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First record of *Cordylophora caspia* (Hydrozoa: Cnidaria) in the Tagus estuary, central Portugal

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The Ponto-Caspian hydroid Cordylophora caspia *has been found for the first time in the Tagus estuary. There is only one previous citation for this invasive species in Portuguese waters. The colonies of* C. caspia *were branched and had healthy gastrozooids and gonophores. The specimens were collected from a saline boundary zone characterized by high fluctuations in salinity (maximum of 15.3 and minimum of 0.2) and high suspended solids loading.* Cordylophora caspia *is capable of colonizing man-made infrastructures such as industrial facilities and can inhabit both brackish and freshwater environments. These features of* C. caspia*, together with its resilience when in a dormant stage (menonts), indicate that the monitoring of this invasive species is advisable in the Tagus estuary.*

Keywords: *Cordylophora caspia*, invasive species, salinity, turbidity, Iberian Peninsula

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INTRODUCTION

The Ponto-Caspian invasive species *Cordylophora caspia* (Pallas, 1771) is a colonial euryhaline athecate hydroid that is mainly distributed throughout the northern hemisphere (Arndt, 1984; Folino-Rorem *et al*., 2009). Invasions by Ponto-Caspian macroinvertebrate species have been facilitated by the construction of man-made canals in Europe. These canals have created three inland migratory corridors in central Europe that connect European river basins (Bij de Vaate *et al*., 2002). *Cordylophora caspia* has made use of these corridors to extend its distribution, thus reaching the Baltic and the River Rhine basin (Bij de Vaate *et al*., 2002) and has spread from these areas throughout the world via ballast water and ship fouling (Rees & Gershwin, 2000; Pienimäki & Leppäkoski, 2004; Streftaris *et al*., 2005).

Detailed descriptions of *Cordylophora caspia* are provided by Morri (1981: 45, figure 13, Pl. I figure 3 & Pl. II figure 3) and Schuchert (2004: 346, figure 10). *Cordylophora caspia* can tolerate a wide range of salinities (Morri & Boero, 1986; Bij de Vaate *et al*., 2002; Janssen *et al*., 2005) and can even inhabit freshwater environments (Roos, 1979; Smith *et al*., 2002), although it grows optimally in mesohaline waters, especially in the salinity range 15–17 (Kinne, 1966; Arndt, 1984). Arndt (1984) stated that *C. caspia* can occur in inland waters when its appearance coincides with ionic anomalies in freshwater (chloride concentrations). Although this may favour the occurrence of *C. caspia* in freshwater environments, the species is able to make physiological and ecological adjustments that enable it to live in soft water of low alkalinity (Smith *et al*., 2002), in agreement with the alternative proposal of Hutchinson (1993) and against Arndt's (1984) prediction. This colonial hydroid has specialized polyps for feeding and reproduction, although asexual reproduction is also possible via production of buds (Roos, 1979; Folino-Rorem & Indelicato, 2005). *Cordylophora caspia* overcomes adverse environmental conditions by producing resistant forms called menonts, which are spherical structures within coenosarc tissue in the stolon of the colony (Roos, 1979; Morri, 1980). Menonts are formed under adverse environmental conditions and as part of a remarkable survival strategy; they remain dormant to regenerate under favourable conditions (Folino-Rorem & Indelicato, 2005). Using settlement panels and aquarium rearing, Morri & Bianchi (1983, see pp. 190–192) described the life cycle of the species in the Po River Delta, where reproduction occurs especially during spring and menonts were found during summer.

The aim of this study is to report the occurrence of *C. caspia* in the Tagus estuary and also to characterize the habitat in which *C. caspia* has been found. Additionally, we intend to bring attention to the occurrence of *C. caspia* in this industrialized estuary, because this hydroid can clog man-made infrastructures (such as industrial pipes and screens, e.g. Folino-Rorem & Indelicato, 2005).

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MATERIALS AND METHODS

Study site

The Tagus estuary is one of the largest estuarine systems in Europe and covers an area of approximately 325 km^2. It is a mesotidal estuary with a tidal range of between 1 m (neap tides) and 4 m (spring tides). The study site is located in an intertidal area of the northern bank of the estuary, in Alverca, 4 km seawards from the head of the estuary at Vila Franca de Xira (Figure 1). The intertidal zone is approximately 30 m wide during spring tides. The surrounding vegetation in the supratidal zone is mainly dominated by *Phragmites* spp. and *Juncus* spp.

A layer of fluid mud was deposited in the intertidal area at the beginning of August 2011 until about the 20 August 2011. Sediment sampling was conducted while the fluid mud was still present in the study site.

Field and laboratory procedures

Field observations were made between 23 June and 18 August 2011. Salinity was measured in the water column (3 replicate samples) with a standard field probe (WTW 340i), between 9 July and 15 August and during consecutive tidal cycles between 16 and 18 August. Four sediment samples were collected from the study area on 15 August 2011, to assess the degree of hydration and the organic matter content. The water content of the sediment was estimated from the weight loss after drying the wet sediment to a constant weight at 100°C. Organic matter was determined by loss of weight on ignition at 500°C for 24 h in a muffle furnace. The salinity, organic matter and sediment water content values are reported as mean ± standard deviation. Salinity is considered a dimensionless parameter (e.g. Stickney, 2009).

Biological samples were collected on 29 August 2011. The biological material was preserved in 70% ethanol and transported to the laboratory to confirm the taxonomic identity of the species. Photographs were taken with a Motic digital camera attached to a stereoscopic microscope.

RESULTS

Species record

Samples of *Cordylophora caspia* were collected from a hard calcareous substrate (limestone) that was only exposed during spring tides, at Alverca in the Tagus estuary (Figure 1). This substrate was heavily colonized by *Balanus* spp. and the tube-building amphipod *Corophium multisetosum*. Tubes of *Corophium multisetosum* were also observed attached to the hydroid colony (see also organic matter debris, Figure 2). *Cordylophora caspia* was restricted to a small area on the top surface of the substrate. Samples of *C. caspia* displayed erect, branching white hydroid colonies, with the stems reaching a height of approximately 2 cm from the stolon (Figure 2). The colonies had gastrozooids

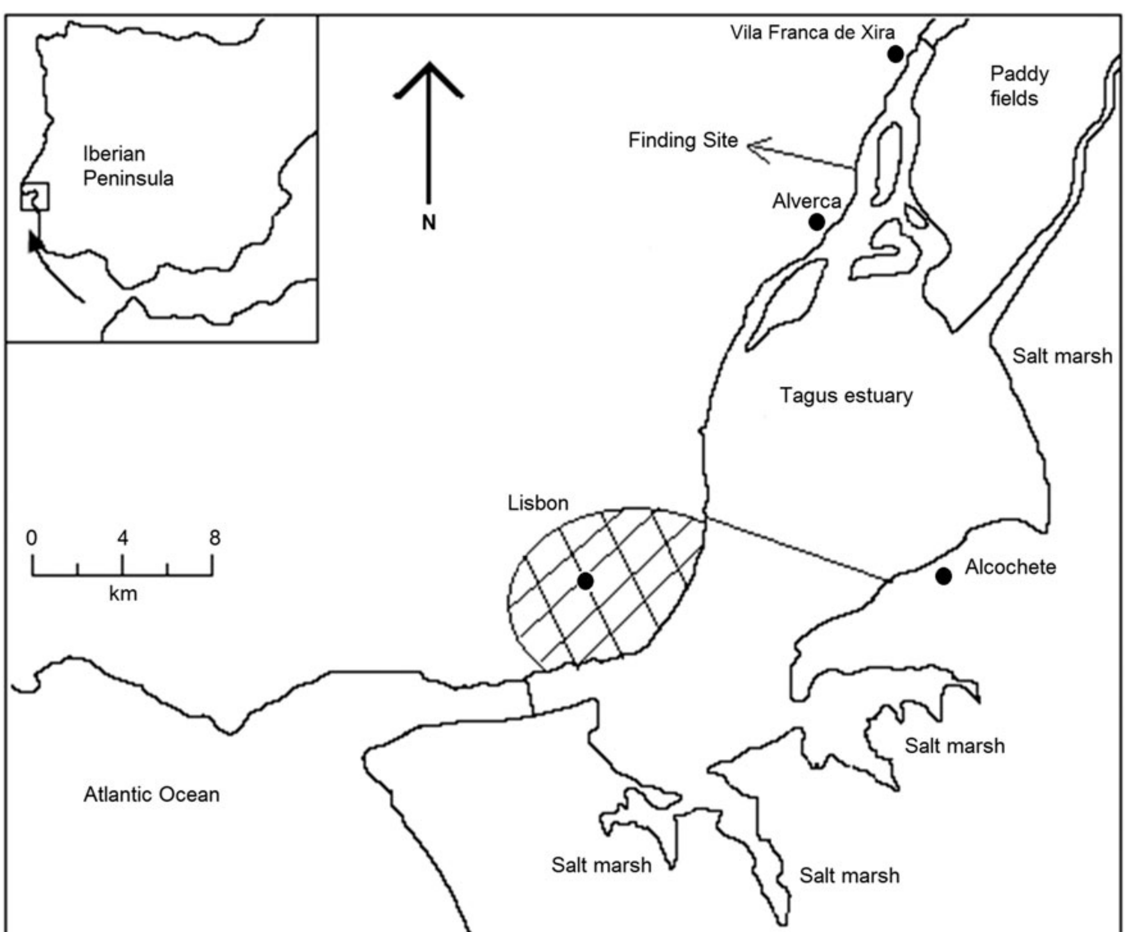

Fig. 1. Site where the colony of *Cordylophora caspia* was discovered at Alverca, the Tagus estuary. Transverse lines over the estuary are bridges.

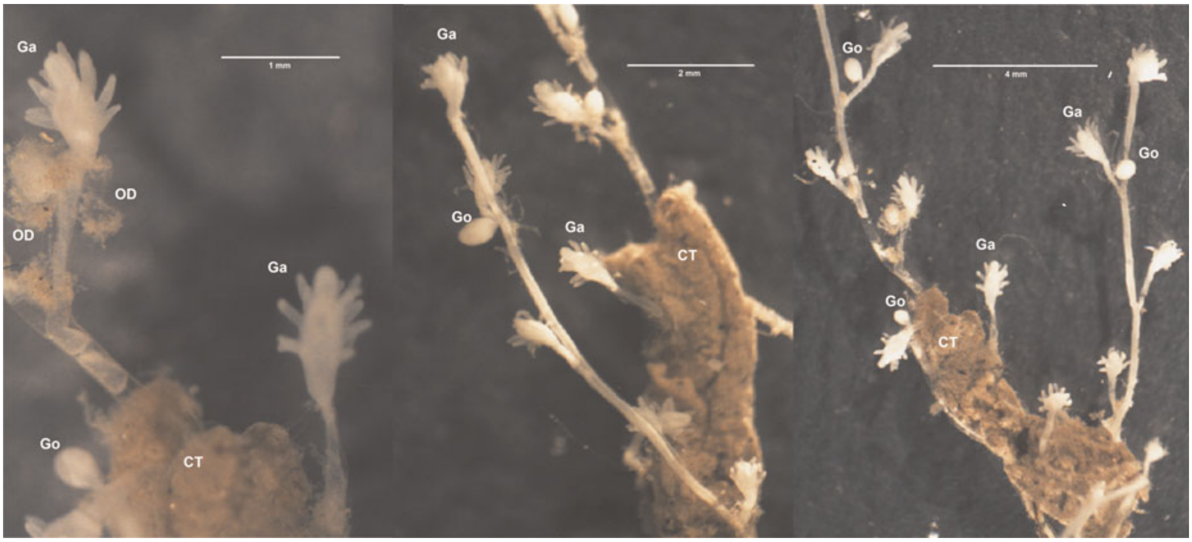

Fig. 2. Details of *Cordylophora caspia* collected in Alverca in decreasing order of magnification (from left to right). CT, *Corophium multisetosum* tube; Ga, gastrozooid; Go, gonophore; OD, organic debris.

with scattered filiform tentacles and gonophores borne on hydranthophores (Figure 2).

Environmental features of the site

The study site is located in a saline transition zone (Figure 1) within which the salinity varies over time from freshwater values to mesohaline values, with a maximum salinity value of 15.3 and a minimum of 0.2 (Figure 3). Sharp saline fluctuations were also recorded daily between low and high tide (Figure 3B). The water column is very turbid in the area, and it was impossible to see the bottom at any depth during the survey, even near the water's edge.

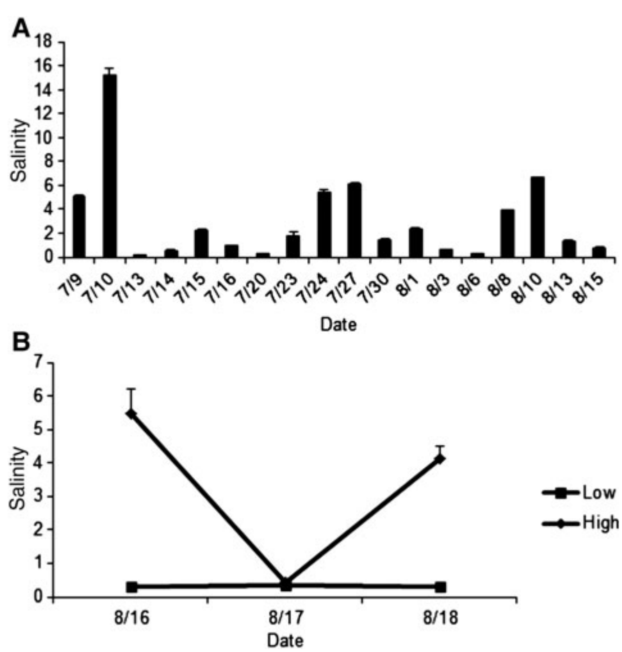

Fig. 3. Salinity fluctuations (mean ± standard deviation) in the study site: (A) over time; (B) during consecutive tidal cycles.

DISCUSSION

Species record, substrate preferences and interaction with other species

Cordylophora caspia was found on limestone at the site (Figure 1), but it can colonize a wide variety of hard substrates (Roos, 1979; Morri & Boero, 1986; Folino-Rorem & Indelicato, 2005; Wintzer *et al.*, 2011). The presence of the species in the fouling on ship hulls and in ballast water aids its worldwide spread (Pienimäki & Leppäkoski, 2004; Folino-Rorem *et al.*, 2009). Bivalves are often reported as a suitable substrate for the settlement of *C. caspia* and the species has been found on, e.g. shells of the zebra mussel *Dreissena polymorpha* (Olenin & Leppäkoski, 1999) or *Dreissena* spp. beds (Ricciardi, 2001), the invasive bivalves *Mytilopsis leucophaeta* (Escot *et al.*, 2003) and *Corbicula fluminea* (Escot *et al.*, 2003; Servia *et al.*, 2006). The invasive bivalve *Corbicula fluminea* inhabits the tidal region of the freshwater sector of the Tagus estuary (Chainho, 2008), potentially facilitating the spread of *Cordylophora caspia* riverwards. Further, Leloup (1952) also suggested that the species might attach to the feathers and legs of aquatic birds, thereby enhancing dispersal.

In turn, other fauna may use species of hydroids as a substrate for settlement (Bradshaw *et al.*, 2003). In this study, tubes of *Corophium multisetosum* were observed attached to the hydroid colony (see also organic matter debris, Figure 2). Roos (1979) described colonies of *Cordylophora* on water-lily stalks crowded by the amphipod *Gammarus tigrinus* in The Netherlands, especially during August. In the latter case, *Gammarus tigrinus* preys on the hydrants of *C. caspia*, whereas *Corophium multisetosum*, a deposit-feeder (see e.g. Cunha *et al.*, 2000), does not. It has been suggested that *Cordylophora caspia* is an attractive substrate for barnacles, amphipods and polychaetes (Von Holle & Ruiz, 1997, cited by Folino, 2000).

Environmental features of the site and species tolerance

The finding site was characterized by high fluctuations in salinity and high concentration of suspended solids. The maximum concentration of suspended sediment in the Tagus estuary (up to 250 mg l^{-1}) was measured in an area located about 5 km downstream of the study site (Portela & Neves, 1994). The dissolved oxygen concentration is usually higher than 5 mg l^{-1}, but lower levels sometimes occur in the mixing zone close to the finding site (Ferreira *et al.*, 2007). This type of environmental feature is commonly described near the estuarine turbidity maximum (ETM) (Eisma, 1993). High concentrations of suspended particulate matter associated with the ETM may lead to the formation of fluid mud (e.g. Kirby & Parker, 1983), as observed in the study area. Since *C. caspia* tolerates low values of salinity, transparency, depth and intermediate levels of dissolved oxygen (Wintzer *et al.*, 2011), it is able to proliferate in these harsh conditions. However, the species is unable to survive low oxygen concentrations (Fulton, 1962). Saline conditions outside the optimum value slow the growth of the colony, reduce the number of branches and shorten the size of the gonophores (Kinne, 1964, 1966; Arndt, 1984), probably because of physiological adaptations to stress (Kinne, 1964). *Cordylophora caspia* can inhabit waters of varying salinity and can even live in freshwater (e.g. Kinne, 1964, 1966; Arndt, 1984; Smith *et al.*, 2002; Folino-Rorem & Indelicato, 2005), which enables the species to extend its distribution riverwards. The regeneration of *C. caspia* from menonts and the ability of this species to quickly proliferate in varying salinities make it difficult to control its populations (Folino-Rorem & Indelicato, 2005) in newly invaded habitats.

Some industries take water for cooling and agricultural purposes from the freshwater tidal reaches of the Tagus estuary, some kilometres upstream from the finding site. A biofouling control plan for this estuarine section could be justified by the ecological and physiological plasticity of *C. caspia* as well as by its ability to colonize and compromise industrial infrastructures (Folino-Rorem & Indelicato, 2005).

Biodistribution

Records of *C. caspia* are scarce in the Iberian Peninsula (Altuna, 2010). The first record of the species on the Portuguese coast was in an oligohaline environment, the Santo André lagoon, in south-western Portugal (Correia *et al.*, 2012; Figure 4). This discovery was made during sampling surveys conducted during the 1980s; however, the species was not observed during a survey conducted in 2010 (Correia *et al.*, 2012). *Cordylophora caspia* was also described

Fig. 4. Distribution of *Cordylophora caspia* in the Iberian Peninsula: (1) Minho River; (2) Tagus estuary; (3) Santo André lagoon; (4) Guadalquivir River; (5) Albufera de Valencia. See text for references. The main Iberian rivers are shown and named.

in freshwater environments such as streams, rivers, lakes and reservoirs, and also in brackish Iberian waters (García-Berthou *et al.*, 2007; Cobo *et al.*, 2010). As such, the species has been reported from the Guadalquivir River (southern Iberian Peninsula; Escot *et al.*, 2003), the Minho River and from Albufera de Valencia (north-west and east of the Iberian Peninsula respectively; Servia *et al.*, 2006). All these locations are shown in Figure 4.

In accordance with Schuchert (2004), *C. caspia* distribution is 'circumglobal in temperate and subtropical regions, usually in brackish waters as in estuaries, river deltas and lagoons'. Arndt (1984) described the worldwide distribution of the species showing that it spread mainly in Europe and North America. Folino (2000) and Folino-Rorem *et al.* (2009) studied the world distribution of the invasive genus *Cordylophora*; these studies were focused on genus rather than species taxonomic level because it is not yet clear if among the current eight species of *Cordylophora* some could be synonyms or actual distinct species.

Concluding remarks

The invasive hydroid *Cordylophora caspia* is reported for the first time in the Tagus estuary, on the central Portuguese continental coast. The species was found in a harsh environment within the Tagus estuary (with acute fluctuation of salinity and high turbidity), which has probably prevented optimal growth of colonies. The worldwide distribution of *C. caspia* attributable to anthropogenic transport vectors, the ecological resilience of the species and its ability to colonize brackish or freshwater environments, the absence of population control and the consequent spread of this invasive species in the Iberian Peninsula suggest that new records of *C. caspia* will be reported in Iberian waters and beyond.

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