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Recent expansion of the oriental shrimp *Palaemon macrodactylus* (Crustacea: Decapoda) on the western coasts of France

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Abstract

The invasive oriental shrimp *Palaemon macrodactylus* Rathbun, 1902 has considerably extended its distribution in transitional waters along the Atlantic and Channel coasts of France during the period 2007-2010. The most probable method of a primary introduction of this species is ballast waters, but passive transport by water currents is also a possible mechanism of colonization (secondary introductions). *Palaemon macrodactylus* is a powerful invader of transitional waters and these new populations should be monitored in the future to assess any consequences to native species.

Key words: *Palaemon macrodactylus*, Palaemonidae, invasive species, western France, transitional waters

Introduction

The oriental shrimp *Palaemon macrodactylus* Rathbun, 1902 is native to the coasts of the north-western Pacific: Japan, Korea and northern China (Newman 1963). The first record outside its native area was in the late 1950s in San Francisco Bay, California (Newman 1963) and the species is now considered to be well-established along the west coast of North America, from Willapa Bay, Washington, to the Southern California Bight (Elder and Fuller 2010). Since that time, it has been reported from southern Australia in the 1970s (Pollard and Hutchings 1990), in Mar del Plata harbour, Argentina, in 2000 (Spivak et al. 2006), and on the eastern coast of the USA: estuarine system of New York City in 2001 (Warkentine and Rachlin 2010) and Mystic River, Connecticut in 2010 (Wajtas 2010). Colonization of European waters by *P. macrodactylus* began in 1992 (Worsfold and Ashelby 2008). Based on published records, there seem to be four different areas of introduction of this species into Europe:

(1) the southern North Sea: estuaries in southeastern England [Thames since 1992 and Medway in 2004 (Worsfold and Ashelby 2008); Orwell in 2001, Stour in 2002 (Ashelby et al. 2004)], estuarine and harbour waters in The Netherlands and Belgium [Scheldt estuary since 1999; IJmuiden, Rotterdam, Zeebrugge, and Oostende in 2004 (d'Udekem d'Acoz et al. 2005)], estuaries in the German Bight, Germany [Weser estuary in 2004, Hooksiel in 2005 (González-Ortegón et al. 2007)]; the Seine estuary, France, in the English Channel, where the species was noticed in 2006 (Dauvin 2009);

(2) the southern Bay of Biscay: Gironde estuary since 1998 and Adour estuary in 2006 (Béguer et al. 2007);

(3) the Gulf of Cádiz (southwestern Iberian Peninsula): Guadalquivir estuary since 1999, Guadalete estuary, San Pedro river, Salado river (Cuesta et al. 2004, González-Ortegón et al. 2007); Guadiana estuary since 2004 (González-Ortegón and Cuesta 2006, Chícharo et al 2009);

(4) the Black Sea: Constanta harbour since 2002, several localities along the Romanian coast in 2009 (Micu and Niță 2009) and Varna Lake in Bulgaria in 2009 (Raykov et al. 2010).

In this study, new records of *P. macrodactylus,* are reported which were mainly collected

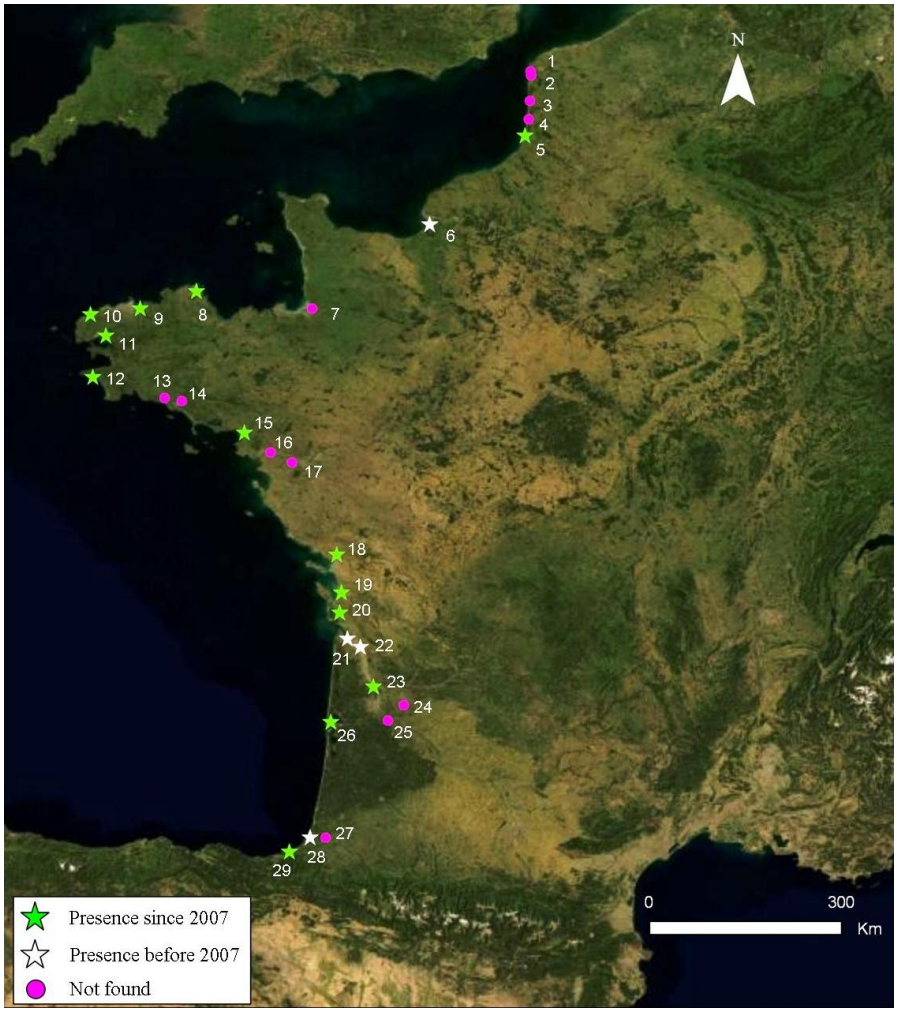

Figure 1. Presence (since and before 2007) and absence of *Palaemon macrodactylus* on the western coasts of France. Numbers indicate the different sampling stations (see code legend in Annex 1).

during sampling of transitional waters for the assessment of ecological quality according to the European Water Framework Directive and show the recent, rapid expansion of the species along the Atlantic and Channel coasts of France.

Materials and methods

Several sheltered systems such as bays or estuaries were sampled from 2007 to 2010 on the western coasts of France (Figure 1). Specimens of *P. macrodactylus* were collected using different sampling methods. In the Charente estuary, shrimps were collected with a plankton net (surface) and a suprabenthic trawl (bottom) in September 2007. In Arcachon Bay, specimens were sampled using brush traps placed near eelgrass *Zostera (Zostera) marina* Linnaeus, 1753 meadows and collected at low tide in March 2010. In the other locations (fish surveys for the implementation of the Water Framework Directive in 2007-2009), *P. macrodactylus* were collected using a trawl in daytime between the mid-flow period and the high tide slack period; each tow lasted about 15 minutes.

Since 2006, and their first descriptions in France (Béguer et al. 2007), all specimens of *Palaemon macrodactylus* (Figure 2A) were carefully identified using the following diagnostic characters (Ashelby et al. 2004; d'Udekem d'Acoz et al. 2005; González-Ortegón and Cuesta 2006):

- a whitish longitudinal dorsal stripe running over the entire body (Figure 2B);
- rostrum with 9 to 15 dorsal teeth (usually 10-13), 3 of which being usually behind the orbit;

(A)

(B)

Figure 1. *Palaemon macrodactylus*, 32 mm, Arcachon Bay, France: (A) lateral view, (B) dorsal view, showing characteristic dorsal white stripe (Photographs by N. Lavesque).

- ventral margin of the rostrum with a double row of setae;
- shorter ramus of the outer flagellum of antennula fused for about 20% of its length to longer ramus.

Discussion

Since its first records in the Gironde (1998), Adour (2006), and Seine (2006) estuaries (Béguer et al. 2007; Dauvin 2009), *P. macrodactylus* has considerably extended its distribution in the bays and estuaries along the Atlantic and Channel coasts of France (Figure 1). It has apparently not yet colonized the most northern estuaries (Slack, Wimereux, Canche, and Authie), although it is well represented in southeastern England (Ashelby et al. 2004; Worsfold and Ashelby 2008), in Belgium and the Netherlands (d'Udekem d'Acoz et al. 2005). Since 2006, all the shrimps collected in these French northern estuaries have been carefully verified by scientists but no Asian shrimp have been found in these areas, yet. The species is also absent from Mont Saint-Michel bay and from two small estuaries in south Brittany (Laïta and Blavet). Finally, and most surprisingly, it has never been recorded in the Loire estuary despite several sampling campaigns and the presence of the international harbour of St-Nazaire.

Locations where this species has been reported as non-indigenous are often in the vicinity of large international harbours. It is thus generally assumed that the most probable vector of introduction for *P. macrodactylus* (as pelagic larvae or adults) is the transport and discharge of ship ballast water (Ashelby et al. 2004; Cuesta et al. 2004; d'Udekem d'Acoz et al. 2005; Spivak et al. 2006; Béguer et al. 2007; González-Ortegón et al. 2007; Micu and Niță 2009). In the present study, most of the records of *P. macrodactylus* might be linked to shipping traffic because sampling stations were close to international harbours: Adour (Bayonne harbour), Gironde and Garonne (Bordeaux), Charente (La Rochelle and Rochefort), Elorn (Brest), Morlaix (Roscoff) and Bay of Seine (Le Havre). However, other records could be explained by the transport of shrimps or larvae by currents. For example, we assume that the presence of *P. macrodactylus* in Arcachon Bay is independent of human activities. Adults or pelagic larvae could be transported by currents from the Gironde estuary located north of Arcachon, where the species is abundant. Waters flowing from the Gironde estuary are usually inclined to the right (clockwise in the northern hemisphere) due to the Earth's rotation (Lazure and Jegou 1998) resulting in northerly directed water currents along the French west coast. However, during summer, north-westerly winds could generate southward currents and low salinity water, possibly originating from the Gironde estuary, is regularly detected at the entrance to Arcachon Bay (Lazure and Jegou 1998). The estimated transit time from the mouth of the Gironde to reach Arcachon Bay is between 4 and 7 days for a current velocity of 10-20 $cm.s^{-1}$ (Lazure and Jegou 1998). These hydrodynamic characteristics support the hypothesis of passive shrimp transport. Such a mode of introduction may also explain the presence of *P. macrodactylus* in the Bidassoa (situated 38 km from Bayonne harbour), the Seudre (influenced by the Gironde estuary plume), the Sèvre Niortaise (33 km from La Rochelle-La Pallice), the Goyen (97 km from Brest), the Aber Wrac'h (57 km from Bay of Brest, 76 km from Roscoff), the Trieux (64 km from St-Brieuc, 112 km from St-Malo) and the Somme (71 km from Dieppe).

Palaemon macrodactylus is a permanent resident of estuaries where it is able to complete its life cycle and high densities are found (Newman 1963; Born 1968; González-Ortegón et al. 2006; Micu and Niță 2009). In this sense, during this study, shrimps were collected in waters with a wide range in salinity (0.5 - 39.1 psu) (Annex) and temperature, e.g. 5 - 19°C in the Bay of Seine (Dauvin et al. 2010) and 2 - 26°C in the Gironde estuary (Lobry et al. 2006). However, Asian shrimps were absent from the fluvial part of the hydrographic systems (Dordogne, Garonne, Adour).

In some cases, the impact of invasive species may be extremely damaging to native species, the local environment and human activities. Marine invasive species may have negative effects on their new environment: introduction of new diseases (parasites, viruses), modification of the trophic web by competition, destruction of economically valuable native species by predation (see e.g. Parker et al. 1999; Ruiz et al. 1999; Goulletquer et al. 2002; Grosholz 2002; Torchin and Mitchell 2004). Introduced species are considered to be one of the most serious threats to the conservation of natural biodiversity (Coblentz 1990; Mooney and Cleland 2001; Shea and Chesson 2002) and are identified as the second greatest cause (after habitat destruction by human activities) of the loss of biological diversity (Wilcove et al. 1998). In European waters, where *P. macrodactylus* has been present for several years, neither ecological effects nor a decline of native shrimp populations have been reported (Worsfold and Ashelby 2008; González-Ortegón et al. 2010; Micu and Niță 2009). Although it might be economically valuable for fishermen and be a food source for many fishes, long-term monitoring of these populations is necessary because an adaptive period is often observed before the expansion of an introduced species (Herborg et al. 2005). Moreover, *P. macrodactylus* has a high invasive potential (Micu and Niță 2009) with a life cycle of 3 years and a long breeding period (April-October in its native range). Each age group produces at least two cohorts compared with only one or two for other Palaemonidae (Omori and Chida 1988). High tolerances to stressful hypoxic conditions and to variations in salinity were observed for *P. macrodactylus* compared to native species (Chícharo et al. 2009; González-Ortegón et al. 2010). Like other carideans, *P. macrodactylus* is mainly carnivorous and competition for food with indigenous species is likely to occur (González-Ortegón et al. 2010). These interactions could lead to a decrease in the native shrimp population abundances. This could be especially the case for the resident species *P. longirostris* Milne-Edwards, 1837 in the Gironde estuary (Béguer et al. 2007) and *P. serratus* (Pennant, 1777) in Arcachon Bay (Thimel 1989), which both support a traditional fishing industry.

The different populations of *P. macrodactylus* present in the world will be soon analyzed with molecular tools with the dual aims of understanding the global expansion of this species and providing insights regarding potential multiple introductions, which are likely due to their relationship with harbour distributions.

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Annex 1. Records of *Palaemon macrodactylus* in transitional waters on the Atlantic and Channel coasts of France.

Code legend	Sites	Number collected	Record date	Depth (m)	Salinity (psu)	Latitude	Longitude
1	Slack estuary	-	2007-2008-2009	-	-	50°48'N	01°36'E
2	Wimereux estuary	-	2007-2008-2009	-	-	50°46'N	01°36'E
3	Canche estuary	-	2007-2008-2009	-	-	50°32'N	01°35'E
4	Authie estuary	-	2007-2008-2009	-	-	50°22'N	01°34'E
5	Bay of Somme	-	June 2009	3-6	18.0-27.0	50°14'N	01°31'E
-	-	1	October 2009	4.8	30		
6	Bay of Seine	presence*	2006	-	-	49°26'N	00°11'E
7	Mont Saint-Michel bay	-	2007-2008-2009	-	-	48°39'N	01°27'E
8	Trieux estuary	6	June 2007	5-15	29.3-34.1	48°48'N	03°05'W
9	Bay of Morlaix	3	May 2007	3-7	31.9-35.0	48°39'N	03°52'W
-	-	-	May 2009	3-8	26.5-34.6		
-	-	-	September 2009	2-19	28.0-35.1		
10	Aber Wrac'h	32	May 2007	1-15	34.3-39.1	48°36'N	04°34'W
11	Elorn estuary	4	April 2007	7-10	32.0-33.0	48°24'N	04°21'W
12	Goyen estuary	7	May 2007	3-4	33.3-35.1	48°00'N	04°32'W
13	Laïta estuary	-	June 2009	1-4	1.7-33.3	47°49'N	03°32'W
-	-	-	September 2009	2-5	0.9-33.3		
14	Blavet estuary	-	June 2009	2-11	8.0-33.4	47°47'N	03°17'W
-	-	-	October 2009	2-13	9.6-32.8		
15	Vilaine estuary	33	May 2007	3-6	2.09-32.88	47°29N	02°24'W
-	-	-	June 2009	2-8	28.0-33.3		
-	-	-	September 2009	2-5	30.1-34.1		
16	Loire (lower estuary)	-	June 2009	2-6	8.5-32.3	47°18'N	02°02'W
-	-	-	September 2009	2-5	10.8-29.8		
17	Loire (upper estuary)	-	May 2009	1-7	0	47°12'N	01°44'W
-	-	-	September 2009	3-5	0.2-0.8		
18	Sèvre Niortaise estuary	6	May 2007	2-3	19.7-32.7	46°19'N	01°06'W
-	-	-	May 2009	2-6	0.3-35		
-	-	527	September 2009	1-3	31.2-37.5		
19	Charente estuary	5	September 2007	-	3-25	45°57'N	01°02'W
	-	larvae	September 2007	-	3-5		
-	-	2	May 2009	8	24.5		
-	-	27	October 2009	4	6.9-32.7		
20	Seudre estuary	44	May 2009	4-8	20.4-23.4	45°45'N	01°04'W
-	-	-	October 2009	3-10	36.6-37.1		
21	Gironde (lower estuary)	10	June 2008	7	-	45°26'N	00°57'W
-	-	30	June 2009	5-13	18.9-25.2		
-	-	35	November 2009	6-10	21.4-24.4		
22	Gironde (upper estuary)	80	June 2009	4-9	5.4-16.8	45°25'N	00°46'W
-	-	29	November 2009	4-7	7.9-13.5		
23	Garonne river (downstream)	7	September 2007	10	-	45°01'N	00°35'W
24	Dordogne river	-	October 2008	2-6	0.1-0.4	44°50'N	00°10'W
-	-	-	September 2009	2-5	0.1-1.8		
25	Garonne river (upstream)	-	September 2009	2-9	0.1-0.5	44°41'N	00°24'W
26	Arcachon bay	larva	October 2010	5.0	29.3	44°40'N	01°11'W
	-	9	March 2010	3-6	26.7-31.2	44°40'N	01°11'W
27	Adour (upper estuary)	-	September 2009	4-7	0.1-0.2	43°30'N	01°16'W
28	Adour (lower estuary)	67	April 2009	5-16	0.5-27.8	43°30'N	01°29'W
-	-	-	September 2009	3-11	0.2-16.8		
29	Bidassoa	1	April 2009	7	25.2	43°21'N	01°46'W
-	-	-	September 2009	2-7	1.9-31.6		