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Indicators of movement and space use for two co-occurring invasive crayfish species

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ABSTRACT

Red swamp crayfish (*Procambarus clarkii*) and signal crayfish (*Pacifastacus leniusculus*) are two invasive freshwater species with a worldwide distribution. The objective of this work was to investigate how the two species move and use space in an area of recent coexistence. Simultaneously, we test the use of new tools and indices to describe their movement patterns. To accomplish this we performed a radio-tracking program within a river-type habitat during two different periods (September/October 2010 and June/July 2013). We used spatial analysis tools to map crayfish radio-location data with and without accounting for the curvature of the river. To assess the consistency of the direction of movement and of the distances traveled by crayfish, two indices were developed. To assess the habitat preferences of each species we applied Ivlev's Electivity Index and the Standardized Forage Ratio. Movement of *P. clarkii* and *P. leniusculus* differed. The average detected movement was 8.8 m day^{-1} for *P. clarkii* and 17.5 m day^{-1} for *P. leniusculus*. However, crayfish behavior ranged from almost complete immobility – sometimes during several days – to large movements, in half a day, up to a maximum of 255 m for *P. clarkii* and 461 m for *P. leniusculus*. The proportion of upstream or downstream movements was independent of the species and both species displayed no preference for either direction. The indices of consistency of movement showed a large interindividual variation. Species and period (2010 or 2013) affected the mean daily distance traveled, maximum observed distance from location of release and percentage of observations under vegetation cover. The Ivlev's Electivity Index and the Standardized Forage Ratio presented similar results. *P. clarkii* showed a preference for pool areas with riparian vegetation cover while *P. leniusculus* preferred riffle and pool areas with riparian vegetation cover. Our work provided new and valuable data for modeling the active dispersal of these two problematic invaders in a context of coexistence.

1. Introduction

Due to their economic value, several species of crayfish were introduced outside their native ranges. Unfortunately there are numerous freshwater crayfish species becoming invasive in the areas of introduction (Holdich, 1988; Henttonen and Huner, 1999; Gherardi, 2013) and the two major examples are the red swamp crayfish (*Procambarus clarkii*) and the signal crayfish (*Pacifastacus leniusculus*). Both species now have very large invasive ranges worldwide and further spread is expected since there are still wide areas of the planet with adequate environmental conditions (Capinha et al., 2011).

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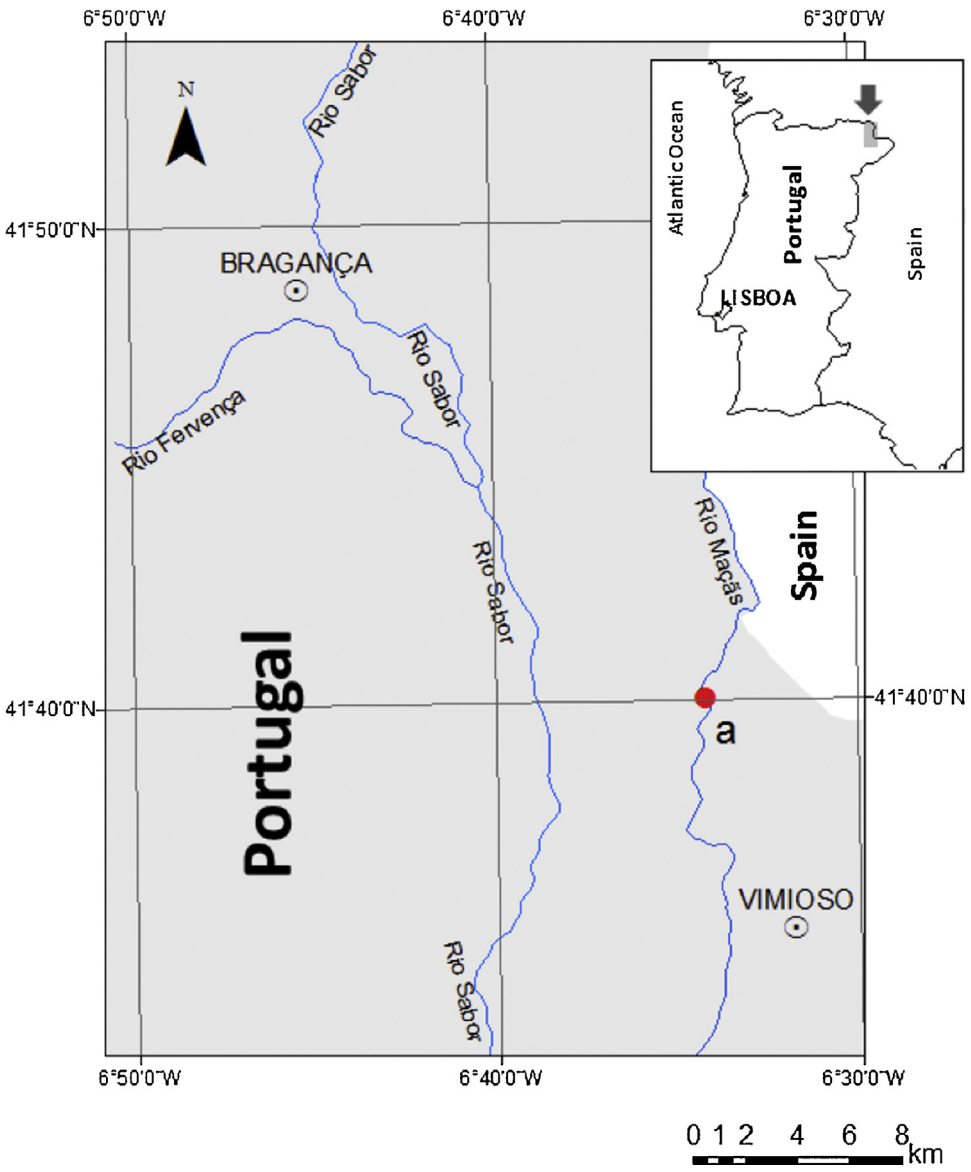

Fig. 1. Location of the study area. The gray area highlighted by an arrow indicates the region within the Portuguese territory covered by the larger map. The red mark signaled by the letter "a" marks the radio-tracking area within the river Maçãs. (For interpretation of the references to color in this text, the reader is referred to the web version of the article.)

The red swamp crayfish is native to subtropical regions of north-eastern Mexico and south-central USA. This species has a highly plastic reproductive cycle (Gherardi, 2006) and a wide ecological plasticity (Gherardi, 2006; Souty-Grosset et al., 2006) and currently it is the most widely introduced crayfish in the world (Gherardi, 2006). In Europe the species was first introduced in 1973 in southern Spain (Habsburgo-Lorena, 1978) and it rapidly spread across several European countries (Laurent, 1997; Souty-Grosset et al., 2006) showing the widest invasive range for an alien crayfish.

The signal crayfish is native from the cool temperate regions of Western North America and it is endemic to Western North America between the Pacific Ocean and the Rocky Mountains. Its habitat ranges from lotic to lentic systems but it is able to tolerate exposure to brackish water (Lowery and Holdich, 1988; Lewis, 2002). *P. leniusculus* was first introduced to northern Europe in the 1960s to replace decreasing stocks of the native *Astacus astacus* (Abrahamsson, 1973; Westman, 1973). Currently this is the most widespread invasive crayfish in Europe, being present in 27 countries (Holdich et al., 2010).

Invasive crayfish affect not only the distribution of native crayfish but also the dynamics and biodiversity of the invaded community (Gherardi and Holdich, 1999; Gherardi, 2006; Holdich et al., 2010). Both *P. clarkii* and *P. leniusculus* are responsible for multiple negative impacts on native species, ecosystems and economic activities in the new ranges. However, these new arrivals increased the commercial value of crayfish in Europe and in many other parts of the world (Nyström, 1999; Souty-Grosset et al., 2006).

On a macroscale, human introductions and environmental suitability can successfully explain the distribution of *P. clarkii* and *P. leniusculus* in Europe (Capinha et al., 2013). However, the local spread and progression of the invasion fronts within or even across country borders needs to be addressed if mitigation, management or containment actions are to be implemented. Several authors studied the progression of the invasion front or the movement patterns of each of these species (e.g. Bubb et al., 2004; Aquiloni et al., 2005; Kerby et al., 2005; Bernardo et al., 2011; Almeida et al., 2013; Johnson et al., 2014) but not the coexistence of the two species. *P. clarkii* and *P. leniusculus* have distinct but nevertheless overlapping