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Short Communication

Aggregations of the invasive ctenophore *Mnemiopsis leidyi* in a hypersaline environment, the Mar Menor lagoon (NW Mediterranean)

Macarena Marambio[1]*, Ignacio Franco[2], Jennifer E. Purcell[3], Antonio Canepa[1], Elena Guerrero[1] and Verónica Fuentes[1]

1 *Institut de Ciències del Mar-CSIC, P. Marítim de la Barceloneta 37-49, 08003 Barcelona, Spain*
2 *Centro Oceanográfico de Murcia, c/ Magallanes 2, 30740 San Pedro del Pinatar, Spain*
3 *Western Washington University, Shannon Point Marine Center, 1900 Shannon Point Road, Anacortes, Washington 98221, USA*

E-mail: marambio@icm.csic.es (MM), ignacio.franco@mu.ieo.es (IF), jennifer.purcell@wwu.edu (JEP), canepa@icm.csic.es (AC), eguerrero@icm.csic.es (EG), vfuentes@icm.csic.es (VF)

**Corresponding author*

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Abstract

The ctenophore *Mnemiopsis leidyi*, a species native to estuaries and coastal regions of the western Atlantic Ocean, was first introduced into the Black Sea in the early 1980s, where it negatively affected zooplankton biodiversity and biomass, and commercial fisheries. This invasive ctenophore was first reported along the Spanish Mediterranean coast in 2009. In 2012, new blooms of this species were reported in the hypersaline and largest coastal lagoon of the Western Mediterranean basin, the Mar Menor lagoon, Spain. Sampling in the lagoon during summer 2012 showed an average abundance of 23.4 ctenophores 100 m^{-3}, in early August, declining to 8.2 ctenophores 100 m^{-3} by early September. The population contained only adults (total length 19 to 79 mm), which increased in size through the summer. Generalized additive models suggested *M. leidyi* abundance was significantly related to temperature, but not to salinity or depth. The Mar Menor lagoon is an anthropogenically-disturbed habitat that may favour this species. Blooms of *M. leidyi* in the Mar Menor lagoon are of great concern given its negative impacts in previously invaded habitats.

Key words: alien species; comb jellyfish; gelatinous zooplankton; hypersaline lagoon; temperature; eutrophication

Introduction

The American comb jelly *Mnemiopsis leidyi* A. Agassiz, 1865 is native to estuaries and coastal regions of the western Atlantic Ocean, from the United States of America to southern Argentina (Mianzan 1999). This ctenophore possesses a strong invasive potential, with physiological elasticity and high reproductive rate, which allows rapid population growth in a wide variety of habitats (reviewed in Costello et al. 2012). In the early 1980s, *M. leidyi* was introduced into the Black Sea, likely via ballast water (Ghabooli et al. 2011). During the last three decades, it has invaded and expanded to almost all Eurasian seas (i.e., Sea of Azov, Sea of Marmara, Aegean Sea, Caspian Sea, North Sea, Baltic Sea and the Mediterranean Sea). The impacts of this species in some of the invaded habitats include reduction of zooplankton biodiversity and biomass, and collapse of commercial fisheries. It is one of the "100 World's Worst Invaders" listed by the International Union for Conservation of Nature (Lowe et al. 2000).

Recent records from the Mediterranean include reports of simultaneous blooms along the coasts of Israel, Italy, and Spain (Boero et al. 2009; Galil et al. 2009; Fuentes et al. 2009, 2010). Since 2009, this ctenophore has been reported in several locations along the Spanish Mediterranean coast, mainly during spring and summer. By contrast, in the Alfacs Bay in the Ebro River Delta (southern Catalonia), where the population was first recorded in 2010, *M. leidyi* persisted through winter and completed its life cycle every year (Marambio et al. unpublished data). These occasional and seasonal records were not alarming due to apparently low numbers of ctenophores observed; however, in the summer of 2012, blooms of *M. leidyi* were reported in a new location, the Mar Menor Lagoon.

The Mar Menor is the largest coastal lagoon (135 km^2 surface area) in the Western Mediterranean. It has traditionally supported artisanal fisheries for prawns, grey mullet, and sea breams (Pérez-Ruzafa et al. 1991). The Estacio Channel was deepened during the early 1970s (Pérez-Ruzafa et al. 1991) resulting in a navigable canal that increased the water exchange between the Mediterranean Sea and the Mar Menor. Since then, the salinity of the Mar Menor has declined from 48.5–53.4 to 42–45 (Pérez-Ruzafa et al. 1991). In the last two decades, anthropogenic pressure, mainly from development of urban areas, increased tourism, and intensification of agriculture have threatened the Mar Menor. Agricultural activities in the area have changed from extensive dry land cultivation to intensively irrigated crops, with fertilizer being channeled directly towards the lagoon (Velasco et al. 2006). These activities were responsible for increasing nutrient input into the lagoon, altering the water properties and sediment composition, and changing the original oligotrophic characteristics towards more eutrophic conditions (Pagès 2001).

The history of gelatinous zooplankton in the Mar Menor is known from the early 1900s with a small population of *Aurelia aurita* (Pagès 2001). Coincident with eutrophication of the lagoon, two large jellyfish species from the Mediterranean, *Rhizostoma pulmo* and *Cotylorhiza tuberculata*, are currently the most conspicuous organisms (Pagès 2001). In summer 2004, there were an estimated 3,500,000 *R. pulmo* medusae and more than 80,000,000 *C. tuberculata* medusae in the basin at the end of August (summer season), with fewer in subsequent years. In the summer of 2012, a new maximum in the basin was reached for both species, with 3,755,000 *R. pulmo* and 133,600,000 *C. tuberculata* medusae, also at the end of August (Franco unpublished data). The proliferation of these two species has caused serious socio-economic problems, mainly in tourism and local commercial fisheries (Pagès 2001). Currently, jellyfish populations appear to be the main top-down controls in the lagoon, with eutrophication possibly a major contribution to their successful development. The same characteristics may offer suitable conditions for *M. leidyi*, which may enhance the negative impact of gelatinous zooplankton in this already disturbed habitat.

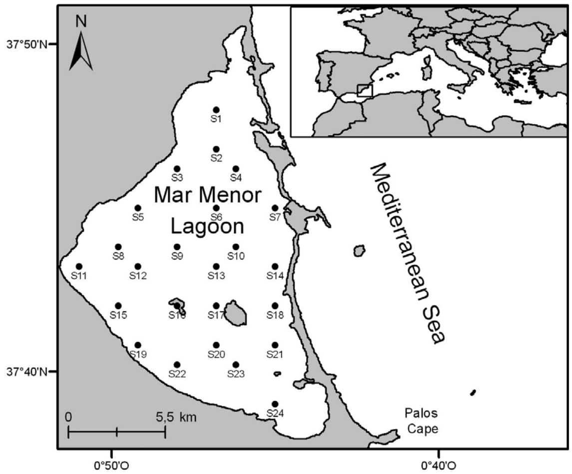

Figure 1. Twenty-four stations sampled from 1 August to 1 September 2012 in the Mar Menor lagoon, Spain.

Each invasion of *M. leidyi* is met with deep concern because it was a major contributor to ecological and socio-economic disasters in the Black Sea in the late 1980s (reviewed in Purcell et al. 2001; Dumont et al. 2004; Costello et al. 2012). A combination of the invasiveness of the species and a disturbed habitat, lack of predators, and favourable environmental conditions enabled a successful invasion with extensive impacts on the invaded habitat (reviewed in Purcell et al. 2001; Dumont et al. 2004; Costello et al. 2012). Therefore, the objective of this study was to document the first confirmed occurrence of blooms of *M. leidyi* in a hypersaline environment, the Mar Menor lagoon, which may potentially favour and support this species due to its environmental characteristics and degree of ecosystem degradation. Intensive sampling during the July-August 2012 bloom was undertaken to evaluate the present state and distribution of the population along the coastal lagoon.

Materials and methods

Study area

The Mar Menor lagoon (37º38'–37º50'N and 0º43'–0º57'W) is located in the SE Iberian Peninsula (Figure 1). This shallow lagoon with an average depth of 3.5 m (Pagès 2001) is hypersaline with higher salinity levels (42–47) than the adjacent Mediterranean Sea due to low precipitation (around 300 mm per year) and high evaporation rates (annual mean 18ºC) (Velasco et al. 2006). The water temperature ranges between

10 and 32ºC (Pérez-Ruzafa et al. 2004). The lagoon is separated from the Mediterranean Sea by La Manga, a 20-km-long and 100 to 900 m-wide sandbar, that has five shallow inlets, including the Estacio Channel (Pagès 2001).

Sampling

The first samples were collected in early July 2012 at one station to confirm the species presence. On 1 August, 18 August, and 1 September, 24 stations were sampled (Figure 1). A 40-cm diameter bongo net (235-µm mesh size) equipped with a flowmeter was towed horizontally at 1 m depth. Collected ctenophores were counted and densities estimated according to the corresponding filtered volumes that range between 22.8 and 36.21 m^3 (30.77 m^3 ± 2.14 m^3 mean ± SD). Total length (TL; oral-aboral length including lobes) of the ctenophores was measured *in vivo* to the nearest 1 mm using a manual calliper. Temperature, salinity, and depth at each station were recorded using a conductivity-temperature-depth profiler (SEABIRD SBE 25, Sea-Bird Electronics, Inc. 13431 NE 20th Street, Bellevue, Washington 98005 USA).

Generalized additive models (GAMs) were performed to test if the density of ctenophores differed with water temperature, salinity, and depth. The influence of spatial autocorrelation of the data was eliminated by including, as a random term, the geographic position of each station (Wood 2006). A Poisson error family and a log link were used to model the count data. To reduce the bias due to different sampling units (different filtered volume of seawater, see above), filtered volume was used as an offset inside the model (Penston et al. 2008; Zuur et al. 2009). All the statistical analyses were made using the free statistical platform R (R Core Team 2012).

Results

The first evidence of *M. leidyi*'s presence in the Mar Menor in 2012 came in late April through the Jellyfish Alert Network of the Spanish Institute of Oceanography (IEO). Since 1996, an exhaustive and continuous monitoring of jellyfish has taken place in the Mar Menor lagoon and, before 2012, *M. leidyi* was not detected. Therefore, initially the ctenophores observed in July 2012 seemed to be an isolated input from the Mediterranean; however, the

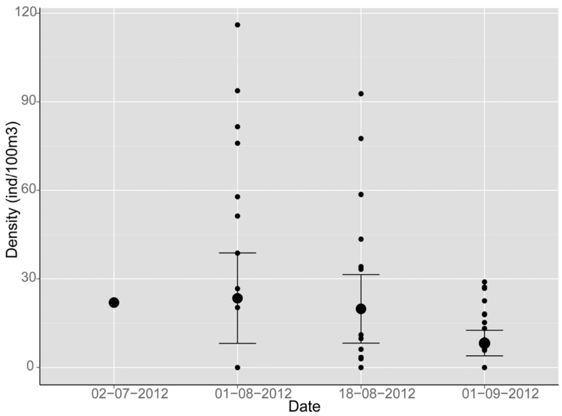

Figure 2. Abundance of the ctenophore *Mnemiopsis leidyi* in the Mar Menor lagoon, Spain, 2 July to 1 September 2012. Mean (± SE) are shown for each sampling date.

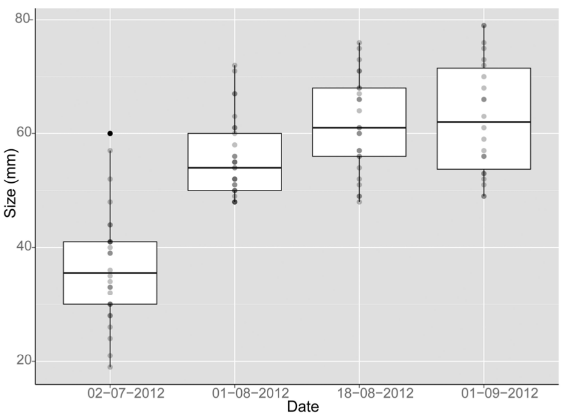

Figure 3. *Mnemiopsis leidyi* size distribution (total length) in Mar Menor, 2 July – 1 September 2012. The data are presented as mean (dark horizontal line) ± SD (white boxes). The point outside the dispersion (vertical) line for 02-07-2012 represents a possible outlier.

population persisted and attained a maximum single station estimate of 116 ctenophores 100 m^{-3} in early August with a slight tendency to decline over time (Figure 2). Average abundance was 23.4 ctenophores 100 m^{-3} on 1 August and 8.2 ctenophores 100 m^{-3} on 1 September.

Mnemiopsis leidyi collected in the study area had the general characteristics described for the species: transparent oval body with lateral compression, four auricles, two elongated oral lobes on each side of the mouth that originated near the level of the statocyst, and absence of warts. The specimens collected during 2012 consisted exclusively of adults with sizes ranging between 19 and 79 mm (53.5 ± 13.8 mm TL mean ± SD) and with sizes increasing from

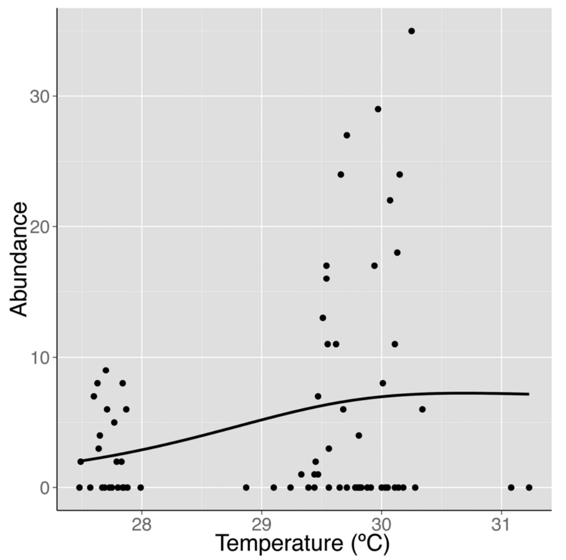

Figure 4. *Mnemiopsis leidyi* temperature distribution in Mar Menor, 2 July – 1 September 2012. A curve representing the best-fit (GAM) was fitted to the data.

an average of 36.6 mm TL to 62.9 mm TL during July-August (Figure 3).

Depth of the sampling stations ranged between 1.4 and 6.2 m (4.9 m ± 1.1 m mean ± SD). Water temperature during sampling averaged 29.1ºC (±1.1º C) and salinity ranged between 42.3 and 45.6 (44.5 ± 7.4 mean ± SD). GAM results showed that *M. leidyi* abundance was significantly related to temperature ($F_{2,72}$ =44.970; P <0.001), but not to salinity or depth. The ctenophore's temperature distribution had a maximum at 30°C (Figure 4).

Discussion

Typical habitats for *M. leidyi* are described as shallow and productive areas affected by river run off and under strong anthropogenic influences (Siapatis et al. 2008), which well describes the Mar Menor lagoon. Siapatis et al. (2008) further argued that the abundance of *M. leidyi* depends on the combination of favourable conditions, i.e., temperature, salinity, food availability, and predator abundance; therefore, the occurrence of *M. leidyi* in the study area does not necessarily mean that this species can reproduce and/or attain high population outbursts. Although population densities observed in the present study are much lower than the maxima reported in the Black Sea (304 ind. m^{-3}; Vinogradov et al. 1989) or the Baltic Sea Fjord system (590 ind. m^{-3}; Riisgård et al. 2010), they are comparable to densities reported for different areas of the eastern Mediterranean (Shiganova et al. 2001b). Phenotypically, the specimens collected in the study area resembled individuals described for the Black Sea, with elongated oral lobes. The maximum size of *M. leidyi* from the Mar Menor was 79 mm TL, which is much smaller than the maximum size of 180 mm TL reported in the Black Sea (Shiganova et al. 2001a).

Even though this study represents the first confirmed record of the species in the Mar Menor, it seems that *M. leidyi* has been observed every summer since 2008 in the lagoon. It was observed by SCUBA divers off Los Urrutias village during July and August 2008, and in August 2009, 2010, and 2011 (E. López-Gallego. pers. obs.). Apparently, all these observations corresponded to isolated incursions from the Mediterranean, but no alarming blooms developed until the summer of 2012, and it is unknown if the species will persist and develop a self-sustained population. The 235-µm-mesh net used in the present study did not detect larvae (<4 mm) or transitional stages (4–10 mm), which morphologically differ from adults mainly by the presence of tentacles and no oral lobes in the case of the larvae stage, and the formation of lobes in the case of the transitional stage. However, additional sampling needs to be conducted within a directed monitoring programme to track potential reproduction and population development.

The Mar Menor lagoon may not sustain a continuous population of *M. leidyi.* The three resident scyphomedusan species, *R. pulmo*, *C. tuberculata* and *A. aurita*, may act as competitors for planktonic prey and as predators of *M. leidyi* larvae. Where *M. leidyi* and *A. aurita* co-occurred in the Black Sea, *M. leidyi* appeared to be a superior competitor for zooplankton prey (Shiganova et al. 2001b); however, in Kertinge Nor, Denmark, *A. aurita* predation decreased all zooplankton populations, which prevented the development of the *M. leidyi* population (Riisgård et al. 2010). Therefore, the presence of at least three other gelatinous zooplanktivores in the lagoon may limit colonization by *M. leidyi*.

Another unknown factor for the future success of *M. leidyi* in the Mar Menor lagoon is the high salinity level (44.5 ± 7.4), which is very different from the low salinity in most native and all invaded habitats. Previous studies show that the reproductive output and physiological capabilities of *M. leidyi* are related to salinity (Yazdani et al.

2007; Jaspers et al. 2011); however, these studies all occurred at salinity levels ≤ 33. To our knowledge, only one study documents *M. leidyi* populations in comparably high salinities. Baker (1973), showed that there was no evidence of the salinity effect on the abundance and distribution of *M. leidyi*. Moreover, Costello et al. (2012) indicated the relation between salinity levels and temperature may influence the survival of *M. leidyi*, stating that low salinity levels can adversely affect survival at low temperatures; however, studies performed in high salinities and over a range of temperatures are still lacking. Hence, research on high salinity and its relationship to especially high temperatures is necessary to know more about the potential success of *M. leidyi* in the Mar Menor lagoon.

The potential ecosystem effects of this invasive species include reduction of biodiversity and biomass of zooplankton, which may have direct and/or indirect effects in the fisheries. Likewise, the presence and blooms of *M. leidyi* may impact tourism and the related activities. Thus, the socio-economic importance of this new invasive species in the Mar Menor for local fishermen and tourism is undeniable. Therefore, additional monitoring of the population, and experimental work to determine the eco-physiological response to the environmental conditions in the Mar Menor and other areas, are necessary to estimate the likely colonization success and effects of this species.

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