived of vegetation and less eutrophicated. Based on our results, fish predation was also a significant factor in limiting red swamp crayfish abundance. We thus concluded that a different hydraulic management, which leaves more water in irrigation canals throughout the winter, could be possibly used to slow down or even reverse the invasion process.

1. Introduction

The sustainable management of human activities has become one of the most imperative goals for the majority of developed countries (UN General Assembly, 2015). A major challenge to achieve this goal has been the divergence between environment conservation and activity development targets (Margules and Pressey, 2000), creating an exacting management gap (Griggs et al., 2013). The concept of ecosystem approach has been developed trying to bridge this gap: it consists of an integrated management of human activities based on the best available knowledge of ecosystems and their dynamics, in order to identify and solve primary causes of ecosystem degradation (UN General Assembly, 1992; Secretariat of the Convention on Biological Diversity, 2004). The product of the ecosystem approach, ecosystem based management, should therefore ensure that development can occur without preventing the ecosystem to provide its services. Being a relatively new concept, its application is not overly widespread and has been perceived to be overly complex and limited in scope to some human activities or particular environments (e.g. such as with fisheries management, Garcia et al., 2003). Furthermore, several other challenges persist on the development and application of ecosystem based management; namely the difficulties in integrating knowledge from different fields and the incredibly complicated interactions between factors that are at play in human-impacted ecosystems (Long, Charles and Stephenson, 2015; Slocombe, 1998).

The field of agriculture management is a prime example of such difficulties, as it involves complex interactions between soil and water ecology (Altieri, 1995; Kramer, 1969). Farmlands often have a long history and are globally widespread; their modified environment providing sustenance to human populations and, perhaps surprisingly, habitats suitable to some species (Clavero et al., 2015; Freemark et al, 2002; Katayama et al., 2013). Often overlooked as a biodiversity-capable environment, irrigation canals are habitat-simplified watercourses that are connected to natural rivers and constitute an interconnected network within farmlands. Managing irrigation canal environments involves governance at different levels (e.g. on fisheries) but perhaps

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the most relevant is hydraulic regulation (Ricart and Gandolfi, 2017). Hydraulic regulation in canals presents challenges common to other human-impacted watercourses, where conservation and production goals often diverge and a major knowledge gap has been underlined as to the effect of variations in water flow on the freshwater plant and animal communities (Bunn and Arthington, 2002; Poff and Zimmerman, 2009).

Similarly, the fauna living in canals can be influenced by pressures much similar to those of natural aquatic environments; primarily eutrophication derived from field fertilization (Castaldelli et al., 2013a; Huang et al., 2017), habitat degradation (Dudgeon et al., 2006) and the introduction of exotic species (Strayer, 2010).

Exotic species are widely recognized as one of the "big five" causes of biodiversity loss (Sala et al., 2000) and can also become invasive, with adverse consequences extending to human activities as well. Among the most invasive exotic species introduced in temperate freshwaters, crayfishes have recently become increasingly common and have had direct effects on native communities (Gherardi and Lazzara, 2006; Rodríguez-Pérez et al., 2016). One of the most prominent and invasive crayfishes, the red swamp crayfish (*Procambarus clarkii*, Girard, 1852), has been found to affect aquatic macrophytes (Carreira et al., 2014) and even damage watercourse banks due to it burrowing habits (Barbaresi et al., 2004). This species thus presents a veritable threat to ecosystem functioning and hydraulic stability, but also a potential impact on crop production (Anastácio et al., 2000) and restoration practices (Rodrigo et al., 2013) posing a serious question to both conservation and agricultural management.

In the lowest portion of the Po River basin, by far the largest and one of the most exploited farmlands in Italy, the presence of red swamp crayfish was reported in 1996 (for a general view, see Gherardi et al., 1999) but its effects or its potential management have been scarcely investigated. This area is also heavily invaded by exotic fish species, which are crayfish predators (e.g. wels catfish *Silurus glanis* L. (Carol et al., 2009) or common carp *Cyprinus carpio* L. (Britton et al., 2007)), but in turn also pose a question of exotic species management. To examine the factors affecting the invasion success of red swap crayfish and to attempt the definition of management strategies, we selected both natural and artificial waterways and worked under the hypothesis that low water levels outside of the growing season could favor crayfish invasion by preventing effective fish predation. We used multivariate analysis to evaluate the relationships between the red swamp crayfish, water quality, macrophytes, watercourse hydraulics and the fish community. Using our results, we identify factors that could be accounted for in hydraulic management, which could be possibly used to slow down or even reverse the invasion process. This test case study could be used as a stepping stone to reduce complexity, achieve sustainable management and be transferred to other regulated watercourses where multiple environmental stressors are present.

2. Materials and methods

2.1. Study area

The waterways investigated in this study are located in the lower stretch of the Po River, within the administrative boundaries of the Province of Ferrara (Emilia-Romagna Region, northeastern Italy). In this area, the natural swamp of the delta has been reclaimed over nearly two centuries and was turned into an heavily exploited farmland, extending over 2200 km^2, half of which is below sea level. To provide water for irrigation, a capillary network of canals was built, which accounts for more than 4000 km in linear extension in the Province of Ferrara. Other waterways include the Po River, a constricted river with a relatively natural flow regime, and the Reno River, a constricted and flow-regulated river.

A total of 34 sampling sites, along 27 different waterways, were sampled to assess presence and abundance of both crayfish and fish (Fig. 1). Moreover, hydrological and environmental variables were also measured. These waterways had variable widths (2–100 m), depths (0.5–4 m) and water current (0–0.3 m s^{-1}; but peak values up to 1 m s^{-1} were registered in the Po and Reno rivers). All water courses presented a muddy-silty layer of variable thickness, covering the clayey sediment of the canal bed, except the Po River, where a prevalence of sandy sediment could be found in the sites sampled. These waterways are also affected by severe microhabitat simplification due to management practices, such as frequent vegetation mowing (Castaldelli et al., 2013a). Irrigation canals are flooded during the growing season (typically April to October) to provide water for irrigation; but water levels are significantly lower outside of this time, further limiting the habitat available to aquatic species.

In the lowest portion of the Po River basin, native white-clawed crayfish *Austropotamobius italicus* (Lereboullet, 1858), belonging to the *A. pallipes* complex, was historically present (Morpurgo et al., 2010), but its abundance and distribution sharply declined in the '70s, with numerous local extinctions in rivers and canals. Afterwards, two exotic crayfish species accidentally escaped from aquaculture ponds, took advantage of the empty niche: the red swamp crayfish was first reported in 1996, and the spinycheek crayfish, *Orconectes limosus* (Rafinesque, 1817), was reported in 2006 about 60 km downstream of the waterways sampled in this study (see Gherardi et al., 1999 for a general overview). It is unclear whether exotic crayfish presence in this area is due to local introductions or dispersal from nearby invaded areas.

In this area, several species of native fish were historically present but exotic fish species introductions date as far back as the XVII century, with most species being introduced around 1970 from Asia or East Europe (Lanzoni et al., 2018; Milardi et al., 2018a). This is one of the most heavily invaded areas in the country, where severe impacts on the native fish communities have been detected (Castaldelli et al., 2013b; Milardi et al., 2018a) and sites with fully exotic fish communities have been found (Lanzoni et al., 2018).

2.2. Crayfish and fish sampling

Sampling of crayfish was conducted between May and June 2009, a period when crayfish were active and environmental stressors, such as flow variations, were not present. In each waterway, crayfish presence was investigated in stretches with homogenous morphology, hydrology and with no tributaries or discharges using plastic traps baited with a can of fish-flavored cat food (see e.g. Lappalainen and Pursiainen, 1995). No professional or sport fishing targeted the crayfish populations in these waterways.

Plastic traps had proved to be the most reliable survey measure in preliminary tests and previous sampling campaigns in the area (2004–2006), due to the high turbidity and the presence of emergent vegetation along the bank (Lanzoni, unpublished data). The traps (40 × 25 × 25 cm, 0.3 cm mesh size) had two openings at opposite ends, plus a central opening for extraction (Fjälling, 1995). A set of 15 traps was used at each sampling event, placed along the waterway banks at depths between 0.5 and 1 m, and left overnight (12 h, from 19.00 to 7.00). 3 replicate sampling events were performed at each site, and catches were expressed as average CPUE, defined as the mean number of crayfish caught per trap, per sampling event. Carapace and total length of all crayfish were measured to the nearest 0.1 mm using calipers. Crayfish wet weight was measured in the field, after removing excess water, to the nearest 0.1 g using an electronic scale.

A temporally and spatially overlapping sampling of the fish fauna was also performed using a combination of electrofishing and netting, adapting the national standard guidelines to the unique conditions of these waterways (Lanzoni et al., 2018). Fish were identified to the species level and individuals of each species counted. Species abundances were expressed in Moyle classes (Moyle and Nichols, 1973), which range from 1 (low abundance, 1–2 individuals per site) to 5 (high abundance, > 50 individuals per site).