

A fish mortality episode reveals the expansion of invasive mummichog *Fundulus heteroclitus* (L., 1766) in southern Spain

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SUMMARY

The mummichog *Fundulus heteroclitus*, a cyprinodontiform species native to the Atlantic coast of North America, was apparently introduced to southern Iberian Peninsula in the early 1970s, if not earlier. Until now, the Barbate marshes constituted the southern limit of the species in the Iberian Peninsula. However, a fish mortality event promoted by an anoxia episode in the Cachón River (July 31st-August 4th 2016) revealed a southward expansion of the species from its known southern limit. It is not known whether the mummichog has already occupied other potentially suitable habitats south to the Cachón River, but this should be of concern, since it could threaten the unique populations of some native fish species in the area.

Keywords: expansion, cyprinodontiform, Iberian Peninsula, Invasive species, tidal creeks, tidal marshes

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The mummichog *Fundulus heteroclitus*, Fam. Fundulidae (L., 1766), is a cyprinodontiform species from the Atlantic coast of North America. In its native range, the mummichog inhabits marshes and other coastal systems, including nearby freshwater habitats (Kneib, 1986). It is usually associated to tidal environments (Taylor et al., 1979; Kneib, 1986; Taylor, 1999), although

it has also been located in areas with no tidal influence out of its native range (Blanco et al., 2003). The species shows considerable ecological plasticity, which allows it to live in these fluctuating tidal habitats with a wide range of salinity (Kneib, 1986). In tidal environments, females of mummichog lay eggs on the vegetation of marshes in equinoctial tides. When tide recedes the

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eggs become dry, but they are resistant to desiccation and can develop out of the water, waiting for a new tide floods again (Taylor et al., 1979). Often, mummichog appears as a numerically dominant fish species, and it is suspected that it may have negatively affected some native endemic species as the endangered Andalusian toothcarp, *Aphanius baeticus* (Gutiérrez-Estrada et al., 1998).

The mummichog was seemingly introduced to Hawaii, and from there to the Philippines, in the early 20th century, although there are doubts on the outcomes of such introductions (Froese & Pauly, 2015). The only place where the mummichog is clearly invasive is the Iberian Peninsula (Figure 1.1), where introduced individuals seem to be derived from northern populations of North America (Bernardi et al., 1995). The mummichog was apparently introduced to southern Iberian Peninsula in the early 1970s, although the introduction date remains unclear and could be older. When first collected in 1973, the mummichog was thought to be a yet unknown Iberian cyprinodontiform, and was even described as a new species, with the name of *Valencia lozanoi* (Gómez-Caruaña et al., 1984), being finally synonymized with *F. heteroclitus* (Fernández-Delgado et al., 1986). Those first Spanish records came from the Guadalquivir marshes, although the species was recorded soon after (1974) in the Guadiana estuary, more than 100 km of coastline away. The mummichog was then located in the marshes of Cádiz Bay in 1983, becoming an abundant species from there to the Guadiana estuary at the end of 1980's (Fernández-Delgado et al., 1989). The species was reported from the Barbate marshes in 1996, although it might have been present there since around 1993 (Gutiérrez-Estrada et al., 1998; Figure 1.2). In 2005 the mummichog was first recorded in the Mediterranean Sea basin, being captured in the Ebro Delta (Gisbert & López, 2007), where it has apparently succeeded in establishing self-sustained populations (López et al., 2012).

In 1996, the Barbate marshes constituted the southern limit of the Iberian range of the mummichog. Gutiérrez-Estrada et al (1998) sampled two sites in the Cachón River, a small watercourse reaching the Atlantic some 7 km to the south-east, but did not find the species there (Figure 1.3). The Cachón River enters the sea through a narrow mouth that is usually blocked by a sandbar during summers (Figure 1.4). In this situation, anoxia and fish mortality episodes are frequent. One of such episodes started on July 31st 2016 and lasted up to August 4th, when the sandbar was artificially broken and the river was connected to the sea (Figure 2). The inspection of the beached dead fishes revealed a high prevalence of mummichog. Individuals of both sexes were found in high numbers and covering a wide range of sizes (22-100 mm, total length), indicating the existence of a well-established population.

The southward expansion of mummichog could be explained either by a human-mediated transport or by a natural colonization event from the Barbate marshes, implying a dispersal through 7 km sand beach marine habitat. The human mediation cannot be ruled out, but seems unlikely because the mummichog is of no interest for recreational fisheries and limited interest as an ornamental fish (Elvira & Almodóvar, 2001). Direct human intervention might have been relevant for the arrival of the mummichog to the Barbate marshes, probably in relation with aquaculture activities. The most common commercial aquaculture species (e.g. *Sparus aurata* or *Dicentrarchus labrax*) are shared among the different marsh systems occupied by the mummichog in southern Iberia (Macías et al., 2007). It might be plausible that the mummichog would have been moved among marshes as a contaminant of commercial species consignments. However, there have never been aquaculture activities in the Cachón River. Although other possibilities cannot be discarded, for example the escape of alive individuals used as live bait for fishing, the natural colonization of this river from the

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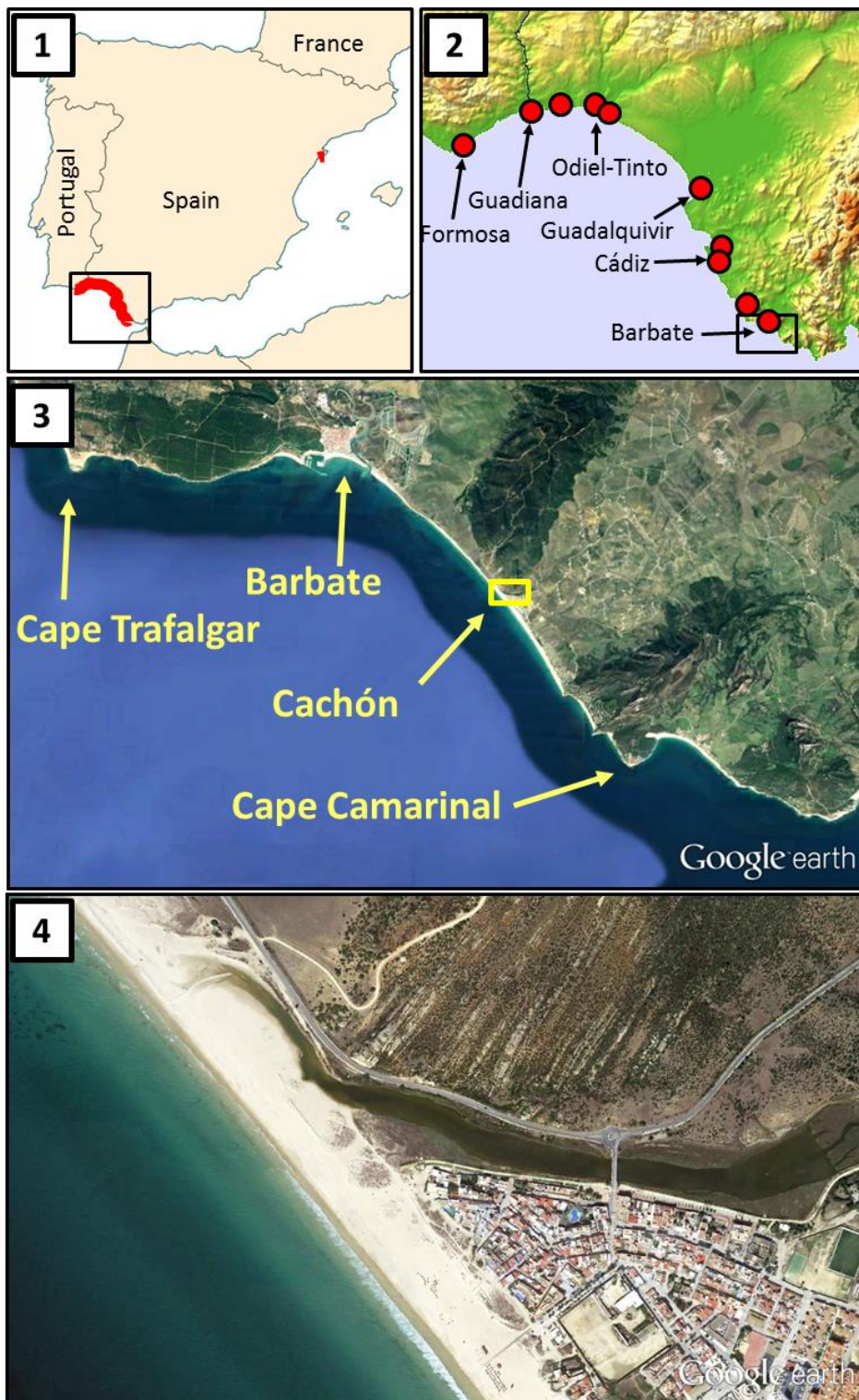


FIGURE 1. Distribution and recent expansion of the mummichog (*Fundulus heteroclitus*) in the Iberian Peninsula. The rectangles in each panel (black in 1 and 2, yellow in 3) represent the area enlarged in the next one. 1) Current distribution of the mummichog in the Iberian Peninsula, marked with a red line. 2) Main population nuclei of the mummichog in southern Iberian Peninsula, adapted from Gutiérrez-Estrada et al (1998) and Catry et al (2006). 3) Situation of the Barbate marshes, the Cachón River and the main nearby coastal geographic elements. 4) The mouth of the Cachón River, in the village of Zahara de los Atunes.

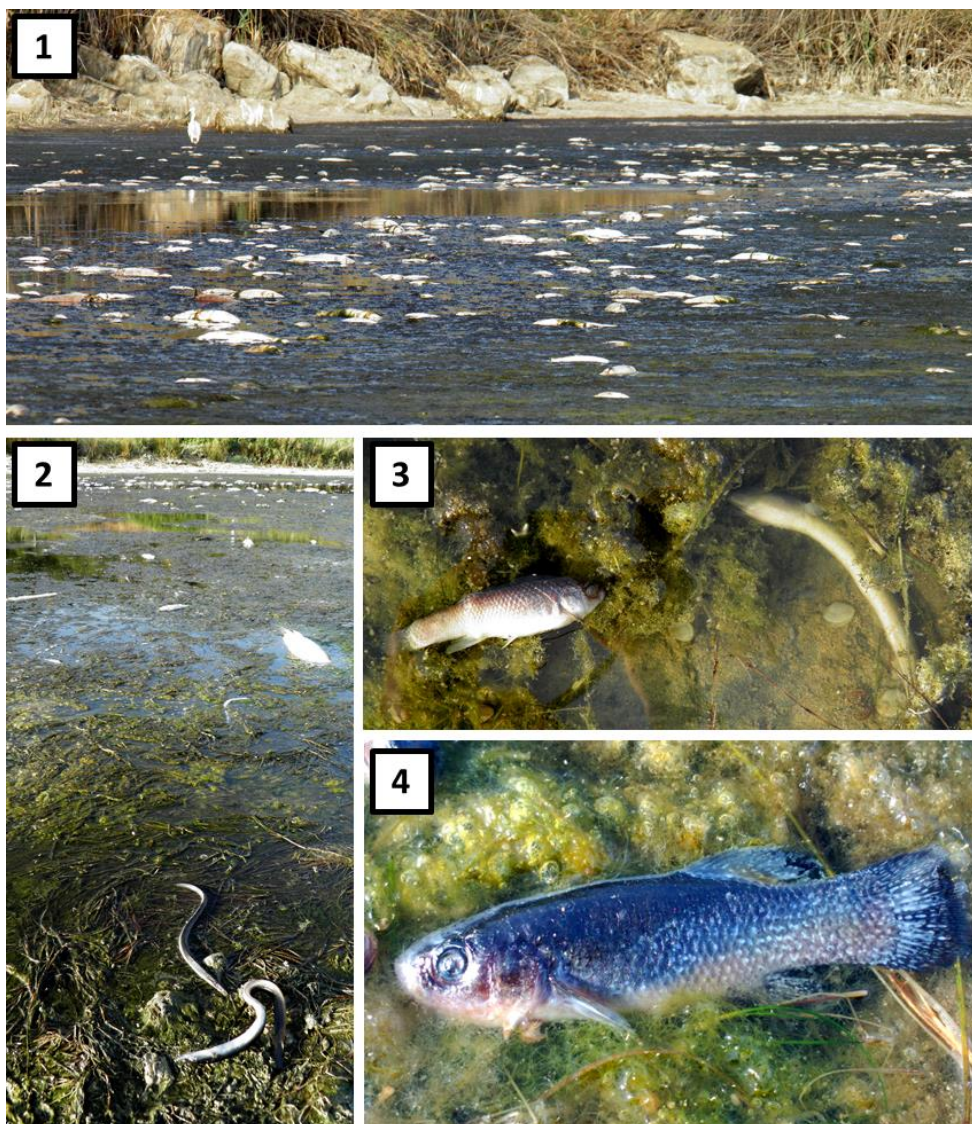


FIGURE 2. Images of the fish mortality episode recorded in the Cachón River between July 31st and August 4th 2016. Images show numerous dead grey mullets (Family Mugillidae, 1), European eels (*Anguilla anguilla*, 2), and female (3) and male (4) mummichog.

Barbate marshes seems a more probable option. In fact, the mummichog is an euryhaline species and it has been shown to be able to use marine environment as dispersal routes. Duvernell et al. (2008) showed that the mouth of the Chesapeake Bay, of around 20 km in its narrowest part, does not represent a dispersal barrier for the mummichog. Even though the mummichog is considered a sedentary species, movements of more than 3.5 km in one year have been recorded in Canada, where aquatic systems are covered by ice for 4 months (Skinner et al., 2005). It would be of interest to collect information, for example from local fishermen,

as to the presence of the species either in the Cachón River or in the area between the Barbate marshes and the Cachón river mouth. This type of information would help to clarify the expansion of mummichog in the area, once it helped to clarify the dispersal of other non-natives in Iberian Peninsula (Gago et al., 2016).

It is not known whether the mummichog has already occupied other potentially suitable habitats south to the Cachón River. In the Bolonia Bay, east to Cape Camarinal (see Figure 1.3) and some 12 km from the Cachón mouth, there is a small coastal

creek with a permanent pool (36.087N; 5.769W) that, to our knowledge, has never been surveyed. The mouth of the Valle River, 20 km from the Cachón mouth would provide highly suitable habitat for the mummichog, but as for 2002 the species was not present there yet (Clavero et al., 2005). The expansion of the species to the Valle River, and to the adjacent Jara and Vega rivers, should be of concern, since it could threaten the unique populations of Moroccan spined loach (*Cobitis maroccana*) in the Iberian Peninsula (Doadrio & Perdices, 2005), a likely endemic yet undescribed *Squalius* species (Perea et al., 2016) and a population of the endangered Andalusian toothcarp (*Aphanius baeticus*) (Clavero et al. 2007).

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AUTHOR CONTRIBUTIONS

MC collected the field data and FBG lead the writing, aided by MC.

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