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First report of the invasive jellyfish *Gonionemus vertens* A. Agassiz, 1862 in the Berre Lagoon, southeast France

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Abstract

The hydromedusa *Gonionemus vertens* A. Agassiz, 1862 was first detected in the Berre Lagoon, south of France, in July 2016. Early June 2017, following an early rise in temperature, much higher numbers of specimens were reported leading to several beach goers being stung and one going into anaphylactic shock. Effort to rehabilitate this highly anthropogenically altered lagoon has led to the redevelopment of the *Zostera* meadows, which might be favoring the clinging jellyfish. Developmental aberrations of specimens were noted, which could be linked to the remaining presence of chemicals from the industrial development period. Impact of this predator species on the functioning of the lagoon ecosystem should also be studied.

Key words: Hydromedusae, Mediterranean lagoon, occurrence, invasive species, human's health impacts

Introduction

Non-indigenous species introductions in sink ecosystems constitute a major source of biological pollution (Boudouresque and Verlaque 2002; Elliott 2003). While many species have been transported and introduced in new areas; some of them have no real impact on invaded ecosystem (Hewitt et al. 2004; Gasith et al. 2011). However, when a species becomes invasive, it has strong ecological and economic impacts: modifying the diversity; the ecosystem functioning (e.g., competition, predation); and affecting human activities (e.g. fisheries, industrial complex and tourism) (Gallardo et al. 2016). Among invasive species, gelatinous zooplankton are important players in locations such as the Berre Lagoon, France.

The Berre Lagoon is the largest (155 km^2) French lagoon along the Mediterranean coast. It has been receiving large volume of freshwaters through natural rivers and succession of large hydroelectric power plants. High nutrient loads leading to excessive eutrophication occurred for over 30 years, and a variety of legislative measures were adopted to improve the health of the lagoon, including measures to reduce strong salinity variations (minimum above ≥ 14: European directive). While the increase in salinity led to an increase of the planktonic diversity, it also enabled colonization by invasive species. For example, the ctenophore *Mnemiopsis leidyi* A. Agassiz, 1860 became established in 2005 and is now a prominent inhabitant of the lagoon and poses threat to the functioning of the pelagic food web, while others can be associated with human health risks. Here we report on the first observations of the highly potent hydromedusae *Gonionemus vertens* A. Agassiz, 1862 in the Berre Lagoon.

Gonionemus vertens (Hydrozoa, subclass Trachylinae) is a small hydromedusa (1–2 cm) and one of 47

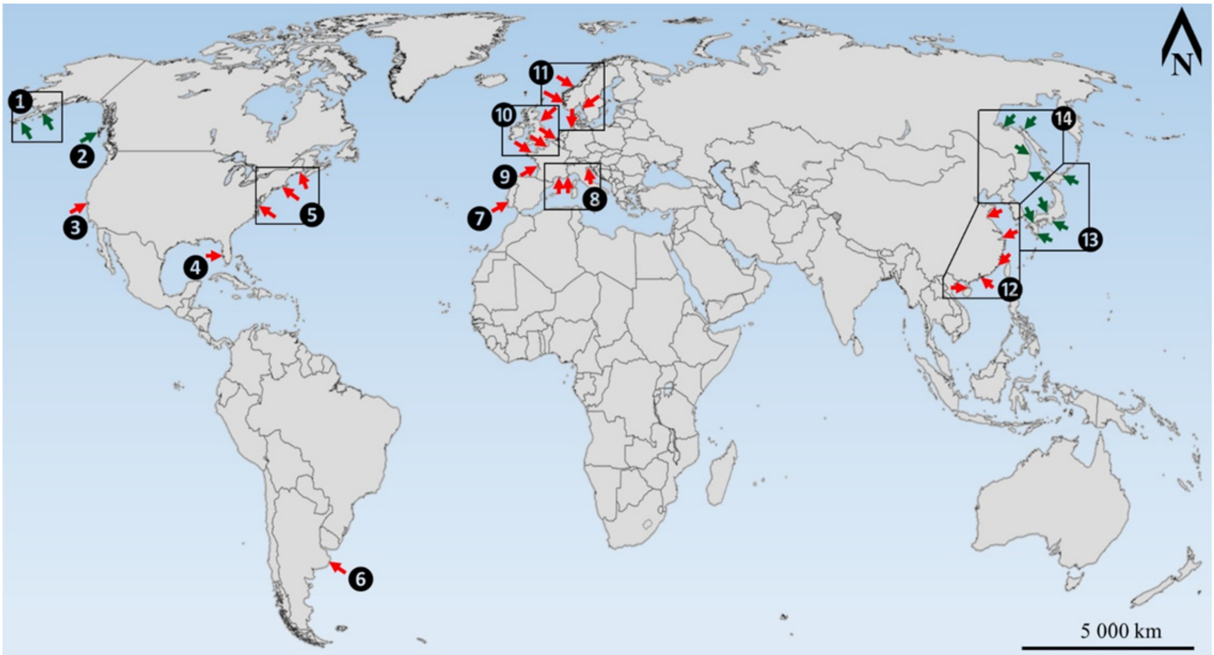

Figure 1. World-wide distribution of *Gonionemus vertens* from literature (Table S2). Green arrows : native areas. Red arrows : introduced populations. ❶ to ⓮ : numbered locations.

known species in the order Limnomedusae (Schuchert 2016). *G. vertens* medusae reproduces sexually, the fertilised egg developed into a ciliated planula, which will then settle on the seabed and grow into a tiny solitary polyp (~ 1 to 2 mm) attached to a substrate (i.e. molluscs' shells). Young medusae or more polyps can be budded off from the initial polyp (Perkins 1902). Cysts formation from polyps has also been observed (Uchida 1976); cysts can also contribute when conditions are favorable to medusae production. *G. vertens* is commonly called the clinging jellyfish as it "clings" onto seagrasses using adhesive patches, modified cells found usually on the lower section of the tentacles. *G. vertens* is a predator of zooplankton, including copepods and fish larvae (Todd et al. 1966), and other organisms living on the seagrass meadows. *G. vertens* is likely native to the North Pacific Ocean (Figure 1) (Fofonoff et al. 2003; Gaynor et al. 2016), but has been introduced to the East coast of the USA (Massachusetts and recently in New Jersey), the coast of Argentina, the Baltic Sea, and North Atlantic (Fofonoff et al. 2003 and reference therein; Rodriguez et al. 2014; Gaynor et al. 2016; Govindarajan and Carman 2016; Govindarajan et al. 2017). *G. vertens* has been reported already, but only one or a few times despite intense research effort in the Mediterranean Sea, around Sète (Thau Lagoon), in Villefranche-sur-Mer on leaves of the seagrass *Posidonia oceanica* (France) and in the Gulf of Trieste (Italy) (Picard 1951; Picard 1955; Edwards 1976; Bakker 1980).

Material and methods

G. vertens medusae were first observed between July 5–12, 2016, in shallow *Zostera* meadows (1.5 m depth) in the Eastern sector of the Berre Lagoon (Figure 2), during a survey directed at *Mnemiopsis leidyi*. Individuals (Table S1) were handpicked using gloves. On 13 June 2017, following a report from a lifeguard that several bathers had been stung, *G. vertens* was observed again but with over 100 specimens counted. Each time temperature and salinity of the surrounding water was measured using a CTD probe. Specimens were observed under a stereomicroscope (Leica® M165C) and identified following Kramp (1959), Arai and Brinkmann-Voss (1980), Bakker (1980) and Bouillon et al. (2004). Specimens were measured to the nearest mm in 2016 and 1 µm using ImageJ software in 2017 (Supplementary material Table S1), development of the gonads recorded, photographed, and preserved in either lagoon-water-formalin solution (4% final concentration) or in ethanol (for later genetic analysis).

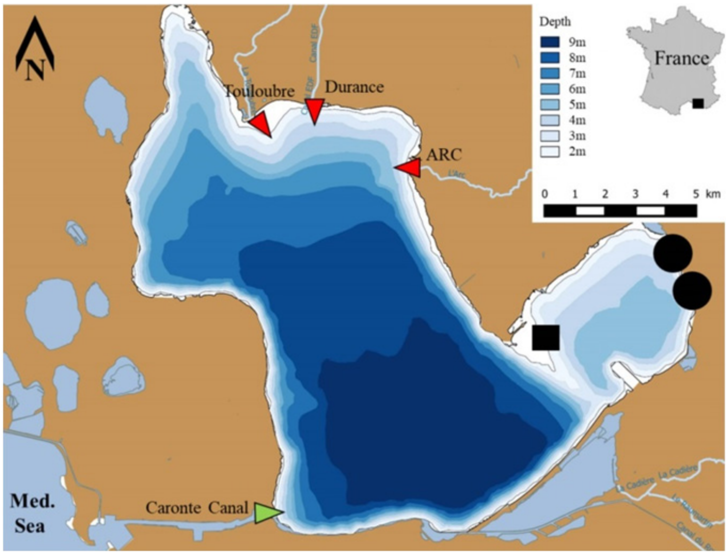

Figure 2. *Gonionemus vertens* observations in the Berre Lagoon in 2016 (black square) and 2017 (black circles). Red triangles: freshwater inputs (Touloubre, Durance (EDF powerplant), Arc) and Green triangle: connection to the sea (Caronte Canal, south-west). Med. Sea: Mediterranean Sea.

Results and discussion

Individuals of *G. vertens* were found either attached to eelgrass (*Zostera marina* and *Zostera noltei*) or swimming at the surface of the lagoon. Temperature and salinity of the water was 22.8–23 °C and 26–27 °C and 22–23 and 20, respectively in July 2016 and June 2017 (Table S1). Our observations are consistent with those of Bakker (1980) in the Netherlands where production of immature free swimming medusae by polyps occurred once water temperature exceeded 17–18 °C. Organisms were significantly smaller in June 2017 (9.955 ± 0.044 mm) than in July 2016 (17.2 ± 0.6 mm) (Mann Whiney Rank Sum Test, $P < 0.001$), highlighting a seasonal growth. Gonads development was similar in both years (Figure 3). Mills (1993) reported also an almost doubling in size of *G. vertens* in the Puget Sound between June and July. Organisms could still be growing through the rest of the productive season as a maximum size of 25–30 mm is often reported (Goy 1973; Bakker 1980) or growth could stop after the Jun/Jul burst (~20 mm, Mills 1993). The earlier and larger occurrence in 2017 compared to 2016 is presumably due to earlier warming up of the water column, warmer temperature being suggested in promoting medusa production (Edwards 1976; Bakker 1980). In the Shrewsbury River (New Jersey, 40.32ºN; 74.05ºW), where temperature and salinity conditions are comparable to that in our study (temp 13–26 °C; salinity 20–26: Shaheen and Steimle 1995), similar annual variations in abundance of *G. vertens* has been reported (Paul Bologna pers. com.), with low number in summer 2016 and larger population in June 2017. *G. vertens* medusae might survive about 3 months, with mortality mainly linked to old age and senescence, rather than to predation (Mills 1993). Intertidal stranding, another reported source of mortality will be very limited in the Berre Lagoon where tides are very small (0.3–0.6 m).

As a cnidarian, *G. vertens* should exhibit radial symmetry, with gonads developing along each of the four radial canals. The Berre Lagoon population consisted mainly (≈ 90%) of "normal" individuals with four visible gonads and 60 tentacles distributed evenly around the umbrella (Figure 3A). However, 10% of the population had developmental aberrations with some individuals having five gonads and 40 tentacles unevenly distributed around the umbrella (Figure 3B), and others having three normal and one atrophied gonad (Figure 3C). Symmetry disorder in jellyfish is well known, especially in the scyphozoan *Aurelia* sp. (Gershwin 1999). Indeed, Gadreaud et al. (2017) hypothesized that symmetry disorder in *Aurelia* sp. collected in the Berre Lagoon could be due to decades of chemical dumping (heavy metal, pesticides and hydrocarbons), which are now forbidden, but residual levels in the sediment (Rigaud et al. 2012; Arienzo et al. 2013) still alter development during the metamorphosis between the polyps and the jellyfish phases.

The invasion of Berre Lagoon by *G. vertens* is still in its early phase and the consequences for the functioning of the Berre Lagoon is unknown, but plankton composition and abundance might sustain even larger population. Despite the presence of the carnivorous ctenophore *Mnemiopsis leidyi*, zooplankton are still plentiful (annual mean: 24 121 ind m^{-3}).

Female *G. vertens* can produce 50–75 000 eggs y^{-1} (Bakker 1980), leading to the development of numerous polyps, which will in turn grow, multiply, bud and form numerous new swimming jellies. Extension of the *Zostera* meadows (Bernard et al. 2007) following the implementation of the 2006 European regulations, for no respect of the convention of Barcelona nor of the Athens protocol, might enhance the population of *G. vertens* by providing additional attachment surfaces. Polyps are usually found on stones and shells. Shellfish development in the lagoon can therefore provide additional substrate for polyp development leading to increasing medusa population.

The *Gonionemus* medusae are typically associated with *Zostera* meadows and attached themselves to the leaves. Some beaches along the Berre lagoon are located close to these meadows and encounters with jellyfish are very likely. While *G. vertens* is a small species, its sting can harm humans, with effects including simple pain, neuropsychiatric changes, and anaphylactic shock (Pigulevsky and Michaleff 1969). The report in July 2015 of a lady going into anaphylactic shock (GIPREB pers. comm.) suggests that *G. vertens* was already present in the lagoon. No other stinging jellyfish than *G. vertens* has been reported, for the Berre Lagoon so far, *Aurelia solida* being mostly harmless to humans; this suggests that the variant of the species present here is the most potent one and may originate from the western North Pacific Ocean (Edwards 1976; Gaynor et al. 2016; Govindarajan et al. 2017), the other variant from the eastern North Pacific Ocean being less venomous. Future work is needed to clarify invasion routes for this species by sequencing 16S ribosomal and the cytochrome oxidase subunit I (COI) loci of preserved samples. Comparison with other available sequences will give us more insight in the origin of our population.

G. vertens is very likely established in the Berre Lagoon, but what are the vectors which led to its introduction? *G. vertens* has already been reported in other Mediterranean's and European's water bodies and so far, its presence in non-native environment has been linked to the transportation of shellfish from Japan or/and ballast waters discharge (Bakker 1980; Katsanevakis et al. 2013; Gaynor et al. 2016). The presence of several species of mussels in the lagoon, the introduced *Musculista senhousia* (from southeast Asia) and the Mediterranean mussel (*Mytilus galloprovincialis*) can be responsible for *G. vertens* introduction in the Berre Lagoon via polyps attached to their shelves. Transportation of cysts adhering to seabirds' feet has also been proposed as a mean of introduction, several migratory birds being reported at time in the Berre Lagoon. Large-scale population genetics analysis should be conducted to help us determine the potential origin of the population observed in the Berre Lagoon as highlighted by Govindarajan et al. (2017).

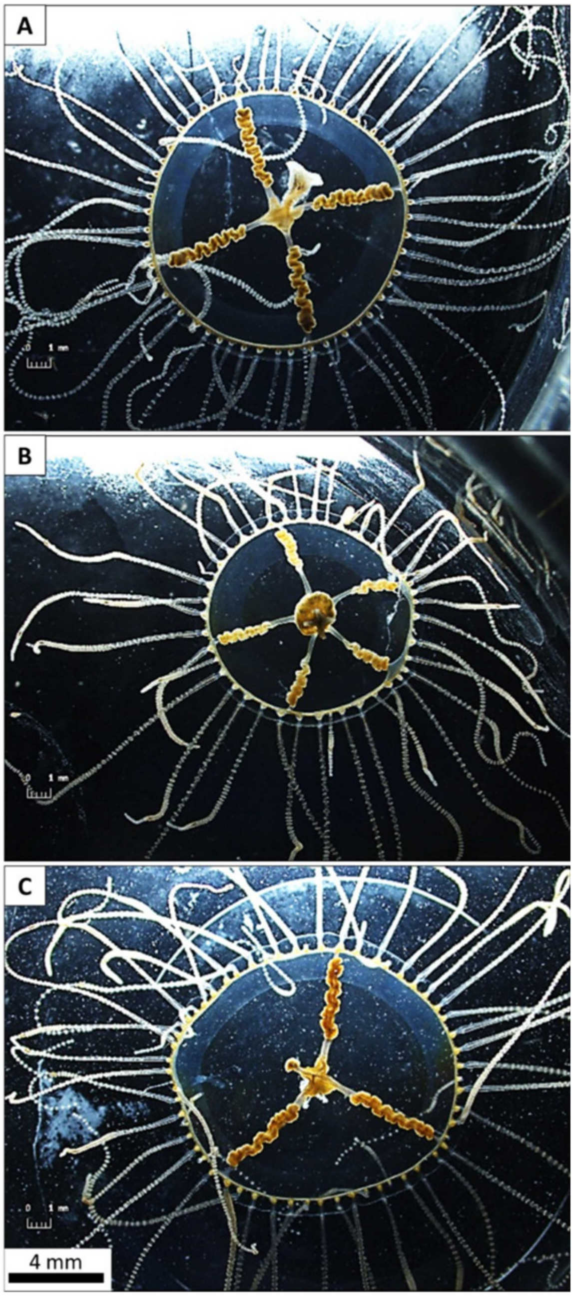

Figure 3. Images of *Gonionemus vertens* (stereomicroscope Leica® DMS1000) collected in the Berre Lagoon. (A) Normal individual, (B) individual with five gonads, and (C) individual with three normal and one atrophied gonad. Scale bar 4 mm. Photographs by Guillaume Marchessaux.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Observations of *Gonionemus vertens* and environmental parameters in the Berre Lagoon.

Table S2. References reported the world-wide distribution of *Gonionemus vertens*.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2017/Supplements/BIR_2017_Marchessaux_etal_Supplement.xlsx