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Research article

First record of the Asian prawn *Palaemon macrodactylus* Rathbun, 1902 (Caridea: Palaemonoidea: Palaemonidae) from the Black Sea

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Abstract

The first specimens of the Asian prawn *Palaemon macrodactylus* Rathbun, 1902, including ovigerous females, were identified in estuarine water bodies along the Romanian coast during early September 2009, in large numbers compared to the native prawns *Palaemon elegans* Rathke, 1837 and *Palaemon adspersus* Rathke, 1837. Examination of archived samples backdated the first occurrence of *P. macrodactylus* in the Black Sea to 2002. The supposed vector of introduction is via ballast water, from ships travelling from Rotterdam. Native to the seas of Japan and Korea, *P. macrodactylus* was first introduced in California in the 1950s, Australia in the 1970s and later to Britain, parts of continental Europe and Argentina. The Asian prawn already has well-established populations in the Romanian Black Sea and, taking into consideration the invasion record and the ecology of this species, it is very likely that it will successfully invade the whole of the Black and Azov Seas and the adjacent estuaries, deltas and limans.

Key words: *Palaemon macrodactylus*, Black Sea, Romania, estuarine, establishment

Introduction

The Asian prawn *Palaemon macrodactylus* Rathbun, 1902 is native to Japan and Korea (Rathbun 1902; Kubo 1942), while the Chinese and Taiwanese records by Holthuis (1980), Liu et al. (1990) and Chan and Yu (1985) might belong to different species (d'Udekem d'Acoz et al. 2005).

Palaemon macrodactylus is euryhaline, showing a strong osmoregulatory capability throughout a salinity range of 3-35 PSU (Born 1968; González-Ortegón et al. 2006). In both its native and introduced ranges it is a permanent resident of estuaries, being able to complete its life cycle in estuarine brackish water. Its normal salinity range is 1-15 PSU, with highest densities of its populations usually occurring in the upper part of estuaries, at salinities lower or equal to 10 PSU (Ogawa et al. 1983; González-Ortegón et al. 2006).

The first introduction outside the species' native range dates from the 1950s, when the shrimp was recorded in San Francisco Bay, California (Newman 1963) where it became established and abundant (Carlton 1979; Siegfried 1980; Jensen 1995). Today its range extends from Willapa Bay, Washington to the Southern California Bight, where it is called "oriental shrimp" (Ruiz et al. 2000; Elder 2009).

The second documented introduction was in the 1970s in southeast Australia (Newcastle) where the Asian prawn became well-established (Buckworth 1979; Holthuis 1980; Pollard and Hutchings 1990; Bruce and Coombes 1997; Walker and Poore 2003).

P. macrodactylus was first identified in Britain in 2004 in the Stour and Orwell estuaries (Ashelby et al. 2004), although reexamination of archived samples backdated its occurrence in the River Thames to 1992 (Worsfold and Ashelby 2006). In continental Europe the species was subsequently recorded from Spain (Cuesta et al. 2004), The Netherlands (d'Udekem d'Acoz et al. 2005; Faasse 2005; Tulp 2006), Belgium (d'Udekem d'Acoz et al. 2005; De Blauwe 2006; Rappé 2007), France (Beguer et al. 2007), Germany (González-Ortegón et al. 2007) and Portugal (Chicharo et al. 2009). At the same time the introduction of *P. macrodactylus* in the southwestern Atlantic was recorded from Argentina, Mar del Plata Harbour (Spivak et al. 2006).

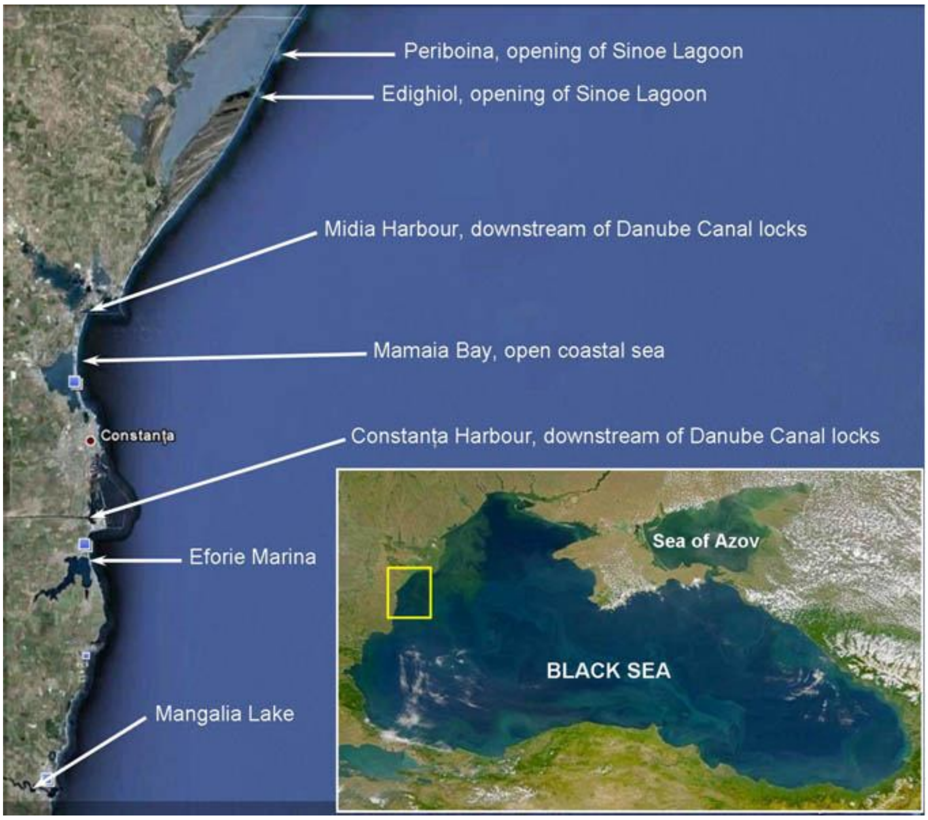

Figure 1. The Black Sea with the study area (yellow rectangle) and the sampling sites (white arrows)

Many aspects of the biology of *P. macrodactylus* have been studied worldwide: life history and reproductive strategies (Omori and Chida 1988a,b,c), egg attachment (Fisher and Clark 1983), brood-associated bacteria (Fisher 1983a), brood infection by a fungus (Fisher 1983b), larval development (Little 1969) and energy budgets (Chin et al. 1992), morphological abnormalities (Beguer et al 2008), predation and diet (Sitts and Knight 1979; Siegfried 1982; González-Ortegón et al. 2009), estuarine distribution in relation with environmental factors (Ogawa et al. 1983; González-Ortegón et al. 2006), osmoregulation (Born 1968; González-Ortegón et al. 2006) and potential impact as an alien species and mitigation measures (Chicharo et al. 2009; González-Ortegón et al. 2009).

In the present paper, the presence of *P. macrodactylus* is documented in brackish water bodies along the coast of Romania. This is the first record of the species in the Black Sea.

Material and Methods

The first specimens of *P. macrodactylus* were collected during September 2009 by SCUBA diving in Constanta Harbour (below the sluice gates of the Danube-Black Sea Canal) and Mamaia Bay during a sampling campaign, which was not directed at this species. The colouration of mature *P. macrodactylus* females (olive green or dark brown with a longitudinal white stripe) readily distinguishes it from the native prawns *P. elegans* and *P. adspersus*, and it was this coloration which caught the eye of the author and prompted immediate recognition as a different species.

Subsequently samples have been collected from Periboina, Edighiol, Midia Harbour, Eforie Marina and Mangalia Lake (Figure 1), using a diver-operated pushnet at depths of 1-5 m. Samples were fixed in 10% seawater-formalin for 24 hours and then transferred to 70% ethanol for storage.

The collected material was identified as *P. macrodactylus* by microscopic examination. The following characters were recognized in the collected specimens:

- rostrum with 10-12 dorsal teeth (including postorbital teeth but not the superior tooth of the apical cleft), of which 2 or 3 teeth are on carapace behind orbit;
- a double row of setae on the ventral margin of the rostrum;
- shorter ramus of the outer flagellum of antennula fused for about 20% of its length to longer ramus;
- lack of a protuberance above spine of the posterolateral margin of the sixth abdominal segment;
- chela of P2 with fingers ≈0.7 x as long as palm.

All these characters are in agreement with the identification keys for European Palaemonidae (González-Ortegón and Cuesta 2006; d'Udekem d'Acoz et al. 2005; Ashelby et al. 2004) (Figure 2).

Feeding habits and general behaviour were investigated by laboratory experiments and by direct underwater observations while diving.

18 specimens of *P. macrodactylus* (5 age 2+ ovigerous females, 3 age 0+ ovigerous females, 10 age 0+ and 1+ males and females) have been deposited at the National Museum of Natural History "Naturalis", Leiden, The Netherlands under accession number RMNH D 53139 .

Results and Discussion

Localities, dates and invasion pathway

909 specimens of *P. macrodactylus* have been collected in total from 7 locations along the Romanian Black Sea coast, from North to South: Periboina, Edighiol, Midia Harbour, Mamaia Bay, Constanța Harbour, Eforie Marina, Mangalia Lake, in September 2009 (for details see geo-referenced record data in Annex 1).

Examination of archived samples taken in 2002 from one of the locations mentioned above (Constanta Harbour, downstream of the Danube-Black Sea Canal sluice gates) and misidentified as *P. elegans* and *P. adspersus* (Micu and Micu 2004) backdates the occurrence of *P. macrodactylus* in the Black Sea to 2002.

The first Black Sea occurrence of *P. macrodactylus* within Constanta Harbour is conducive to the hypothesis that the vector of introduction was ship ballast water. All points of introduction, reported until now, worldwide are in or near major international harbours, and Constanta is the largest maritime traffic hub in the Black Sea. Continuous ship traffic exists between Constanta and Rotterdam, from where the Asian prawn has been previously recorded (d'Udekem d'Acoz et al. 2005), so it is possible that Rotterdam may be the secondary source for the introduction of *P. macrodactylus* in the Black Sea.

Habitat choice in the Black Sea

All sampling sites are in brackish waters, since the surface salinity of the Romanian Black Sea is 14-15 PSU on average. However, only one of the sampling sites, Mamaia Bay, is situated in open coastal waters with relatively stable salinity, while all the others are in estuarine waters, where salinity is lower and unstable due to freshwater inflow and mixing. Salinity ranged between 4.2-12.8 PSU across all estuarine sites.

Habitat choice of *P. macrodactylus* portrays it as a cryptic and sciaphilic (shadow-loving) species, more sciaphilic than any of the native Black Sea shrimps. Younger specimens encountered during sampling were clinging on the underside of rocks, concrete slabs or hidden inside *Ficopomatus enigmaticus* (Fauvel, 1923) biogenic reefs, while most of the mature specimens were hidden in rock crevices and meters-deep recesses of concrete structures. Where hard substrata were not present, the prawns were completely hidden in the densest vegetation available: *Potamogeton pectinatus* L. meadows or algae. This agrees well with literature data on its behaviour, regarding nocturnal vertical migrations, preying mainly at night and only in hidden and darker places during daytime (Sitts and Knight 1979).

In Japan the favourite habitat of *P. macrodactylus* are dense meadows of *Zostera japonica* Ascherson & Graebner and its sciaphilic habits are used by commercial fishermen, who catch it with brush traps (Omori and Chida 1988c). At the locations sampled in the Black Sea the habitats preferred by *P. macrodactylus* are, in this order: rock and concrete, biogenic reefs built by the polychaete *Ficopomatus enigmaticus* or mussels *Mytilus galloprovincialis* Lamarck, 1819 and vegetation (*Potamogeton* meadows, filamentous algae or reed).

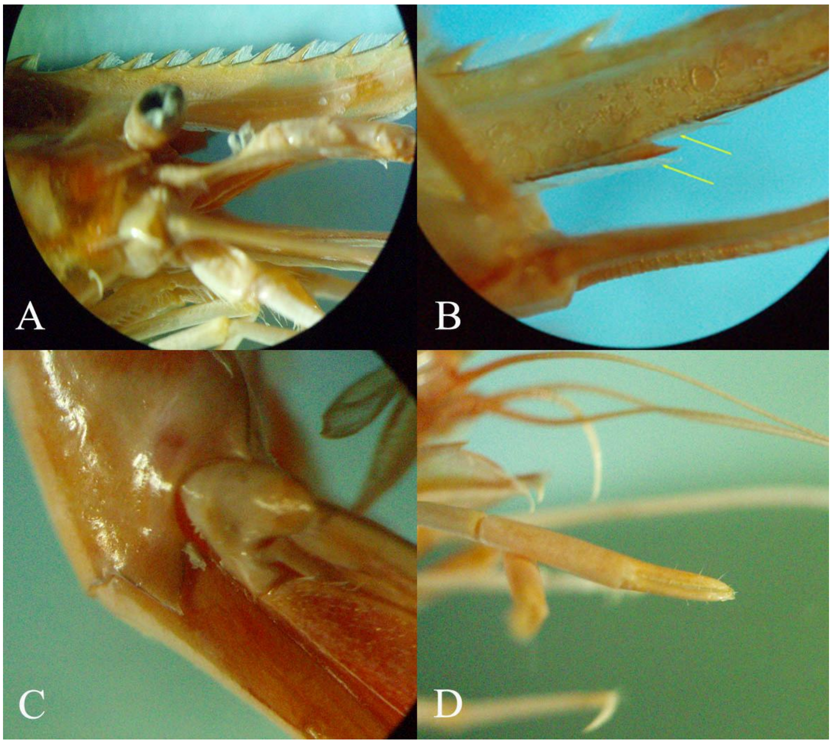

Figure 2. Morphological characters of specimens captured in the Black Sea: dorsal teeth of rostrum, 3 behind orbit (A), double row of setae on the ventral margin of the rostrum (B), no protuberance above spine of posterolateral margin of 6th segment (C), chela of P2 with fingers ≈0.7 x as long as palm (D)

Reproductive and establishment success

P. macrodactylus has a life cycle of 3 years. In the native range the breeding season is April – October (Omori and Chida 1988a), and it might be the same in the Black Sea since we found plenty of ovigerous females of all ages in September.

Females spawn repeatedly during a long annual breeding season for 3 years, after maturing early in their life. Each age group of females produces several new cohorts per year: 0+ females spawn 1-2 times in their first season, while 1+ and 2+ females spawn 5-9 times per season, with inter-spawning periods of about 20 days. Incubation of the brood is also 20 days, with a new series of eggs ripening in the ovaries during the incubation of the current brood. The same incubation period has been observed by the authors in *P. macrodactylus* females from the Black Sea kept in aquaria.

The 0+ age group consists of two sub-populations, named short-term and long-term generations. The short-term generation is spawned early in the season and matures and reproduces by the end of the same season, putting out a great reproductive effort. The long-term generation is spawned late in the season and reproduces the next year. The proportion between the two generations (number of 0+ females spawning) is influenced by the duration of warm climate suitable to breeding (Omori and Chida 1988a,b,c).

This mixed reproductive strategy and high reproductive output, coupled with high osmo-regulatory capability and the ability to withstand long transport times in ballast water, renders the Asian prawn a very competitive and successful invader.

The long persistence of *P. macrodactylus* populations on the Romanian coast (at least 3 full life cycles have been completed during 2002-2009) and the common occurrence, in vast numbers, of ovigerous females of all ages and young adults clearly show that the species is already well-established in the Black Sea. It could have been present in the Black Sea even before 2002, but we could not find earlier archived samples to ascertain this.

Figure 3. Ovigerous *P. macrodactylus* females: age 2+ (top) and 0+ (bottom). Divisions on the scale bar are millimeters

Size and morphology

In Japan the maximum size attained by *P. macrodactylus* is 18 mm carapace length (CL), while the size of the smallest ovigerous females is 8.5 mm CL (Omori and Chida 1988a). Maximum size in collected Black Sea specimens was 15.8 mm CL (shortest carapace length, measured from the anterodorsal midpoint between the postorbital edges to the postero-dorsal edge of carapace), reached by a mature ovigerous female. The smallest ovigerous female had a CL of 5.9 mm (Figure 3), which is much smaller than that recorded from the native range.

External deformities were observed only in 5 specimens (0.55% of the total catch) and concerned only the rostrum, which was curved downwards in 2 cases and deflected laterally in 3 cases. In all cases the dentition of the rostrum remained normal.

Predatory behaviour and potential ecological impacts

Throughout its native and introduced range, the diet of *P. macrodactylus* includes mysids, gammarid amphipods, copepods, polychaetes, small bivalves, decapod and fish larvae, but carnivory exceeds detritivory, as plant fragments might originate in the gut of mysid prey. The prawn is mainly predatory, items of animal origin accounting for 75-93% of its gut contents. Mysids are the main prey (44-79%), followed by copepods which are abundant in gut contents and polychaetes which contribute more biomass. *P. macrodactylus* selects for mysids of 4-8 mm total length and TL of consumed mysids is positively correlated with size of the predator (Sitts and Knight 1979; Siegfried 1982).

Suitable potential prey items are abundant at all sites where we have collected *P. macrodactylus* in the Black Sea: mysids like *Paramysis agigensis* Băcescu, 1938, *Mesopodopsis slabberi* (van Beneden, 1861), *Limnomysis benedeni* Czerniavsky, 1882, *Diamysis bahirensis* (G.O. Sars, 1877); gammarid amphipods like *Dikerogammarus haemobaphes* (Eichwald, 1841), *D. villosus* (Sowinsky, 1894), *Chaetogammarus placidus* (G.O. Sars, 1896), *Lanceogammarus andrussovi* (G.O. Sars, 1896), *Pontogammarus maeoticus* (Sowinsky, 1894), *Obesogammarus crassus* (G.O. Sars, 1894), *Microdeutopus gryllotalpa* Costa, 1853; polychaetes like *Alitta succinea* (Frey & Leuckart, 1847), *Syllis gracilis* Grube, 1840, *Paranais litoralis* (Müller, 1780), *Salvatoria clavata* (Claparède, 1863); postlarvae of bivalves like *Mytilus galloprovincialis*

Lamarck, 1819, *Mytilaster lineatus* (Gmelin, 1791), *Anadara inaequivalvis* (Bruguière, 1789), *Cerastoderma glaucum* (Poiret, 1789), and larvae of the mud crab *Rhithropanopeus harrisii* (Gould, 1841) (Micu and Micu 2004; Băcescu 1954).

In the estuarine environments inhabited by *P. macrodactylus* competition for these food items could possibly occur with native small fish, juvenile native Danube crayfish *Astacus leptodactylus* Eschscholtz, 1823 and the introduced mud crab *Rhithropanopeus harrisii*, while in the coastal sea the most obvious competitors are the native prawns *P. adspersus* and *P. elegans*. However food supply is abundant and it is highly unlikely that it could become limiting for any of these predators.

Other resources like shelter are not limiting either and, should they become, the habits of *P. macrodactylus* may help in resource-sharing with these species. Laboratory observations of the authors have shown that the Asian prawn is more benthic and cryptic than native species, preferring to walk rather than swim whenever it is possible, hiding in deep and narrow recesses where the natives have not been observed, and hunting only in darkness. More importantly, *P. macrodactylus* is as yet the only prawn in the upper reaches of estuaries, as the native prawns rarely occur there.

When occurring in sympatry, *P. macrodactylus* has a clear competitive advantage over native prawn species through its mixed reproductive strategy and high reproductive output, as well as in the length of its spawning season. In situ diving observations by he authors have shown that while native *P. adspersus* and *P. elegans* spawn from June to August, *P. macrodactylus* spawns until the end of October. Water temperatures at which *P. macrodactylus* can spawn in the Romanian Black Sea start in the month of May, so its spawning season is 3 months longer than that of native prawns.

However, considering the relatively long presence of *P. macrodactylus* in the Romanian Black Sea (since 2002, possibly even earlier), no deleterious effects on native species have been recorded. This is consistent with the fact that in Britain, where the species has been present since 1992 (Worsfold and Ashelby 2006), no ecological effects are yet apparent and no measurable decline of potential native competitors has been recorded (ICES 2005). Also in the Guadalquivir estuary no negative effects could be identified in spite of extensive ecological niche overlap with the native *Palaemon longirostris* H. Milne-Edwards, 1837 (González-Ortegón et al. 2009).

In conclusion the estimated ecological effect of *P. macrodactylus* on the Black Sea ecosystem is not apparently negative. There is also the potential for a positive socio-economic impact, since the occurrence of large prawn populations in estuarine waters (where previously there was none) might lead to the development of a new fishery and also of aquaculture farms in the lagoons of the Danube Delta.

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Annex 1. Records of *Palaemon macrodactylus* in the Black Sea

Location	Record coordinates		Record date	Salinity (PSU)	Number collected	Habitats
	Latitude, °N	Longitude, °E				
Periboina	44°36'42"	28°55'44"	21.09.2009	4.2	59 (7 ovigerous ♀♀)	Rocks *Potamogeton meadow*
Edighiol	44°34'10"	28°54'07"	21.09.2009	4.5	68 (12 ovigerous ♀♀)	Rocks *Potamogeton* meadow
Midia Harbour, downstream of the Danube-Black Sea Canal sluice gates	44°19'25"	28°37'39"	20.09.2009	6.2	357 (51 ovigerous ♀♀)	*Ficopomatus enigmaticus* reefs *Potamogeton* meadow Concrete structures
Mamaia Bay	44°13'55"	28°38'04"	02.09.2009	14	25 (5 ovigerous ♀♀)	Algal thickets on sand
Constanta Harbour, downstream of the Danube-Black Sea Canal sluice gates	44°05'58"	28°37'31"	03.05.2002	10	41	*Ficopomatus enigmaticus* reefs *Mytilus galloprovincialis* musselbeds Concrete structures
Constanta Harbour, downstream of the Danube-Black Sea Canal sluice gates	44°05'58"	28°37'31"	05.09.2009	6	202 (21 ovigerous ♀♀)	*Ficopomatus enigmaticus* reefs *Mytilus galloprovincialis* musselbeds Concrete structures
Eforie Marina	44°03'49"	28°38'32"	11.09.2009	12.8	83 (11 ovigerous ♀♀)	*Ficopomatus enigmaticus* reefs *Mytilus galloprovincialis* musselbeds
Mangalia Lake	43°48'45"	28°31'10"	15.09.2009	11.7	115 (15 ovigerous ♀♀)	Rocks *Potamogeton* meadow