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ORIGINAL PAPER

Distribution, ecology and impact of a small invasive shellfish, *Hemimysis anomala* in Alsatian water

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Abstract The dissemination of *Hemimysis anomala* (*H. anomala*) in Europe and more recently in North America highlights the problem of proliferation of invasive species able to form large colonies. Concern relates mainly to competition for food, in particular the zooplankton that *H. anomala* feeds on at the juvenile stage and that could be lacking for many other species, like young fish. A recent study describes the spread of *H. anomala* towards the south of France by the Rhône River (Wittmann and Ariani in Biol Invasions, 7 pp, 2008). We have also found it near the Marne east of Paris, as well as in an increasing number of rivers and gravel pits in Alsace. We confirm here that *H. anomala* is very prolific, reproducing three times a year, in March/April, June/July and September/October. During the winter, we observed gatherings of thousands of individuals in open water from mid-December until March/April, with females carrying eggs in March when water reaches 7–8°C. The tracking of the population of *H. anomala* in an Alsatian gravel pit during three consecutive years shows a marked reduction in the number of individuals after a period of strong growth, which could be explained by substantial predation by perch and other predators. Finally, the ecological impact of the establishment of *H. anomala* was evaluated indirectly by the study of alevin and hydra populations, chosen for their nutritional dependence on zooplankton. Combined with the decrease of the *H. anomala* population observed over the period studied, our data suggest that a major impact on the aquatic community by *H. anomala* is unlikely at least in the studied area. Statements in this article were all recorded and corresponding sequences presented on http://riedbleu.free.fr/films_Hemimysis.html.

Keywords *Hemimysis anomala* · Invasive aquatic species · Distribution · Alsatian freshwater · Ecological impact

Introduction

Hemimysis anomala (*H. anomala*; G.O. Sars, 1907, Crustacean, Mysidacea) is a small shrimp, 6–11 mm long, from the Ponto-Caspian area, which emigrated using river transport and boat ballasts (Jazdzewski 1980). It reached most of western Europe and more recently North America, where it established in the Great Lakes (Pothoven et al. 2007; Kipp and Ricciardi 2007). Interconnections of the large rivers by canals create hydrographic networks at the origin of its propagation from Ponto-Caspian area (Bij de

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Vaate et al. 2002). *H. anomala* is not at all the only nor the first species originating from this area and spreading throughout the world; *Corophium curvispinum*, *Hypania invalida*, *Dikerogammarus villosus*, *Jaera istri*, and *Limnomysis benedeni*, to name a few, had already followed this route. *H. anomala* is a euryhaline species, present in many sites of variable salinity: from freshwater to seawater with 18 ‰ salinity (Bacescu 1954; Komarova 1991) equal to that of the habitat of origin: the Black Sea. Such a relative low salinity arises from the fact that many rivers (i.e. Danube, Dniepr and Dniestr) empty into that sea. This great tolerance to salinity variations explains the easy adaptation of *H. anomala* to the newly colonized areas, in particular rivers and freshwater lakes as well as the Baltic Sea, the largest brackish sea in the world, with a salinity of 7 ‰. But the majority of more saline seas remain uncolonized, e.g. the Mediterranean Sea (38.5 ‰), the Atlantic (36.5 ‰), Pacific (35 ‰) or Antarctic Ocean (34.7 ‰), where it is confined to brackish water of the estuaries.

In France, the opening to navigation of the Danube-Main Canal in 1992 remains the main factor in propagation of species from the Ponto-Caspian area (Bij de Vaate et al. 2002). The first observation of *H. anomala* in the Rhine basin was in 1997 in the Neckar River (Schleuter et al. 1998), and in 1998 in the Main River (Schleuter and Schleuter 1998). In 1999, *H. anomala* was also found in the stomach of young perch in Holland in the delta of the Rhine River (Kelleher et al. 1999). The first observation in France was in 2005 in the Rhine River near Neuf-Brisach as well as in two remote gravel pits, located near the Ill, a 223 km long Alsatian river encountering the Rhine north of Strasbourg. It is by that river that *H. anomala* would have arrived in these gravel pits and colonized, owing to floods (Dumont 2006).

Here we report precise details on colonization from the Rhine by *H. anomala* in the Alsatian hydrographic network and give a progress report over 3 years of the ecology of this small shellfish. The impact on local communities is also discussed. The observations described here were all obtained during scuba diving and recorded on a digital movie camera. The corresponding motion picture can be seen on the website of our association "Ried Bleu", created for knowledge and protection of the Alsatian aquatic environment. (http://riedbleu.free.fr/films_Hemimysis.html).

Results

Distribution

Since our previous publication reporting the discovery of *H. anomala* in Alsace (Dumont 2006), this small shellfish continues to colonize Alsatian inter-connected rivers. Specimens of *H. anomala* were collected in July 2007 in the "Brunnwasser" River in Daubensand at a place known as "the Blue Hole" (48°21′ 04.11″ N, 7°43′ 38.71″ E) and in March 2007 in the "Marne to Rhine" Canal in Saverne (48°43′ 53.93″ N, 7°20′ 20.70″ E) along with other invasive species like *Corophium curvispinum* and *Atyaephyra desmaresti*. In April 2008, *H. anomala* was also found in a third gravel pit in Erstein, 50 m from the Ill River (48°25′ 54.85″ N, 7°40′ 23.21″ E) and, in June 2007, in an artificial lake close to the Marne, 30 km east of Paris (48°51′ 56.09″ N, 2°39′ 22.45″ E).

Reproduction

In winter 2005/2006 during daytime, we observed for the first time in open water, the formation of compact swarm of several tens of thousands of individuals (Dumont 2006). Since then, we have carried out many investigations to understand the purpose of such gatherings and if they were formed each winter. Our observations carried out in winter 2005/2006, 2006/2007 and 2007/2008 in two different gravel pits showed that these gatherings of individuals form in open water in mid-December when water temperature is around 7–8°C (Fig. 1).

Fig. 1 Winter gathering of *Hemimysis anomala* in open water

They continue all winter, even when the lake is frozen (water at 3–4°C), and then disperse in spring. These gatherings took place during three consecutive years. The individuals mass in shallow water under a pontoon or a tree trunk or at great depth (7–15 m), where they form compact swarms (1–2 m in diameter) in the mats of Characea (*Chara hispida*). At nightfall, the swarms disperse, in search of food, to reform at sunrise at the same places. At the beginning of March, with water around 7°C, 13.5% of the females carry eggs in their marsupial poach (computed from 770 individually randomly taken animals, Fig. 2). In April, when the temperature reaches 8–10°C, the swarms disperse to form small scattered colonies, hiding during the day in various cavities, e.g. in the interstices of trees roots, under stones or pieces of bark fallen in water.

It is in these cavities that *H. anomala* spends the warm season, leaving only during the night to search for food. We observed females carrying eggs at two other periods: in June/July and in September/October, so there are three the number of generations per year.

Census of the populations of *Hemimysis anomala*

Enumeration of populations of *H. anomala* is a complex task due to the multiplicity of the shelters in which the colonies live. Nevertheless, one can have an idea of population sizes through night observations when the animal leaves its shelter or else by measuring the size of the swarm during the winter in open water. The latter approach was carried out in a gravel pit (48°20′ 09.49″ N, 7°34′ 00.61″ E) during three successive winters. We measured a dense swarm of five meter in length by one meter diameter at 5 m depth, as well as eight colonies of one meter diameter approximately in greater depths (7–12 m) in winter 2005/2006. The next winter, we measured five solitary swarms (~ 1 m diameter) in variable depths (1–20 m). Finally, we measured only two swarms (1 m diameter) in 12 m of depth in mats of Characea in winter 2007/2008.

Fig. 2 *Hemimysis anomala* bearing eggs

Predation

Predation of *H. anomala* by bullheads (*Cottus gobbio*), larvae of dragonflies (*Calopteryx virgo*) and perch (*Perca fluviatilis*) could be observed during night dives. Corresponding records can be viewed on: http://riedbleu.free.fr/films_Hemimysis.html.

Impact

To measure the impact of *H. anomala* on other species, we studied populations of hydra (*Pelmatohydra oligactis*), chosen because it eats only zooplankton, especially Copepoda and Cladocera. Our data show that hydra are particularly numerous in one of the two studied gravel pits, especially between 3 and 18 m with a maximum population between 5 and 7 m, mainly at the ends of Characea (*Chara hispida*) patches (http://riedbleu.free.fr/films_Hemimysis.html). Such a massive presence indicates, so far, little or no interference of *H. anomala* on the hydra population, which lives in the Alsatian gravel pits.

Discussion

Our data demonstrate spread of *H. anomala* in many canals and rivers of Alsace. Its presence near the Marne, east of Paris, shows a spread towards the west via the Marne to Rhine Canal. Recent work of Wittmann and Ariani (2008) highlighted the expansion of the species towards the south of France, by the Saône and the Rhône Rivers towards the Mediterranean Sea. Thus, eventually this small shellfish will be present in all the inter-connected networks in Europe, but also in North America, as attested by its recent discovery in the Great Lakes (Pothoven et al. 2007; Kipp and Ricciardi 2007).

Previously (Dumont 2006), we explained that *H. anomala* used the Ill River, affluent of the Rhine, to colonize isolated gravel pits. They did not need to swim upstream in the Ill, as they came from the mouth with the Rhine River (medium flow of 58 m^3/s in Strasbourg); the low water level of the Ill is sustained by upstream contributions of Rhine water, on the one hand at Mulhouse since 2003 via the Huningue Canal and the Qualtelbach River (6 m^3/s, distance from the mouth with the Rhine River: 100 km) and on the other hand at Colmar since 1883 (4 m^3/s, distance from the mouth with the Rhine River : 57 km). We explained earlier that the passage of *H. anomala* from the Ill River towards certain gravel pits was by regular floods in this area.

In April 2008, our discovery of *H. anomala* in a gravel pit close to the Ill River, however, out of the floodplain, led us to assume a possible underground transfer of species via ground water. Indeed there exists in the Alsatian plain a free exchange between ground water and the rivers (between alluvium accumulated in the Rhenish basin during the quaternary period; Trémolières et al. 1993); a kind of natural balance, maintained by seasonal excess and lack of water. In fact, in a period of high water, the river replenishes the ground water. The gravel pits of the floodplain of Alsace are connected to the ground water and their levels vary according to the latter. It is thus likely that in periods of high water, small species or larvae can be transported between rivers and gravel pits, for short distances, by a kind of underground channel. The transfer by water birds or fishermen could be a second transport mechanism. We do not favor the latter, as all gravel pits colonized by *H. anomala* in Alsace are very close to the Ill River. Further, to our knowledge, no gravel pit far from the Ill or Rhine Rivers has yet been colonized.

The ecology of *H. anomala* has only recently became clearer owing to work on its reproductive behavior. Borcherding et al. (2006) studied the ecology of *H. anomala* in a gravel pit communicating with the Rhine (km 842.8, 51°46′60″ N, 6°19′60″ E). These authors observed two generations in 1 year, one in April/May, one in September/October. Borcherding also suspected that there could be an additional generation. We observed females carrying eggs in March/April and September/October, but also in June/July. *H. anomala* is thus very prolific in our region, leading to the question of the impact of this species on various freshwater communities.

During three consecutive winters we observed large shrimp gatherings beginning in mid-December when water reaches 7°C, followed by dispersal to isolated colonies at the beginning of April when the water reaches 8–9°C. Starting in March, many females carried eggs, suggesting a gathering with reproductive goals. The massing of many individuals allows genetic mixing that cannot occur the rest of the year when *H. anomala* lives and reproduces in small colonies dispersed in various shelters. Because *H. anomala* is negatively phototactic and is subject to predation by fish, winter, with its low light levels, short days, and the fasting of many fish due to low temperatures, is the ideal season for such a gathering.

These gatherings cease with the increase of water temperature and longer days. Borcherding et al. (2006) suggest that populations of *H. anomala* could decrease in winter because of mortality due to low temperatures. The swarms we observe in winter, even under ice, are very active and seem unaffected by the low temperature (3–4°C). Borcherding et al. used a trap to estimate the number of individuals, which certainly leads them to underestimate the populations due to winter gatherings. Concentrating of the species in a handful of sites may mislead them to deduce a reduction in the number of individuals.

As it is very difficult to estimate populations of *H. anomala* because of the multiplicity of shelters in which the colonies can hide, we estimated the populations by measuring the size and number of the swarms formed in winter in open water. In winter 2005/2006, at the study sites, we observed a swarm five meters long and one meter in diameter as well as eight other more modest gatherings. During the two following winters, we observed a great reduction in the size and number of colonies as described above. Further work will help us to determine if this reduction presages a long term disappearance of the invader or if, as we believe, after one period of great multiplication, the population of *H. anomala* is on the way to finding a sort of "balance" in the ecosystem under strong predatory pressure. Many of these predators, after a period of adaptation, recognize *H. anomala* as a good meal. During night dives, we observed predation of *H. anomala* by bullheads (*Cottus gobbio*), larvae of dragonflies (*Calopteryx virgo*) and perch (*Perca fluviatilis*), confirming work of Kelleher et al. in 1999, who found *H. anomala* in the stomach of perch in the delta of the Rhine in Holland. Others have come to the same conclusion (Borcherding et al. 2007; Hermasch and Murawski

2007). The light of our projectors certainly disturbs the behavior of the animals and facilitates detection of *H. anomala* by predators, but it also makes it possible to highlight that many species eat this small shellfish.

Could *H. anomala* compete for food and habitat with other species? Concerning habitat, the predilection of this mysid for small cavities and shelters could create competition with other species dependant on the same habitat, in particular various shellfish. Thus, several times we observed seemingly friendly cohabitation of *H. anomala* with American crayfish (*Orconecte limosus*), aquatic sowbug (*Asellus aquaticus*), zebra mussel (*Dreissena polymorpha*) as well as insects larvae (Ephemeridae and/or Trichoptera). On the other hand, shelters under rocks inhabited by fishes like the bullhead (*Cottus Gobio*) or the stone loach (*Nemacheilus barbatula*) were never colonized by *H. anomala*. With respect to food, *H. anomala* is omnivorous, able to change diet according to the availability of nutrients (Kaestner 1993). Viherluoto described the species as planktivorous, eating phytoplankton when juvenile and zooplankton when adult (Viherluoto 2001). Ketelaars et al. (1999) studied populations of zooplankton in the Biesbosch Reservoir in the Netherlands and observed significant drops in Cladocera populations after establishment of *H. anomala*. We often observed them eating various organic remains, such as dead fish, like carp. Around such fish corpses, compact swarms of *H. anomala* were busy tearing off pieces of flesh using their periopods. These banquets are generally shared with other shellfish such as aquatic sowbugs (*Asellus aquaticus*), American crayfish (*Orconecte limosus*) and insect larvae. We also observed cannibalism in some cases. If the cannibalistic and detritivore mode of *H. anomala* does not damage other species, organic matter in decomposition being abundant and available in the studied areas, the question remains: could consumption of plankton affect the planktivorous species such as other invertebrates and young fish? Indirect observations help us to answer this question. Ketelaars et al. (1999) and Borcherding et al. (2006) showed that populations of zooplankton (in particular Cladocera) can decrease following establishment of *H. anomala*, but we have no data on the effects of this reduction on other planktivores. This is why we studied hydra (*Pelmatohydra oligactis*), whose food consists of zooplankton, in particular Copepoda and Cladocera. In the gravel pit we studied, a large population of hydra was found mainly between 5 and 7 m. They develop on Characea (*Chara hispida*) and trees and branches fallen into water. Surprisingly, they even grow on fishing lines hooked in these trees, where they form linear colonies. In April in the same location, we also observed reproduction of roach (*Rutilus rutilus*), their offspring forming very large swarms that we followed throughout the year. In the summer, despite substantial predation by perch and pike, the fingerlings are still numerous, measuring 3–4 cm, a stage less dependant on zooplankton for feeding. These observations, though not quantified, show little or no effect of the presence of *H. anomala* on the studied populations. Combined with the decrease of the population observed over our study period, our data suggest that *H. anomala* may not affect the local aquatic community. The preliminary character of our observations means more research is needed for longer periods and in different aquatic systems (in particular lotic habitats) to better understand the effects of *H. anomala* in our area but also in other areas of the world.

Movies of observations detailed in this article are visible on the Internet: http://riedbleu.free.fr/films_Hemimysis.html.

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