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HOW TO STUDY THE SOCIO-ECOLOGICAL IMPACTS OF INVASIVE SPECIES: THE CASE OF THE CTENOPHORE *MNEMIOPSIS LEIDYI* IN BERRE LAGOON (SOUTHEAST FRANCE)

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MEDITERRANEAN LAGOONS
INTERDISCIPLINARITY
COMB JELLYFISH

ABSTRACT. – Berre Lagoon is an ecosystem historically disturbed by strong industrial discharges and significant freshwaters inputs from both natural and anthropogenic (hydroelectric powerplant) sources. While rehabilitation policies initiated in 1994 are already showing some success, the introduction and proliferation of *Mnemiopsis leidyi* since 2005 could limit their effectiveness. The originality of this study is to associate oceanography and sociology to estimate the impact of *M. leidyi* on the functioning of this socio-ecosystem. This article presents an overview of a broad range of results obtained using interdisciplinary approach. It appeared that *M. leidyi* has an impact on plankton community functioning and on human activities, particularly on fishing. Therefore, in the context of biological invasions, the prospects for the rehabilitation of Berre Lagoon remain subject to the unpredictability of nature.

INTRODUCTION

In the Mediterranean Sea, more than a thousand marine species are considered non-indigenous species (NIS) (Zenetos *et al*. 2010) and their numbers have been increasing exponentially since the beginning of the 20th century (Katsanevakis *et al*. 2009, Boudouresque & Verlaque 2010, Zenetos *et al*. 2010). In the Mediterranean Sea, there are several vectors of species introduction. The main vector is the opening of the Suez Canal between the Red and Mediterranean Seas allowing the entry of Lessepsian species into the Eastern Mediterranean basin (63 % of NIS observed in the Mediterranean; Boudouresque & Verlaque 2005). This canal has made the Mediterranean Sea a shortest maritime route for global maritime trade, linking America to Asia, leading to a high level of maritime traffic likely to introduce species (ballast water, fouling). Aquaculture and shellfish farming are also efficient vectors for the introduction of species accompanying fish and other mollusks (Boudouresque & Verlaque 2005, 2012).

While the majority of introduced species do not pose a direct risk to humans; however, 86 Mediterranean NIS are considered to have a strong socio-ecological impact (Katsanevakis *et al*. 2014), particularly in the coastal zone, the area most studied. Because of the various advantages they present for a range of industries (tourism, trade, agriculture, fishing), coastal environments are the most impacted by human pressures. At the same time, certain of the marine compartments are developing, such as the gelatinous zooplankton (Re *et al*. 2014, Halpern *et al*. 2015, Gibbs *et al*. 2017, Visbeck 2018).

In the Mediterranean Sea, eight species of gelatinous zooplankton are exotic. Five species of cnidarians entered the Mediterranean via the Suez Canal (*Phyllorhiza punctata* von Lendenfeld, 1884*, Cassiopea andromeda* (Forsskål, 1775)*, Carybdea marsupialis* (Linnaeus, 1758)*, Marivagia stellate* Galil & Gershwin 2010*, Rhopilema nomadica* Galil, Spanier & Ferguson 1990), while *Gonionemus vertens* A. Agassiz, 1862 was certainly introduced in polyp form with shellfish for shellfish farming (Marchessaux *et al*. 2017). The ctenophore *Mnemiopsis leidyi* A. Agassiz, 1865 has been transported in the ballast water of commercial ships and *Beroe ovata* Bruguière, 1789 has been accidentally introduced into the Black Sea (Bordehore *et al*. 2014, Brotz & Pauly 2016). The impact of these alien gelatinous species on the environment and on human activities has been relatively poorly documented. Katsanevakis *et al*. (2014) reported on the impact of some of them in Europe.

Mnemiopsis leidyi is a ctenophore (class Tentaculata, order Lobata) endemic to the American Atlantic coasts: South American coasts, Gulf of Mexico and Chesapeake Bay (Purcell *et al*. 2001, Mianzan *et al*. 2010, Costello *et al*. 2012) and which mainly colonizes estuaries, lagoons or inland seas (Purcell *et al*. 2001). Areas invaded by *M. leidyi* are generally subject to anthropogenic pressures such as eutrophication or overfishing, the latter favoring the success of *M. leidyi* (Bilio & Niermann 2004, Daskalov *et al*. 2007). *Mnemiopsis leidyi* was ranked among the 100 most invasive marine species in the world (Lowe *et al*. 2004).

Mnemiopsis leidyi appeared in the Black Sea in 1982 (Fig. 1) (Vinogradov *et al*. 1989, Reusch *et al*. 2010, Bolte *et al*. 2013, Ghabooli *et al*. 2013) and it has since spread to the Caspian Sea (Vinogradov *et al*. 1995), the Sea of Marmara (Isinibilir & Kideys 2004) and the Mediterranean Sea (Aegean Sea, Galil *et al*. 2009; Adriatic Sea,

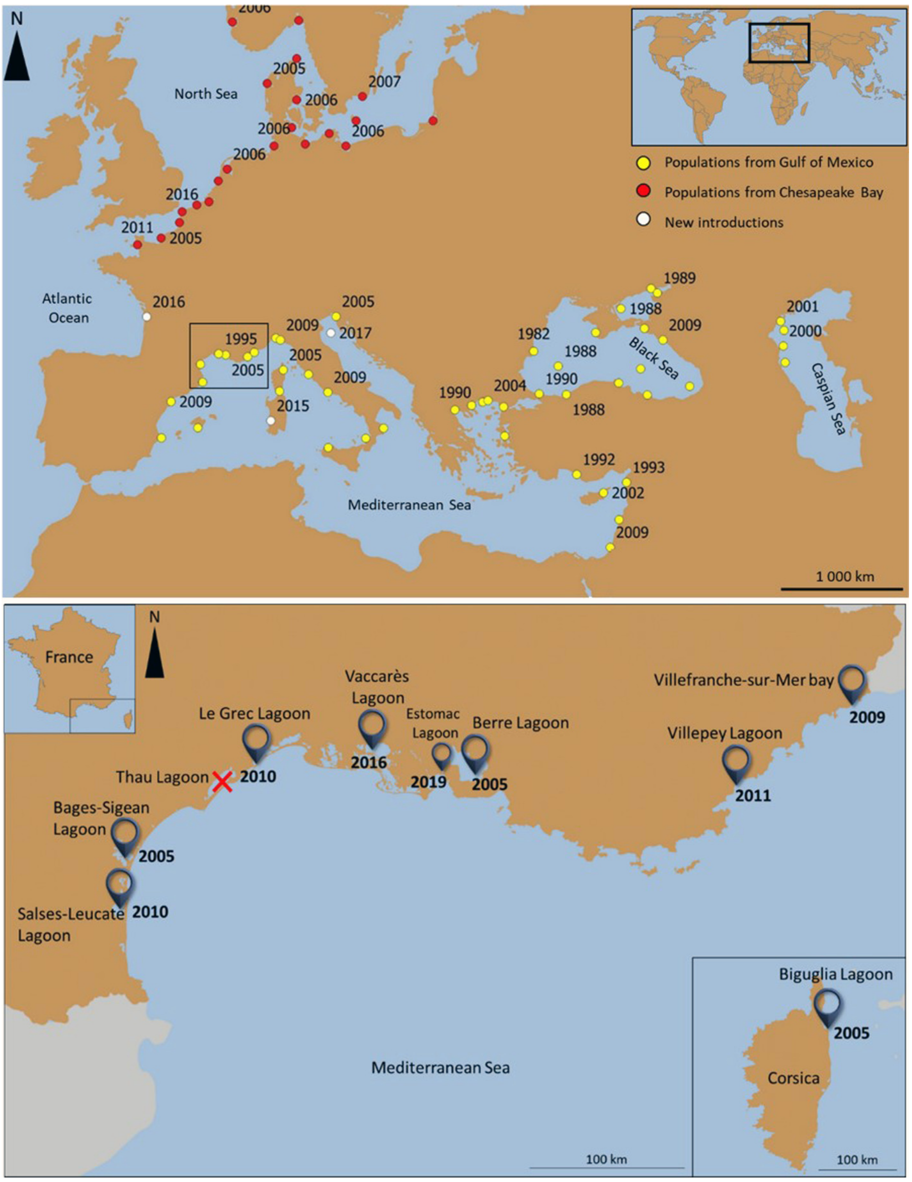

Fig. 1. – Distribution map of the introduction areas of *Mnemiopsis leidyi* in Europe (top) and on French Mediterranean coasts (below). Red cross: no *M. leidyi*.

Shiganova & Malej 2009; North-Western Basin, Boero *et al*. 2009, Fuentes *et al*. 2010, Bolte *et al*. 2013, Ghabooli *et al*. 2013, Marchessaux *et al*. 2020a, b) following the hydrodynamic circulation or again by means of shipping. More recently, new invasions were observed in northern Europe, in 2005 in Norway and the Baltic Sea (Javidpour *et al*. 2006, Oliveira 2007, Javidpour 2008). The organisms in this case were thought to originate from the east coast of the USA (Chesapeake Bay) (Reusch *et al*. 2010), while the Mediterranean populations were thought to originate from Mexico. On the French Mediterranean coastlines, *M. leidyi* was first formally identified in the Berre Lagoon in 2005 (Fig. 1, Table I, Marchessaux *et al*. 2020a), and has been episodically present in six other Mediterranean lagoons (Fig. 1, Table I) but the first arrival of *M. leidyi* along French Mediterranean coastlines could have occurred much earlier. *Mnemiopsis leidyi* has been observed in widely varying conditions of temperature (0 °C-31 °C), salinity (0.1-40) and chlorophyll *a* concentration (0.02-9.7 µg L^{-1}) reflecting its high ecological tolerance.

From the beginning of the 19th century, the rapid development of modern science led to the increased specialization of scientists. The (re)establishment of dialogue between disciplines is recent. From the 1970s onwards, in the field of the environment, it has been encouraged, if not driven by social demands that submit to researchers' questions that escape their disciplinary divisions (Jollivet 1992, Henry & Jollivet 2002, Claeys-Mekdade 2003, Gerini 2005). Thus, the overall functioning of an ecosystem cannot be explained in a compartmentalized approach alone (Legay 2004, Boudouresque *et al*. 2020). Neither the life sciences on the one hand nor the human sciences on the other are capable of separately providing

Table I. – Hydrological conditions of invaded French Mediterranean lagoons.

Date	Location	Latitude	Longitude	References
2005	Berre Lagoon	43.4592	5.1059	Marchessaux *et al.* (2020a)
2005	Bages-Sigean Lagoon	43.1054	2.9920	Delpy *et al.* (2016)
2005	Biguglia Lagoon	42.6263	9.4649	Etourneau (2011)
2009	Villefranche-sur-Mer bay	43.6994	7.3161	Fuentes *et al.* (2010)
2009-2010	Salses-Leucate Lagoon	42.8584	2.9956	Delpy *et al.* (2016)
2010	Le Grec Lagoon	43.5379	3.9433	Marchessaux & Belloni (2021)
2011	Villepey Lagoon	43.4047	6.7171	Marchessaux *et al.* (2020b)
2016	Vaccarès Lagoon	43.5353	4.6370	Marchessaux *et al.* (2020b)
2019	Estomac Lagoon	43.4445	4.9536	Marchessaux *et al.* (2020b)

complete answers to these questions. Thus, the researcher becomes a "*border-crosser*" (Jollivet 1992) bridging the life sciences and the human sciences in order to grasp the complexity of interactions between ecological and social processes.

Currently, the opening up of research is characterized by a process of knowledge dialogue (Jollivet & Legay 2005). Interdisciplinarity is one of the methods for sharing knowledge and fields (Jollivet & Legay 2005). Interdisciplinarity responds to the dual objective of an articulation between the disciplines involved while preserving the theoretical and methodological specificities of each. The different forms of collaboration between disciplines need to be clearly defined. Claeys & Thian-Bo-Morel (2015) proposed clarification of attempted to elucidate the differences between three possible forms of collaboration between disciplines: multidisciplinary, interdisciplinary and transdisciplinary: "*multidisciplinary can be defined as the aggregation of different disciplines, interdisciplinarity by interpenetration between several disciplines and finally transdisciplinary by challenging disciplinary boundaries that can produce meta-disciplinary*" (Claeys & Thian-Bo-Morel 2015). Interdisciplinarity responds to the dual objective of close interaction between the disciplines involved while preserving the theoretical and methodological specificities of each. Thus, each specialty retains its own study methods (protocols, concepts) but, within the framework of interdisciplinarity, it is essential for its success to create links to build bridges between these specialties (Charaudeau 2010).

This interdisciplinary approach is essential for studying biological invasions. The human aspect must be taken into consideration in the study of biological invasions for a global understanding of the ecology, the impact, and the societal challenge this phenomenon involves (Dalla Bernardina 2010, Javelle *et al*. 2010, Atlan & Darrot 2012, Pimentel 2014). Indeed, the accidental introduction and invasion of *M. leidyi* in Europe has had a strong impact on invaded ecosystems and human activities. From a sociological point of view, this study deals with a major contemporary issue, relating to what Giddens (1990) calls "*the consequences of modernity*" and its environmental paradoxes. The case study chosen, relating to the anthropogenic causes and consequences of the development of *M. leidyi*, is an innovative research theme in sociology that is part of a broader reflection on "*the place of the animal*" (Staszak *et al*. 2002) and "*the proliferating nature*" (Claeys & Sirost 2010).

The notion of invasive alien species proposed by Charles Sutherland Elton in his book "*The ecology of invasion by animals and plants*" (Elton 1958) really became widespread in the scientific literature from the 1980s onwards. It has been the subject of passionate academic controversies tending to oppose the human sciences and life sciences. In the United States, this debate was particularly crystallized around the publications of the philosopher Sagoff (1999, 2005), Simberloff (1998, 2003) and Simberloff *et al*. (2013), founder of the journal Biological Invasion. Sagoff was concerned about the lexical and potentially ideological similarities between the vocabulary of biological invasion ecology and that of xenophobic nationalist policies. In response, Simberloff (2003) defended a precautionary principle, advocating a posture of generalized suspicion towards all new alien species. It is worth noting that the book of Elton (1958) was based upon ecological concepts that were considered as widely outdated by modern ecologists (*e.g*., Boudouresque & Verlaque 2012).

In France, the beginning of the 2000s was marked by the controversy over the invasive green macroalga *Caulerpa taxifolia* colonizing the *Posidonia oceanica* seagrass meadows of the Mediterranean. In this case, the oceanographers involved played the role of high-profile whistleblower (Meinesz *et al*. 1993, Boudouresque *et al*. 1995, De Villèle & Verlaque 1995, Meinesz *et al*. 2001, Humair *et al*. 2014). On the other hand, social scientists analyzed these scientific discourses and their media uptake their diffusion in the media as the fabrication of a modern myth (Dalla Bernardina 2010).

At the same time, sociological studies led by naturalist sponsors, notably the International Union for Conservation of Nature (IUCN), were developed (McNeely 2002). These studies were part of a social engineering approach using non-critical perception surveys aimed at formulating awareness campaigns to combat biological invasions. They have been well received in the journal Biological

Invasion, which expresses a cautious opening towards the human sciences (Simberloff *et al*. 2013). Nevertheless, this was a situation of "*science under influence*" (Jollivet 1992), depriving the social sciences of their critical power.

In between these two extremes, a dialogue that is both appeased and critical has emerged, often a little on the fringes of the academic power base. For example, in France, the hydrobiologist ethnologist were collaborating, producing constructive focused on around the invasive aquatic plant *Ludwigia peploides* (Menozzi & Dutartre 2007). Other experiments followed on the same principle of critical and peaceful co-construction (Kalaora 1998, Charpentier & Claeys-Mekdade 2006). What these different experiences have in common is that they have opted for "interdisciplinarity from below" (Zuindeau 2006). This mode of interdisciplinarity proposed an entry through objects and fields of study to calm epistemic tensions between the human and social sciences and the life sciences. It is a question, to use the expression of Brendon Larson (Larson 2005), of demilitarizing the problem of biological invasions, this "*war of the roses*".

This study on Berre Lagoon is in line with this "interdisciplinarity from below" approach (Zuindeau 2006). It involved submitting to investigation by natural and sociological sciences a complex subject, the proliferation of *M. leidyi*, which they could only fully elucidate through a co-understanding of the interactions between biological and anthropogenic processes in the socio-ecosystem of the Berre Lagoon. In this article an overview of the main results obtained based on a socio-ecological approach are presented to determine the potential impact of the invasive ctenophore *M. leidyi* on the socio-ecosystem of the Berre Lagoon.

MATERIALS AND METHODS

The creation of a common study protocol linking up the methodological tools of the different disciplines involved was a fundamental step in the implementation of interdisciplinary research. The interdisciplinary approach adopted in this study combined *in situ* oceanographic data, laboratory analysis and measurements with sociological investigations and citizen science (Fig. 2). This linkage provided a better understanding of the dynamics and possible impacts of the invasion of *Mnemiopsis leidyi* on the socio-ecosystem of the Berre Lagoon.

The conceptual framework of risk was used following formula: Risk = hazard × vulnerability. Risk resulted from the combination of hazards and vulnerability. Risk was defined as the result of damage caused because of interactions between disturbance factors (hazards) and vulnerability factors (use). The ctenophores represented the disturbance or hazard elements, and vulnerability was characterized by the more or less high exposure of humans (the practice of users) to the hazard (Veyret & Reghezza 2006, Gilbert 2009). In this study, hazard was measured by oceanography (presence, abundance of ctenophores, etc.) and vulnerability was analyzed by sociology (observation of lagoon frequentation patterns, behavior of users, etc.). Risk is also an object of discourse for individuals. In this case, the sociological survey records the levels of risk expressed by social actors and their ways of naming and qualifying these risks. In common parlance, when faced with the proliferation of an animal species, social actors tend to talk more about discomfort (Mieulet 2015). From this point of view, discomfort can be defined as the negative consequences experienced by social actors, in this case the users of the Berre Lagoon, when an event occurs, in this case the proliferation of gelatinous zooplankton.

A bimonthly monitoring (temperature, salinity, oxygen, chlorophyll *a*, abundances of zooplankton and ctenophores) was performed in the Berre Lagoon between October 2015 and September 2017 (Marchessaux *et al*. 2020a). Laboratory experiments were performed to study the physiology of *M. leidyi* (respiration, excretion, ingestion, digestion, reproduction, larval growth, and survival in starvation conditions) to determine its invasive potential. The human experiments were characterized by semi-directional interviews with different actors of the lagoons (fishermen, bathers, naturalists, yachting clubs, etc.). Finally, a citizen science was also performed to complete *in situ* monitoring and study the evolution of nuisance caused by cteno-

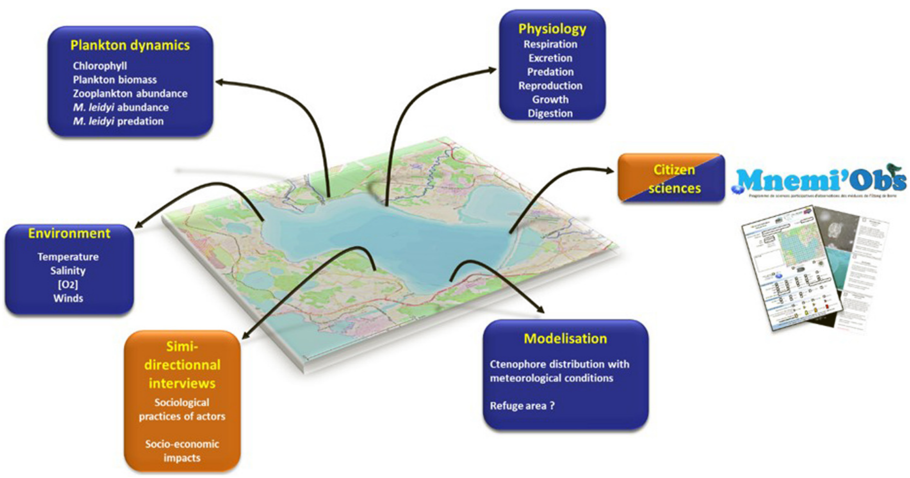

Fig. 2. – Diagram illustrating the strategy for interdisciplinary study of the dynamics and impact of *Mnemiopsis leidyi*. In blue: oceanography; orange: sociology.

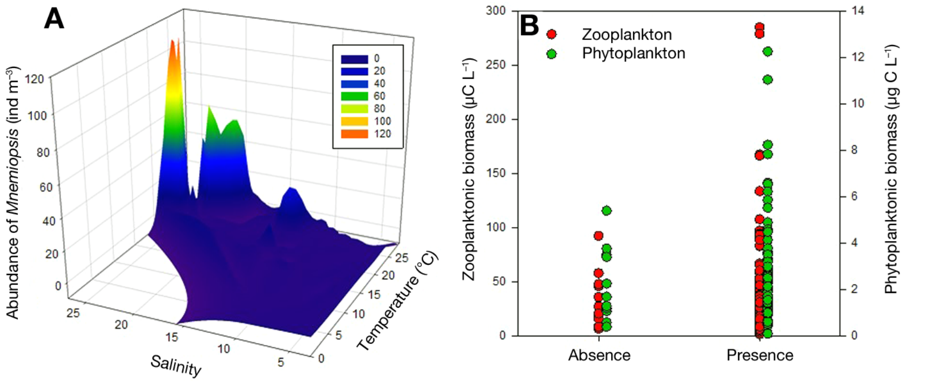

Fig. 3. – **A**: Three-dimensional representation of the abundance of *Mnemiopsis leidyi* (rainbow colors, ind m^{-3}) as a function of temperature (°C) and salinity in the Berre Lagoon; **B**: Zooplanktonic and phytoplanktonic biomasses (µg L^{-1}) during periods of absence or presence of *M. leidyi*. Data from 2010 to 2017 extracted from Marchessaux *et al.* (2020a).

phores proliferations. More details on the *in situ* monitoring are available in Marchessaux *et al.* (2020a) and, data presented in these articles were mainly extract from this article and presented differently.

RESULTS AND DISCUSSIONS

The main thread of this work was the perspective between human experiences and the measured. The human experiences concerned the experiences and testimonies of the social actors encountered. This human experience can be sensory, involving the body of individuals and their five senses, sight, touch, smell, taste, and hearing. This experience may be social, taking shape in the relationships between social actors and/or maybe economic, relating to the actors' losses and gains. Thus, it was a question of analyzing how different physical and socio-economic experiences could lead to a different understanding, definition, and quantification of the same phenomenon, in this case, the causes and consequences of the proliferation of gelatinous zooplankton.

What is the success rate of Mnemiopsis leidyi *invasions in the Berre Lagoon?*

Native to estuarine and lagoon environments, *Mnemiopsis leidyi* was able to maintain itself over a wide range of temperatures (1 °C to 32 °C; Kremer & Reeve 1989, Purcell *et al.* 2001, Lehtiniemi *et al.* 2012) and tolerated significant variations of salinity (0 to 40; Shiganova *et al.* 2004, Grove & Breitburd 2005). In the Berre Lagoon, *M. leidyi* was observed for temperature and salinity comprised between 3 °C and 28 °C and, 0 to 25, respectively (Fig. 3A) with highest abundances, 43 ± 24 ind m^{-3} (data range: 27 ind m^{-3}-95 ind m^{-3}), comprised between 19-25 for temperature and 22-28 for salinity. *Mnemiopsis leidyi* can also survive in areas with very little oxygen (> 1 mg O_2 L^{-1}; Decker *et al.* 2004, Grove & Breitburd 2005). Under unfavorable dietary conditions, *M. leidyi* can self-digest from its reserves and can thus survive for weeks (Ivanov *et al.* 2000, Yousefian & Kideys 2003, Anninsky *et al.* 2005).

The success of *Mnemiopsis leidyi* in Berre Lagoon was certainly due to a sufficient supply of carbon (Fig. 3B). According to Kremer (1994) the quantity of carbon limiting the development of *M. leidyi* was estimated at 3 µg C L^{-1}. Long-term monitoring data showed that the amount of particulate organic carbon (POC) did not fall below this threshold for the survival of *M. leidyi* (Marchessaux *et al.* 2020a). The sufficient supply of carbon in the Berre Lagoon therefore allowed *M. leidyi* to produce enough eggs (Reeve *et al.* 1989), and to have an optimal growth rate (Rapoza *et al.* 2005, Sullivan & Gifford 2007, Marchessaux 2019).

The other success of *M. leidyi* in native and introduced areas was possible thanks to the presence of refugia areas during winter (Costello *et al.* 2006, Marchessaux *et al.* 2020a). In the Berre Lagoon, the Vaine sub-basin provided favorable conditions (low temperature and salinity variations, sufficient carbon content, low currents) to maintain *M. leidyi* in critical environmental conditions (*i.e.*, cold winters; Fig. 4) (Marchessaux *et al.* 2020a).

Impact of Mnemiopsis leidyi *on the Berre Lagoon socio-ecosystem*

The notion of socio-ecosystem refers to the relationship between Society and the Environment and the effects that one can have on the other. Considering the links

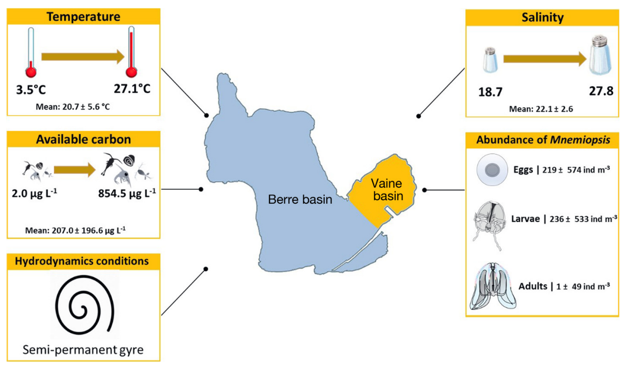

Fig. 4. – Assessment of the conditions measured in the refugia area of *M. leidyi* in the Berre Lagoon. Redrawn from Marchessaux *et al.* (2020a).

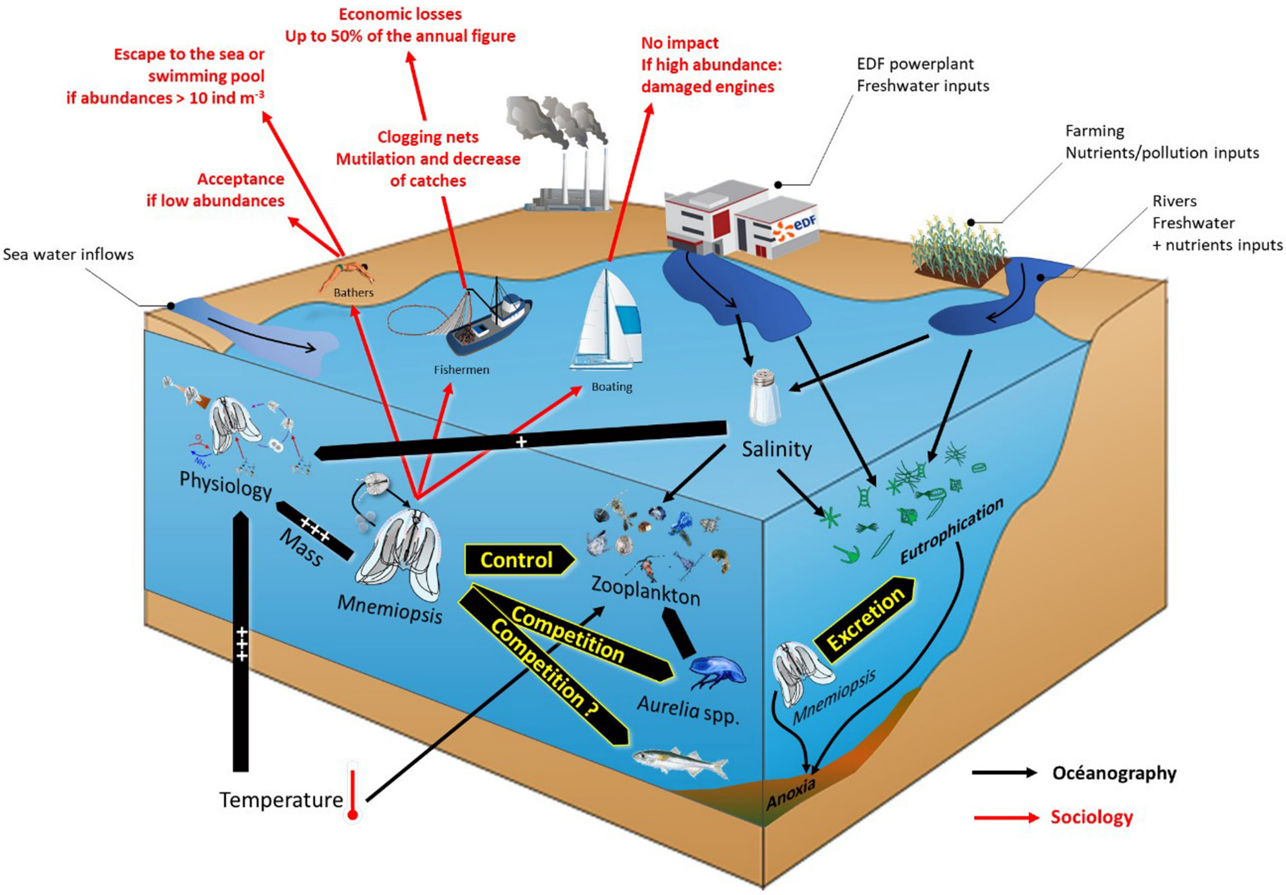

Fig. 5. – Overall summary of the interactions identified between *Mnemiopsis leidyi* and the socio-ecosystem of the Berre Lagoon.

between society and the environment, the framework of our interdisciplinary study allowed us to establish a complete inventory of the interactions and impacts of the invasion of *M. leidyi* (Fig. 5).

A voracious predator, *M. leidyi* had a significant predation pressure on the zooplankton community, whose grazing on phytoplankton remained limited in this context. The presence of *M. leidyi* contributed to the eutrophication of the lagoon on the one hand by controlling the zooplankton and on the other hand by contributing to phytoplankton development through the excretion of ammoniacal nitrogen (~ 3 %; Marchessaux 2019) as observed in Chesapeake Bay (3 %; Nemazie *et al.* 1993) and in York River (4 %; Condon *et al.* 2009). These hypoxic crises, which generally occur in summer, are fatal for populations of benthic organisms.

The potential competitiveness of *M. leidyi* for the resource had certainly contributed to the decline of the autochthonous cnidarian *Aurelia* spp. (jellyfish) whose observation in the environment became limited in time. In the light of this potential competition between the two gelatinous species, the hypothesis of competition with planktonophagous fish in the lagoon can be proposed.

This has not been tested in our study, but if there was competition, a decrease of commercial fish species could be observed, which could have catastrophic economic consequences for the professional fishery. Professional fishing was the human activity most impacted by gelatinous species blooms. The damage caused by *M. leidyi* was significant (clogging of nets, mutilation of catches, damage to equipment, increased workload) and involved losses of up to 50 % of the annual revenues. Bathing activity was little affected. The presence of *Mnemiopsis leidyi* was acceptable for bathers because this species is not stinging. On the other hand, this study has determined a threshold of bathers' acceptability (10 ± 8 ind m^{-3}). Beyond this threshold of acceptability, the swimmers deserted the beaches of the lagoon. Boating was not affected by the proliferation of *M. leidyi* but, in the case of strong proliferation, damage to the cooling systems of boat engines has been observed.

Mnemiopsis leidyi *invasion and rehabilitation efforts*

This interdisciplinary study has demonstrated the extent to which current European rehabilitation efforts were potentially counteracted by the presence of *Mnemiopsis leidyi*. To address this issue, based on the data collected in oceanography (abundances of ctenophores and zooplankton, ctenophores gut contents, physiology) and sociology (impact on different activities, discomfort of users, citizen science), we propose two scenarios (Fig. 6).

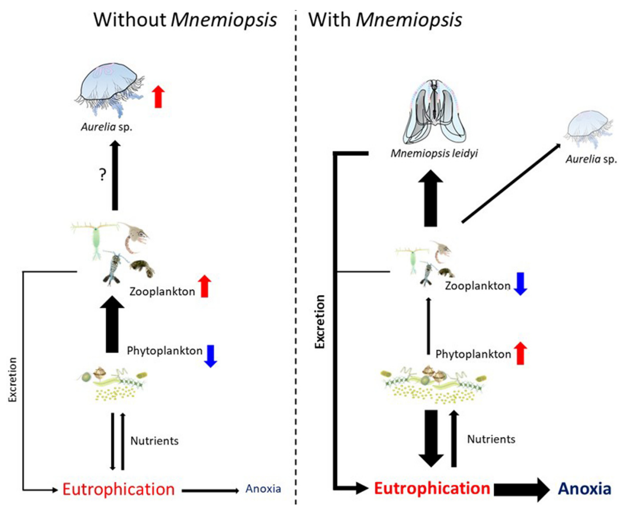

Fig. 6. – Conceptual diagram of the possible scenarios of changes in the functioning of the pelago-benthic food web in the Berre Lagoon in the absence or presence of *Mnemiopsis leidyi*.

Scenario 1 – No Mnemiopsis leidyi *(before introduction)*: Without *M. leidyi*, zooplankton exerts a "top-down" control over phytoplankton, decreasing in synergy with the decrease in freshwater and nutrient inputs inducing significantly low eutrophication of the lagoon and limiting hypoxic/anoxic crises. Without ctenophores, *Aurelia* spp. could recover in the lagoon.

Scenario 2 – With Mnemiopsis leidyi *(current configuration)*: The presence of a large population of *M. leidyi* counters rehabilitation efforts and helps to maintain eutrophication. *Mnemiopsis leidyi* controls the zooplankton community that can be ingested at a rate of up to 80 % of its abundance per day. This directly results in a reduction in zooplankton grazing pressure on phytoplankton communities. In addition, the $N\text{-}NH_4$ excretion of *M. leidyi* contributes 3.8 % of the ammonium inputs to the lagoon, which also promotes phytoplankton growth via regenerated production. Thus, by a "top-down" and "bottom-up" effect, the population has a favorable effect on the maintenance of eutrophication in the Berre Lagoon.

The issue of combating the proliferation of *M. leidyi* in the Berre Lagoon was raised by more than 80 % of the users encountered. Opinions suggest that controlling the proliferation of *M. leidyi* is one of the priority issues for future management of Berre Lagoon. The contribution of our interdisciplinary study enabled us, with knowledge of the users' wishes in terms of management, to report on the factors favoring the maintenance of *M. leidyi* and the interactions within the socio-ecosystem. Based on this observation, management measures will be proposed (anti-jellyfish nets, risk maps, etc.).

CONCLUSION

The convergence of life sciences (LS) and human and social sciences (HSS) responds to a social and political demand, both of which are growing in the context of the development of environmental policies and their application. This *rapprochement* of LS and HSS helps to overcome the problem of the life sciences considering pristine ecosystems in isolation from human influence and it is therefore necessary to consider the human factor in ecological studies. The combination of LS and HSS can give rise to misunderstandings, particularly from the point of view of methodology, which are mitigated by the interdisciplinary approach that consists in the interpenetration of disciplines aimed at the co-construction of scientific protocols and the coproduction of new knowledge that goes beyond the aggregation of disciplinary knowledge.

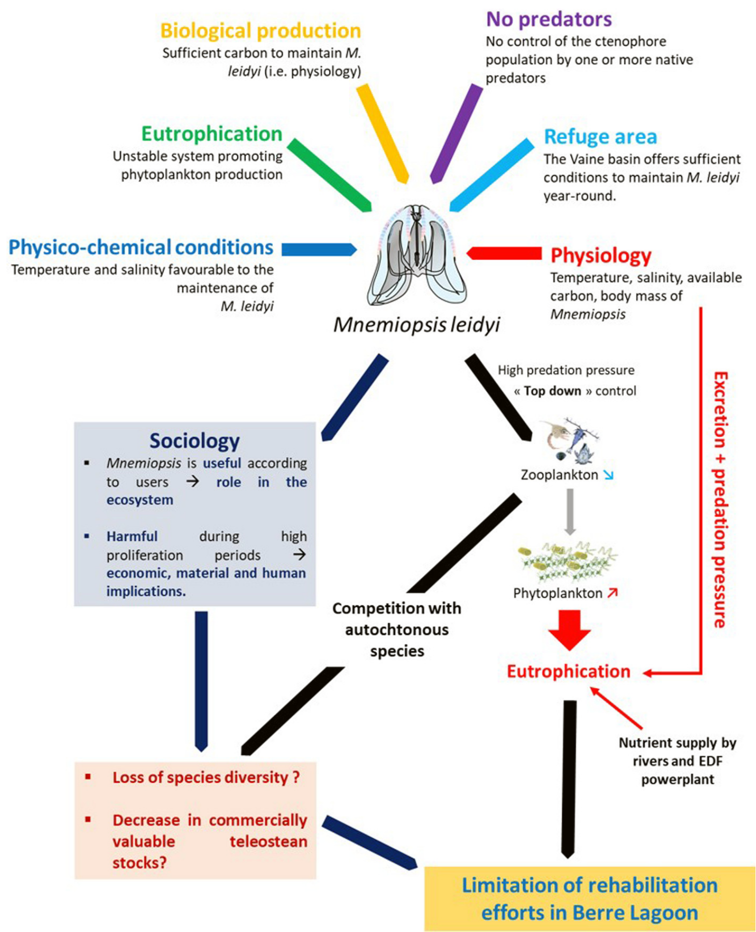

Fig. 7. – Summary diagram of the parameters effecting on the physiology of *Mnemiopsis leidyi* and its role in the socio-ecosystem of the Berre Lagoon.

In fact, the interests and objectives of each discipline are brought together in a reciprocal and mutually beneficial comprehension by excluding the false hierarchy between LS and HSS. The success of interdisciplinarity lies in the acceptance by the life sciences of the critical posture of the human and social sciences and, conversely, the recognition by HSS of the materiality of life as analyzed by the life sciences. This collective practice does not exclude the skills and methodologies of each discipline, but resides in an acculturation over time, respect, and mutual trust from a human and scientific point of view.

This study is in line with this bottom-up interdisciplinary approach, where the two disciplines involved had to deal with a complex subject, the proliferation of *M. leidyi*, which they can only fully understand through combined understanding of the interactions between biological and anthropogenic processes in the Berre Lagoon (Fig. 7). The interdisciplinary approach has fully proved its worth in this work. The testimonies of users have sometimes led us to seek/question ecological aspects that would not have been explored in the case of a life science study alone. Moreover, the contribution of sociology in this work has represented a real added value in that thanks to the network developed with the users of the lagoon, we were able to place able to obtain complementary data on the distribution and the dynamics *in situ* of the ctenophores and on the other hand the proliferation of *M. leidyi* was placed within the societal requirements concerning this socio-ecosystem.

In Berre Lagoon, the installation of *M. leidyi* in conjunction with the implementation of rehabilitation efforts in this case illustrates the fragility of the ecosystem historically disturbed by human activities. Heavy freshwater discharges from the EDF (*Électricité de France*) hydroelectric powerplant and industrial and urban discharges have considerably altered the hydrological functioning and have thus destroyed a large part of the lagoon's habitats. The anthropogenic pressures have allowed the arrival and development of invasive species (*i.e.*, *M. leidyi*, *Gonionemus vertens, Acartia tonsa* Dana, 1849, *Ulva* sp., etc.). Thus, Berre Lagoon represent anthropized place where ecological history has conditioned its management but also the fluctuations of nature.

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