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Short Communication

# Disjunct distribution pattern of *Procambarus clarkii* (Crustacea, Decapoda, Astacida, Cambaridae) in an artificial lake system in Southwestern Germany

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## Abstract

*Procambarus clarkii* is among the worst invasive species that have invaded Europe. It originates from the central south of the USA and northeastern Mexico and is a hardy, r-selected generalist. There exists a marked gradient in population numbers from southwestern to northeastern Europe: The Iberian Peninsula, Italy and France have the bulk of the populations, while northeastern populations are mainly scattered and isolated from each other. In the present study I report on the distribution of *P. clarkii* in an artificial lake system along the River Danube in Southwestern Germany, which is within its northeastern range limit. The presence of *P. clarkii* was confirmed in nine lakes and one canal with stagnant water. *Procambarus clarkii* was absent from lotic situations, which may indicate that *P. clarkii* thrives chiefly in stagnant or slow flowing waters. A probable explanation is that those habitats heat up faster and reach higher summer temperatures than most lotic habitats. Since *P. clarkii* is considered as a `warm water´ species, lentic habitats probably offer more favorable temperatures. The populations form two disjunct distribution centres, isolated from each other by around seven km linear distance. It is not known for sure when the species was initially introduced, but it may have been present in the western distribution centre since the mid 1970s. The emerging disjunct distribution pattern is a synergistic result of introductions into two lakes and subsequent active spread to surrounding habitats, including migration overland. *Procambarus clarkii* numbers are often high and the species has become a nuisance to recreational fishery, since it tends to grab on to exposed fish bait. Two noble crayfish (*Astacus astacus*) populations were wiped out rapidly by *P. clarkii*, presumably due to crayfish plague transmission. Although eradication may prove impossible, population management, e.g. intense trapping and stocking of predatory fish, is strongly suggested. Early eradication, if necessary relying on extreme control methods (e.g. chemical agents), should be attempted when *P. clarkii* invades further lakes.

**Key words:** non-indigenous crayfish, active spread, red swamp crayfish, migration overland

## Introduction

Freshwater crayfish (Astacida) are considered as keystone species in littoral communities. They are the largest mobile freshwater invertebrates, are long-lived, act as polytrophic omnivores and alter their habitats (Momot 1995; Nyström 1999, 2002). The three indigenous crayfish species (ICS) of Central Europe face the competition of at least eight established non-indigenous crayfish species (NICS; Holdich et al. 2009). All ICS species are endangered throughout their Central European range and the ongoing spread of NICS is among the biggest threats to the remaining stocks (Souty-Grosset et al. 2006; Holdich et al. 2009). NICS can also cause ecological havoc and may eliminate plant or animal species from ecosystems (Rodríguez et al. 2005; Nyström 1999).

The red swamp crayfish, *Procambarus clarkii* (Girard, 1852), is one of the most important freshwater decapods farmed for consumption (Huner 2002). It shows considerably ecological plasticity and is listed among the "100 of the worst" invasive species by the `Delivering Alien Invasive Species In Europe´ project (DAISIE 2010). It is a known carrier of the parasitic oomycete *Aphanomyces astaci* Schikora 1906, the causative agent of the crayfish plague (Souty-Grosset et al. 2006). The crayfish plague is fatal for all ICS and has inflicted pan-European mass mortalities since its initial introduction in 1859 (Holdich et al. 2009).

*Procambarus clarkii* originates from the central south of the USA and northeastern Mexico, but has been translocated widely. It is now established in every continent except Australia and Antarctica (Huner 2002). The red swamp crayfish was first introduced into Europe

in 1973, when Spain intentionally imported the species for commercial crayfish production. In the subsequent decades, *P. clarkii* expanded its introduced range rapidly, supported by illegal introductions, and is nowadays widespread and abundant in whole southwestern Europe and northern Italy. Wild populations were also reported from most Central European countries, although there exists a marked gradient in population numbers from southwestern to northeastern Europe: Northeastern populations are mainly scattered and isolated from each other, while Spain, Italy and France have the bulk of the populations (Huner 2002; Souty-Grosset et al. 2006; Holdich et al. 2009).

In the present study, I report on the distribution of *P. clarkii* in an artificial lake system along the River Danube in Southwestern Germany, which is within its northeastern range limit. The presence of an `American crayfish´ in some of these lakes has long been known to local fishermen but only recently drew scientific attention when a strong noble crayfish, *Astacus astacus* (Linnaeus, 1758), population was rapidly wiped out by *P. clarkii*, presumably due to crayfish plague transmission (cf. Keller 1996). Up to date no attempt has been made to evaluate the distribution of *P. clarkii* in the lake system.

## Crayfish survey

Most habitats in the study area are artificial gravel pit lakes along the River Danube, in total numbering approx. 100. In order to assess the current distribution of *P. clarkii*, I interrogated local fishing associations and authorities. Specific localities (N = 19) were selected on the basis of the gathered information and each locality was visited at least once from July to September 2008. Two of the localities were at small streams, one at a shallow backwater of the Danube River and 16 at gravel pit lakes. Localities were visited at night, beginning two hours after sunset, and the shallow water at the lake or stream margins was monitored for 30 to 45 minutes with flashlights. Apart from living crayfish, I searched after burrowing activities (Figure 1) and shed exuviae. Living crayfish and exuviae were identified by examining distinct morphological peculiarities of *P. clarkii*, e.g. a closed areola (space between the cardiobranchic grooves), a distinct median spine on carpus of the large chelipeds and prominent tubercles on the median margin of the chelae palm (propodus; see Figure 1).

## Results

The presence of *P. clarkii* was confirmed in nine lakes and one canal with stagnant water (Figure 2, Table 1). Two disjunct distribution centres were found to exist: one south of the Danube River in the vicinity of Burlafingen and one north of the Danube River in the proximity of Lake Riedheim. Both distribution centres are isolated from each other by around 7 km linear distance; no crayfish were found either in-between or in the Danube River.

## Discussion

The presence of *P. clarkii* was confirmed at ten localities, but due to the large number of nearby lakes in the area and the difficulties in detecting crayfish at low population densities, it is possible that further lakes are colonized by this crayfish. Nevertheless, the distribution of *P. clarkii* in the lake system was assessed for the first time and the present data may serve as a basis for future studies (primary geo-referenced data are available in Table 1).

In the study area, *P. clarkii* seems to be confined to artificial lentic habitats, chiefly gravel pit lakes, although lotic systems (e.g. the River Danube, canals and smaller streams) are found nearby (Figure 2). The absence of *P. clarkii* from lotic situations is in accordance with its prime habitats in its original home range, which are temporary lentic systems (Huner and Romaire 1978; Huner 2002). Introduced populations in the Netherlands, Switzerland, England and Germany were also predominately reported from lentic habitats, although some records exist from smaller streams and rivers (Frutiger et al. 1999; Henttonen and Huner 1999; Soes and van Eekelen 2006; Holdich and Sibley 2009; Dümpelmann et al. 2009; unpublished data). The prevalence of records from lentic habitats in Central Europe may indicate that *P. clarkii* thrives chiefly in stagnant or slow flowing waters. A probable explanation is that those habitats heat up faster and reach higher summer temperatures than do most lotic habitats. Since *P. clarkii* is considered as `warm water´ species and prefers temperatures between 21 and 27°C (Huner and Barr 1991), lentic habitats probably offer more favorable temperatures. This may especially hold true at higher latitudes/altitudes, where low winter temperatures probably restrict breeding season and growth (cf. Frutiger et al. 1999; unpublished data).

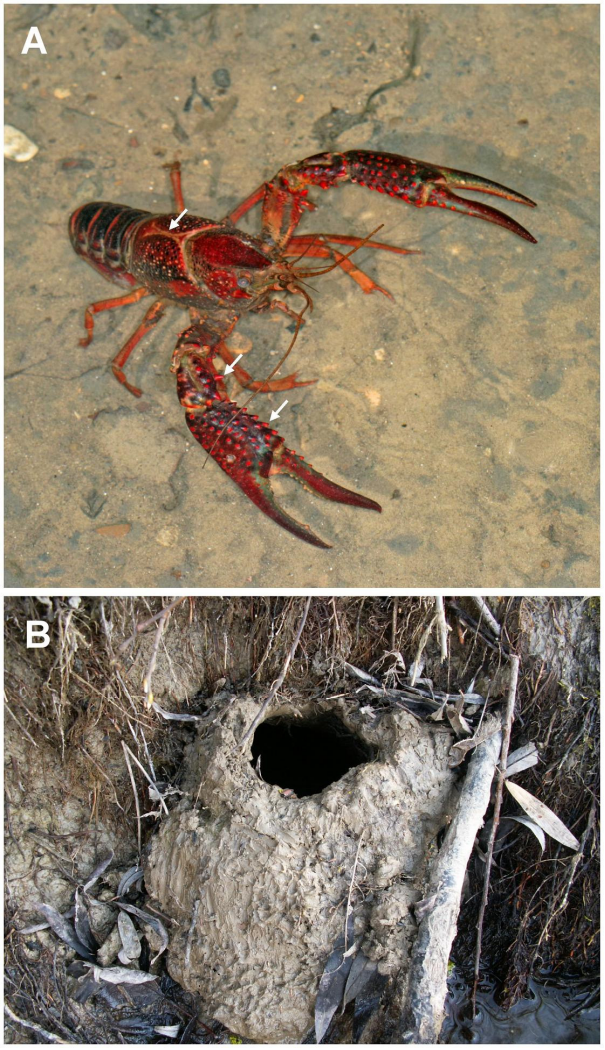


**Figure 1. A**: *Procambarus clarkii* form 1 male (reproductive form). Arrows indicate distinct morphological peculiarities (from left to right): closed areola (no space between the cardiobranchic grooves), distinct median spine on carpus of the large chelipeds and prominent tubercles on the median angle of the chelae palm (propodus). **B**: typical red swamp crayfish burrow along the shoreline of Lake Riedheim.

It is not known for sure when the species was initially introduced, but it may have been present in the vicinity of Burlafingen (western distribution centre) since 1975/6. According to local fishermen, less than 50 specimens of an `exotic crayfish species´ were introduced into a gravel pit lake (Hechtsee) at this time, which today features a dense *P. clarkii* population (see Figure 2). The commercial success of *P. clarkii* in Spain led to a series of illegal introductions in Spain, Italy and France in the 1970s and 1980s (Souty-Grosset et al. 2006) and it is conceivable that *P. clarkii* was stocked into Lake Hechtsee for the same motive. This scenario is also in accordance with the invasion history of the surrounding lakes: the most southern lakes in the western distribution centre were colonized only within the last decade and one small pond still holds a noble crayfish population. The populations in the eastern distribution centre are reportedly younger than the initially stocked population in the western distribution centre and occurred later in the mid 1990s. The absence of *P. clarkii* from the lakes in-between and the Danube River suggests human mediated translocation to Lake Riedheim, the first lake in the eastern distribution centre that was colonized. After the loss of a noble crayfish population in Lake Riedheim, fishermen were aware of the risks of transplanting NICS and the subsequent invasion of the adjacent lakes was therefore most likely the result of natural active spread. The active colonisation of these lakes stresses the high potential of *P. clarkii* to migrate

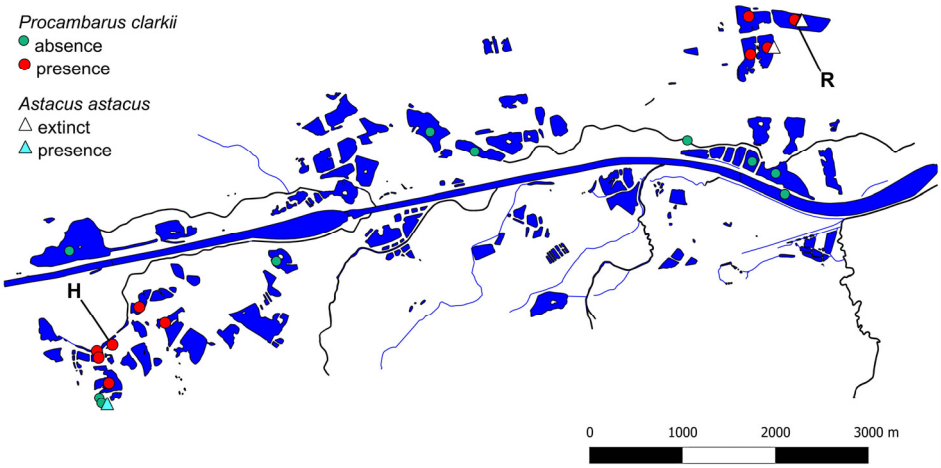


**Figure 2.** Distribution of *Procambarus clarkii* and indigenous noble crayfish (*Astacus astacus*) in the study area. `H´ denotes Lake Hechtsee (site of first *P. clarkii* introduction) and `R´ Lake Riedheim (second introduction). The surrounding lakes were most likely colonized by migration overland.

**Table 1.** Localities with confirmed presence of *Procambarus clarkii*. NN means no name.

| Locality | Surface area [ha] | Latitude N | Longitude E | Comment |
|---|---|---|---|---|
| NN | 0.9 | 48°25'57.56" | 10°04'21.47" | |
| Burlafinger Vereins See | 5.1 | 48°25'44.63" | 10°04'29.00" | |
| Hechtsee | 0.4 | 48°25'59.55" | 10°04'30.30" | probable site of initial introduction |
| NN | 2.9 | 48°26'12.67" | 10°04'43.80" | |
| NN | 5.0 | 48°26'04.87" | 10°04'58.51"´ | |
| NN | 6.8 | 48°27'50.68" | 10°10'08.16" | |
| Riedheimer See | 9.3 | 48°27'49.53" | 10°10'32.35" | former *A. astacus* population |
| NN | 5.2 | 48°27'40.08" | 10°10'15.92" | former *A. astacus* population |
| NN | 5.9 | 48°27'38.49" | 10°10'06.51" | |
| NN | 1.0 | 48°25'59.52" | 10°04'27.80" | |

considerable distances overland as there are no connecting surface water bodies (cf. Huner and Barr 1991). Crayfish migrating overland were indeed encountered during the study period and crayfish roadkills were frequently reported from a nearby freeway. Overall, the emerging, disjunct distribution pattern is a synergistic result of initial translocation by man (Lake Hechtsee and Lake Riedheim) and subsequent active spread to surrounding habitats.

The introduction and spread of *P. clarkii* has led to adverse economic, and probably also ecological effects: The invasion of Lake Riedheim by *P. clarkii* was followed by a rapid disappearance of resident noble crayfish (cf. Keller 1996). A second noble crayfish population in the lake south of Lake Riedheim was wiped out soon after. The noble crayfish populations have been valuable to the local fishing associations, because noble crayfish were sold for stocking purposes and consumption. Although *P. clarkii* has reached high population densities in some lakes (e.g. an estimated adult population of approx. 13,400 crayfish in Lake Riedheim; unpubl. data) it was never harvested intensively. Currently, recreational fishermen harvest only one *P. clarkii* population extensively, chiefly for personal consumption. Red swamp crayfish numbers are often high and dense populations may structure benthic communities (unpublished data). *Procambarus clarkii* also constructs deep burrows along the shoreline of Lake Riedheim and the openings are occasionally covered by typical `crayfish chimneys´ (excavated mud; Figure 1). The species has become a nuisance to recreational fishery since it tends to grab on to exposed fish bait.

In Central Europe, *Procambarus clarkii* might not spread along rivers to the same substantial extent as other NICS, e.g. signal crayfish (*Pacifastacus leniusculus* (Dana, 1852)) and *Orconectes* spp. (Dehus et al. 1999; Souty-Grosset et al. 2006; Chucholl 2009). However, it has proved to migrate considerable distances overland and the existing populations are latent `bridgeheads´ for a further active spread. Although eradication of the existing populations may prove impossible (Aquiloni et al. 2009; Freeman et al. 2010), population management, e.g. intense trapping and stocking of predatory fish, is strongly suggested (Frutiger and Müller 2002; Hein et al. 2006; Freeman et al. 2010). Early eradication, if necessary relying on extreme control methods (e.g. chemical agents, Sandodden and Johnsen 2010), should be attempted when *P. clarkii* invades further lakes.

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