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Integrated Ecosystem Management for Exploited Coastal Ecosystem Dynamics Under Oligotrophication and Climate Changes

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Abstract :

Global change causes fluctuations as rainfall deficits that in some cases amplifies the reduction in nutrient intakes required for water quality regulation. In this context, oligotrophication reduces the pelagic production of coastal ecosystems and promotes the return of benthic macrophytes such as Zostera meadows. It is now necessary to know and understand the potential benefits related to the return of seagrass beds associated with the environmental recovery of shellfish-exploited-ecosystems (SEE). The French–Japanese SAKURA project aimed to (1) clarify and compare relationships between dynamics of nutrient levels, phytoplankton, and oyster production in the Thau Lagoon (France) and Hiroshima and Aki bays, using historical data analysis and carrying capacity models, (2) highlight the Zostera spp. contribution to oyster life cycles studying the variability of larval recruitment, survival, growth of juveniles, and trophic regime of oysters in the presence or in the absence of Zostera spp. meadows, (3) describe and compare the dynamics of socio-ecosystems of SEE under oligotrophication. First results of the SAKURA project permitted to start to improve knowledge on the influence of oligotrophication processes on the ecological status of shellfish-exploited-ecosystems and on the oyster life cycle. Analysis is still ongoing. Now, the French and Japanese partners want to deepen the interdisciplinary approach and the knowledge of this major sea and coastal challenge by expanding their partnership in the international community to address more holistically the conservation of biodiversity and the sustainable use of resources in the changing coastal seas.

Keywords : Oyster aquaculture, Oligotrophication, Seagrass, Coastal productivity, Socio-ecosystem

1. Introduction

Global environmental change and recent continental and coastal management actions have gradually and successfully decreased nutrient contents of coastal waters in some regions (Collos et al. 2009, Yanagi 2015, Derolez et al. 2019). However, some stakeholders suggest that the improvement in water quality is now causing another issue in natural contribution to people called “oligotrophication”. Oligotrophication could reduce pelagic primary productivity in coastal ecosystems, sometimes resulting in the decrease of fishery catch because coastal fisheries have adapted to the previous eutrophic environment from the 1970’s to the 2000’s. For example in Seto Inland Sea, Japan, most of the recent fishery-target species are pelagic fishes and their preys derive from pelagic production. Typical rafted-culture of bivalves in offshore areas has been prospering with eutrophication. In France, oligotrophication has also been recently observed and raised some worries on oyster productivity for some shellfish farmers (Derolez et al. 2017, Bec et al. 2018). An especially issue is improvement of oyster recruitment process is an urgent treatment for sustainable farming (Lagarde et al. 2017, 2018). In contrast, oligotrophication with high water transparency has helped the recovery of benthic primary productivity including macrophytes including seagrass vegetation, which are important for climate change mitigation (*i.e.* limitation of hypoxia and acidification) and adaptation such as carbon storage and protection from sea-level rise and storm surges (Hori et al. 2017, Tsurita et al. 2017). The recovery of these ecosystem services has been warmly welcomed by other stakeholders concerned with environmental issues.

In this context, a French-Japanese SAKURA-Hubert Curien project funded by JSPS (Japan Society of the Promotion of Science) and Campus France (French Embassy in Japan) triggered a collaboration between the MARBEC research unity Marine Biodiversity, Exploitation and Conservation (Ifremer, CNRS, IRD, Montpellier University) and the Japan Fisheries Research and Education Agency (FRA) from 2017 to 2018. The project had been developed to better understand the links between conservation and exploitation of Shellfish-Exploited-Ecosystems (SEE) and the impacts on human well-being by developing an inter-disciplinary approach among ecological and social dimensions. The two study sites were Hiroshima, Aki Bays (Seto Inland Sea) and Thau Lagoon (Mediterranean Sea) (**Erreur ! Source du renvoi introuvable.**). These sites were both intensively exploited by shellfish farming and characterized by ecological trajectories of oligotrophication under global change.

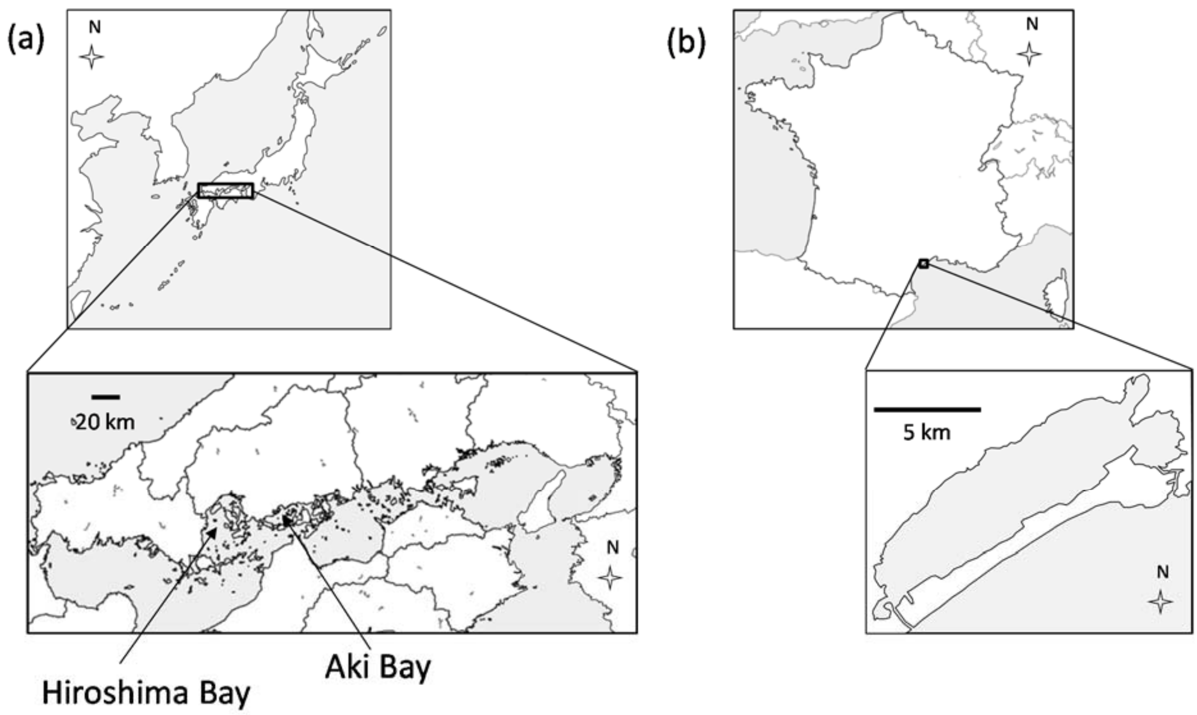


Figure 1 - The two comparative study sites with *a*) Seto inland Sea, including Hiroshima and Aki Bays and *b*) Thau Lagoon near the Gulf of Lion, Mediterranean Sea. These maps were revised from Hori et al. (2018).

Three tasks had been developed taken into account ecological, economic and social issues. The first task aimed to clarify the state and process of ecosystem productivity under oligotrophication and global environmental change. The relationships between nutrient level and functioning of shellfish-exploited-ecosystems were described in terms of ecological status and oyster performances, using historical data analysis and ecosystem modeling.

The aim of the second task was to find good practices and the ecological tools for adaptation and mitigation to the oligotrophic environment under global change in shellfish farming ecosystems. In particular, we were interested in two ecological processes: oyster recruitment and seagrass-oyster interaction. Seagrass beds provided various ecosystem functions for oyster growth and survival in the original habitat of pacific oyster. As part of this task, *in situ* experiments were conducted in Japan and France in 2017 and 2018 in order: (i) to explore the larval recruitment variability in shellfish farming areas in the presence or absence of seagrass (*Zostera* spp.*)* meadows, (ii) to test the impact of seagrass vegetation on shellfish performances and (iii) to identify seagrass trophic contribution to oysters.
The third task was to clarify the value chains of local communities surrounding the oyster industry, to identify human well-being. This task was carried out according to an interdisciplinary approach integrating interactions between ecological functions and social/economical activities, at the scale of social-ecological systems (SES).

2. Methods and preliminary results

2.1. Clarification of nutrient input dynamics and relationship between nutrient levels, phytoplankton and oyster production

2.1.1. Analysis and comparison of the temporal evolution of the ecological status of water column and oyster performances in the Thau Lagoon and in the Hiroshima Aki bays using long-term time-series (1998-2016).

As part of the SAKURA (French-Japanese program for science and technology cooperation) and CAPATHAU (Trophic CAPAcity of THAU Lagoon) projects[1], analyses of the temporal evolution of the ecological status of the water column and oyster performances were conducted using long-term time-series (1998-2016) in the Thau Lagoon (see Bec et al. 2018 for details on database) and in the Seto Inland Sea (Ministry of transportation[2]) (**Erreur ! Source du renvoi introuvable.**). Historical data concerned physicochemical parameters, nutrient inputs from the watershed, nutrient contents in water column, phytoplankton biomass and growth, and production of oysters. A decrease of water nutrients and phytoplankton concentrations and a lower contribution of diatoms to the phytoplankton abundance were highlighted in the Thau Lagoon from 1998 to 2016. This trend was associated with a decrease of nutrient inputs from the watershed and rainfall levels, and with an increase of temperature (Derolez et al. 2017, Bec et al. 2018). The production of shellfish halved from 2008 to 2010, due to high mortality rates of oyster juveniles, associated with the OsHV-1 pathogen. Growth rates and condition indexes of oysters were higher in the 2014 to 2017 period than in the 1993 to 2007 period. The levels recorded from 2014 to 2017 still corresponded to high values, making the Thau Lagoon the best site in France for oyster growth (Bec et al. 2018).
The historical databases from Thau Lagoon, Hiroshima and Aki Bays were merged. The annual oyster production levels recorded in most of the sites of Hiroshima Bay (ie. Kure, Eba, Hatsukaichi and Edajima, **Erreur ! Source du renvoi introuvable.**) are currently 3 to 4 times higher (18662 to 29452 t) than in Thau Lagoon (6651t), whereas the production was comparable to Aki Bay's production (4549 t). A significant decrease of oyster production occurred during the 1990's in most of the Japanese sites. Data of growth and condition index were not available for the Japanese sites.

[1] http://www.dlalbassindethau.fr/2017/09/12/capathau-un-programme-scientifique-pour-etudier-la-productivite-des-bassins-de-production-et-elaborer-des-scenarios-de-gestion-a-long-terme/ ;
https://youtu.be/gmNwr5pqQS0
[2] http://www.pa.cgr.mlit.go.jp/chiki/suishitu/

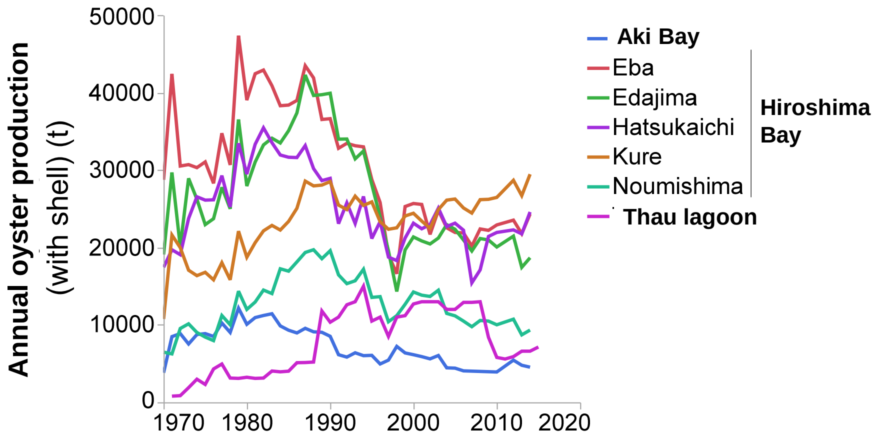


Figure 2- Evolution of oyster production (in tons with shell) recorded in Aki and Hiroshima Bays (Eba, Edajima, Hatsukaichi and Kure) in Japan and in Thau Lagoon in France, from 1970 to 2016.

First analyses on environmental data (**Erreur ! Source du renvoi introuvable.**) showed that the Thau Lagoon, Aki and Hiroshima Bays were mainly discriminated by: 1) dissolved inorganic nitrogen (DIN) concentrations, with higher levels observed in the Japanese sites, and by 2) salinity, chlorophyll *a* and phosphate (DIP) concentrations, with higher levels observed in France. Comparative analysis of temporal evolution of ecological status are in progress. Results will help to better understanding the environmental shifts that occurred and their potential consequences on oyster production.

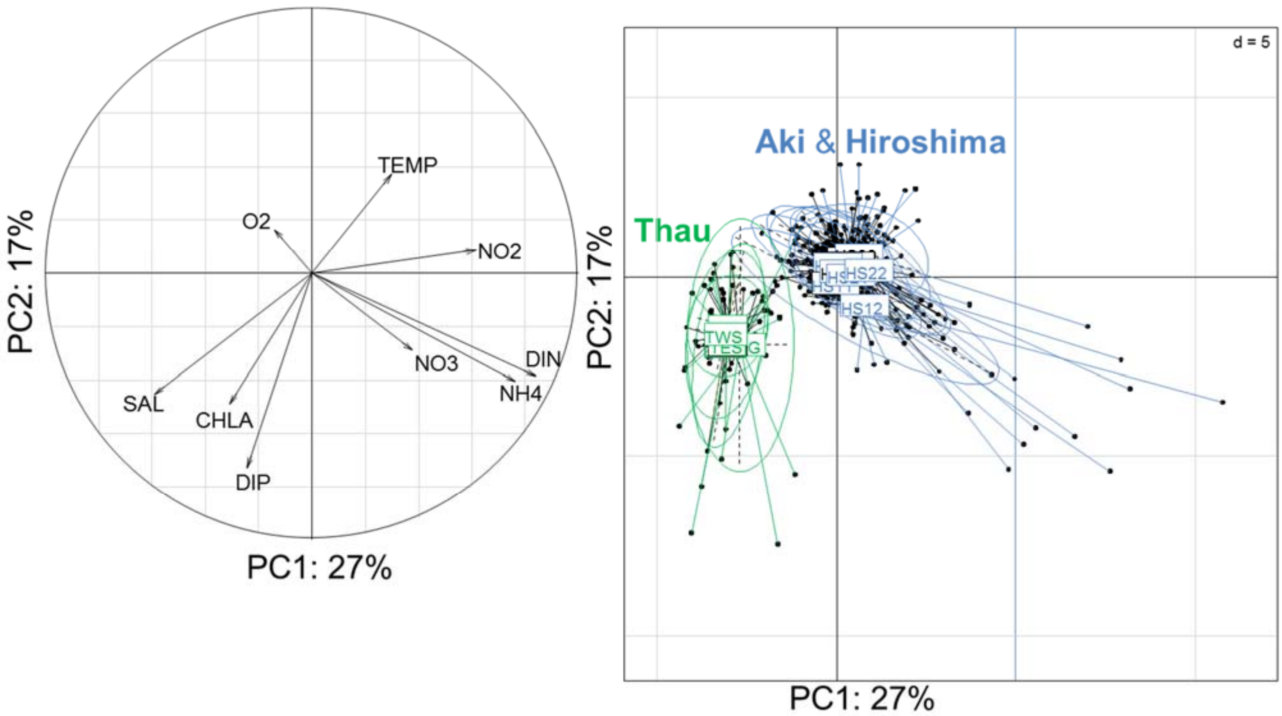


Figure 3 - PCA analysis on French-Japanese historical database including physico-chemical parameters (TEMP: Temperature, SAL: Salinity, O2: Oxygen, CHLA: phytoplankton Chlorophyll-a biomass, NO3: nitrate, NO2: nitrite, DIN: Dissolved Inorganic Nitrogen, DIP: Dissolved Inorganic Phosphate) recorded during summer from 1998 to 2016 in Thau lagoon (France) (in green), Aki and Hiroshima Bays (Japan) (in blue).

2.1.2. Analyze the influence of several management scenarios on ecological status and oyster production using carrying capacity modelling

Carrying capacity modelling tools have been developed in Japan and France to test the effect of several scenarios of nutrient input and oyster exploitation on ecological components and oyster production. One of the main objectives of such tools was to help managers to maintain sustainable shellfish culture in coastal ecosystem under oligotrophication and global change. Exchanges of expertise between both countries facilitated the development of the tools and analysis of scenarios. Results from modelling carried out in France were further described (Pete, Guyondet, et al. 2018, Pete, Richard, et al. 2018). Results highlighted that the variability of oyster production was mainly controlled by hydrometeorology, with oyster production being 1.8 to 2.3 times higher during rainy years than dry years. In comparison to the current situation (Reference scenario), higher oyster productions (biomass at harvest = 13981 tons) were achieved when normal waste water treatment plant (WWTP) efficiency were used (decrease of 75% N and 60% P). Maximum WWTP efficiency (decrease of 90% N and P), however, induced a decrease of oyster production (biomass at harvest = 10762 tons) by 12.9%, without significantly improving the ecological status of the Thau lagoon. The scenario of stocking oyster density (biomass at harvest: 13216 tons) to its authorized maximum (set by the French regulation body, initial condition seeding: 1047 10^6 of 1.4cm-0.03g Dry Flesh Mass for pregrowing oysters and 288.6 10^6 of 6.6 cm-0.18g Dry Flesh Mass for growing oysters) triggered an increase of oyster productions by 7% at the expense of thinner oysters with a lower condition index. This result, therefore, highlighted the trophic competition between oysters within growing structures. Currently, considering the real N and P inputs and oyster stock (biomass at harvest = 12360 tons; initial seeding condition: seeding 532 10^6 pre-growing oysters + 235.7 10^6 growing oysters), the Thau Lagoon remains an exceptional site for oyster farming associated with a "good" ecological status condition (Bec et al. 2018, Pete, Richard, et al. 2018). Nevertheless, this work also demonstrated that oyster production might be threatened if drastic measures are undertaken on WWTP, particularly on phosphorus that seems to control primary production in the Thau ecosystem (Pete, Richard, et al. 2018). The scientific collaboration with Japanese researchers will help to significantly improve the model of the Thau Lagoon by integrating a biological compartment for clams, which can be harvested and whose stock has considerably decreased since the 2000's.

2.2. Ecological tools of adaptation and mitigation to oligotrophication: Highlighting the *Zostera* spp. contribution to oyster life cycles (years 2017-2018)

Our hypothesis was that seagrass beds could support oyster production and improve its quality and sustainability. The seagrass contribution to oyster production was divided into two processes in relation to the oyster life cycle stage: recruitment processes from the larval stage to spat settlement, and post-recruitment processes with spat growth. A series of *in situ* experiments were conducted in Japan and France in 2017 and 2018 in order: (1) to explore the larval recruitment variability in shellfish farming areas in the presence or absence of *Zostera marina and Z. noltii* meadows, (2) to test the influence of seagrass vegetation on shellfish performances (sanitary quality, survival, growth) and (3) to identify seagrass trophic contribution to oysters. The methods and preliminary results were described below. To our knowledge, there was no case study directly demonstrating the effect of oyster-seagrass interactions on ecosystem functioning of target ecosystems, although there were some modelling researches on the material cycling in a coastal ecosystem including oyster and seagrass beds (e.g. Kishi & Oshima 2008).

2.2.1. Larval recruitment variability in shellfish farming areas

Settlement and recruitment of oysters were monitored at six contrasting stations during August 2017 from east to west, in the absence or presence of *Zostera* spp. meadow and shellfish farming in the Thau Lagoon (Figure 4), The oyster collectors were deployed as described by Lagarde et al (2018, 2019) (Figure 5). The collectors were deployed in the water column (Figure 5a, b) inside/outside shellfish farm sites and above and below the canopy in *Zostera* spp. meadows inside sites with *Zostera* (Figure 5c). All collectors were sampled after 2 weeks of immersion to assess pediveligers and postlarvae abundance and after 4 weeks of immersion to assess oyster spat abundance.

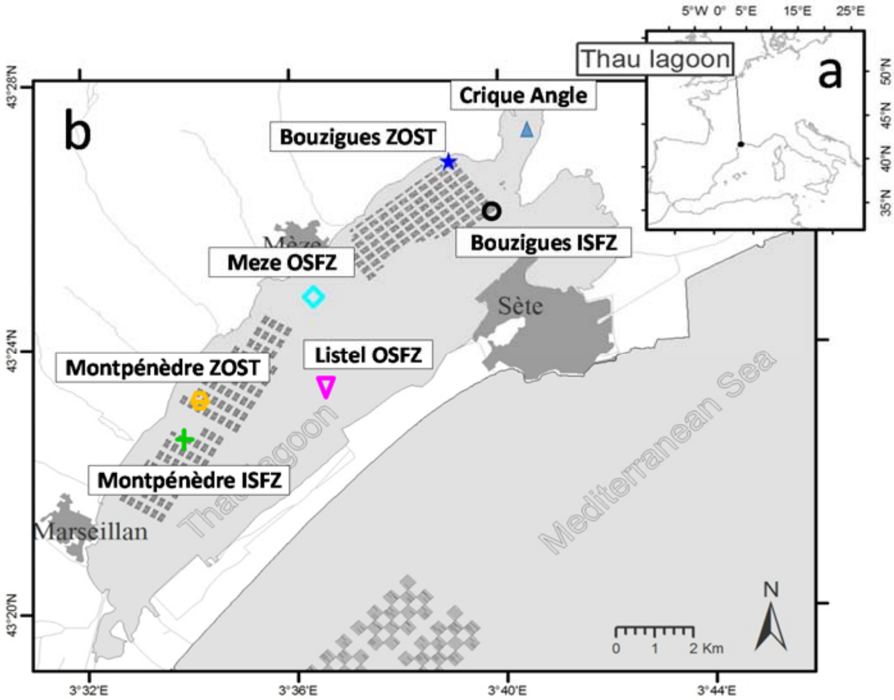
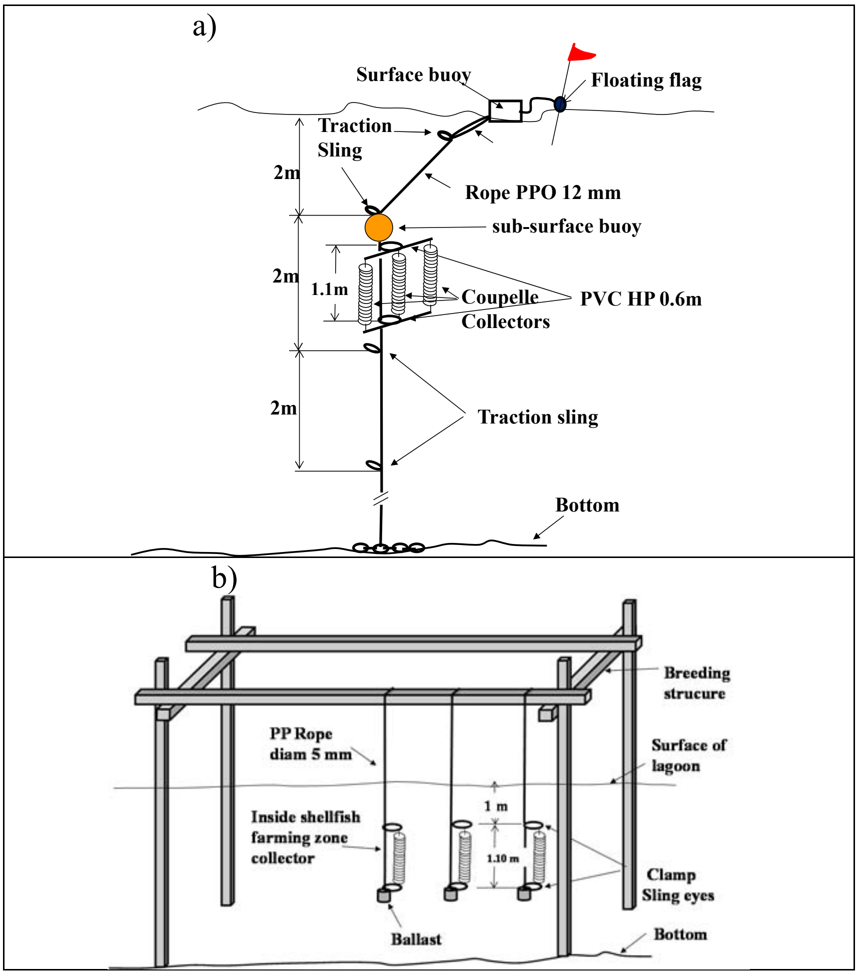


Figure 4 - a) The Thau Lagoon in south of France with b) the six sampling sites scattered from east to west with three conditions (ISFZ; Inside Shellfish Farming Zone, OSFZ: Outside Shellfish Farming zone, Zost: *Zostera* spp. meadows).



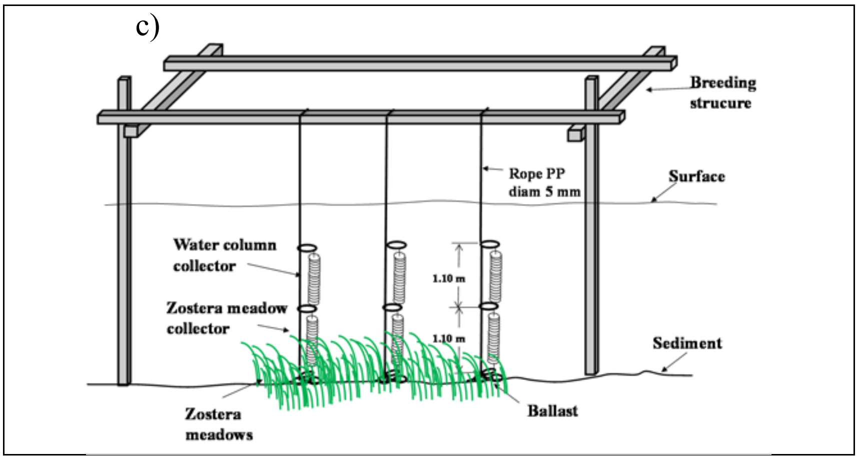


Figure 5: Mooring system used a) Outside Shellfish Farming Zone (OSFZ) in the Thau Lagoon. The gear supported 3 replicates of "coupelles" collectors. b) Inside Shellfish Farming Zone (ISFZ) and c) inside shellfish farming zone with *Zostera* spp. meadows (ZOST). PP: polypropylene. These figures were revised from Lagarde et al (2017, 2018).

Erreur ! Source du renvoi introuvable. showed that in the two *Zostera* spp. sites (ZOST) of Montpénèdre and Bouzigues, young settlers abundances were lower in the canopy of *Zostera* spp. meadows than in the water column. The best sites for settlement were the OSFZ sites (Listel, Meze), these results confirm those of Lagarde et al. (2017 & 2018). Zostera meadows show no higher favorability for oyster settlement than other nearby sites in term of abundances.

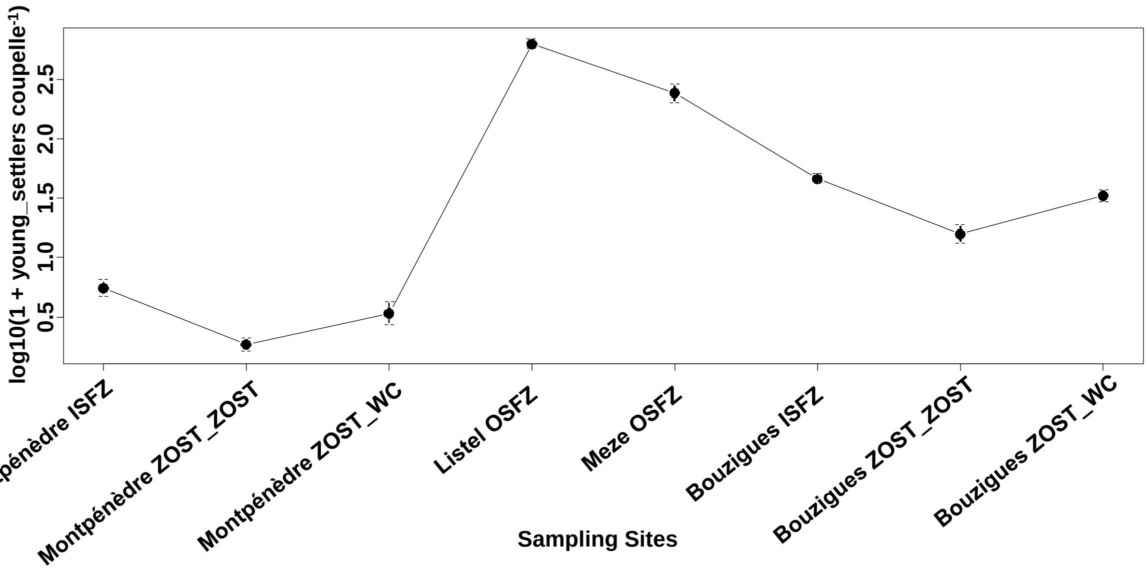


Figure 6 -Young settlers (pediveligers and postlarvae) assessment (mean ± SE) on the different conditions, ISFZ Inside Shellfish Farming Zone, OSFZ Outside Shellfish Farming Zone, ZOST_ZOST collectors inside *Zostera* meadow, ZOST_WC collectors in water column above *Zostera* meadows.

Results showed no positive effect of seagrass meadows on the oyster recruitment in the French study site (Figure 7). The relationship between young settlers (pediveligers and postlarvae) and recruited oysters was different according to the sampling stations (Figure 7). Sites with *Zostera* spp. meadows appeared to be less profitable than other sites in terms of recruited spat abundance. These differences reflected different ecological processes in the contrasting stations.

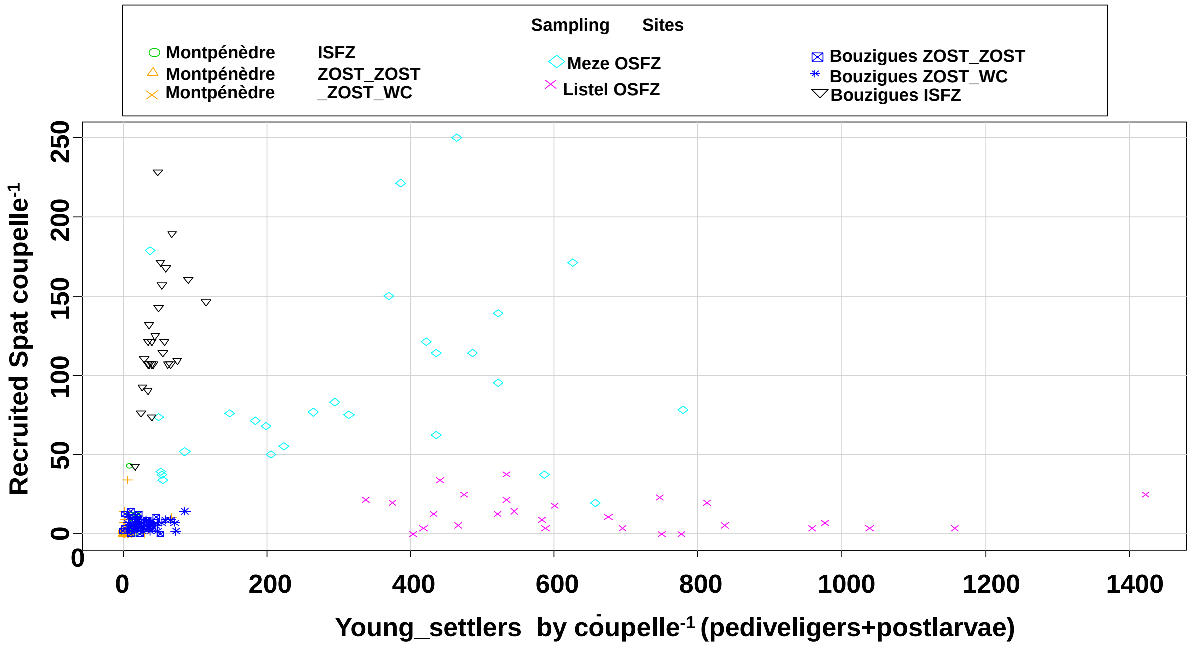


Figure 7 - Relation between abundances of settlement (pediveligers and postlarvae) and recruited *Crassostrea gigas* on the six contrasted sampling sites in Thau Lagoon. Sampling Collectors were ISFZ for sites Inside Shellfish Farming Zone, OSFZ for sites Outside Shellfish Farming Zone, ZOST_ZOST for sites with *Zostera* spp. and collectors was in *Zostera* spp. meadows, ZOST_WC for sites with *Zostera* spp. and collectors were in the water column (See Figure 4 and Figure 5).

Perspectives will be to determine the ecological processes inducing spatial variability of the observed relationships between settlement and recruitment. Biochemical analyses (lipids, fatty acids) are ongoing on planktonic components and oyster larvae to understand the link between the nature of trophic resources (quantity and quantity of food intake by autotrophic or heterotrophic primary production) on each sampling station and, larval physiology and success and size of metamorphosis (lipids, fatty acids, prodissoconch 2 size and abundances).

2.2.2. Influence of seagrass vegetation on shellfish performances (sanitary quality, survival, growth)

Some authors related a 50% reduction in the relative abundance of potential bacterial pathogens capable of causing disease in humans and marine organisms to seagrass beds presence (Lamb et al. 2017). Our hypothesis was thus that seagrass beds could maintain or improve the safety and sanitary condition of oysters that would possibly give an added value to oyster products. To clarify the effects of seagrass vegetation on microbiome in both oyster and ambient sea waters, two series of experiments were carried out in the Thau Lagoon in 2017 and 2018 in the presence and absence of *Zostera* spp. meadows (Figure 5: Bouzigues ISFZ, Bouzigues ZOST, Montpénèdre ZOST, Montpénèdre ISFZ) for analyzing environmental DNA and oyster microbiomes. Analysis is ongoing. In parallel, the effect of *Zostera* spp. meadows was tested in 2018 on growth and survival of juveniles oysters after 3 months of growing (September-December) inside and outside *Zostera* spp. meadows at Bouzigues and Montpénèdre in the Thau Lagoon (Figure 5).

2.2.3. Seagrass trophic contribution to oysters.

To highlight the trophic contribution of seagrass to oysters, sampling of sea water, oysters at commercial size, benthic organism, fish, and sediment was done in presence and in absence of *Zostera* spp. meadows in Bouzigues, Montpénèdre and Crique de l'Angle (Figure 4) in 2017 and 2018 to analyze the difference in carbon and nitrogen circulation between oyster aquaculture areas within seagrass vegetation and those without seagrass vegetation. The analyses are ongoing but the tentative result from core samples exhibited clear differences in organic carbon (OC) storage in the sediment (Figure 8).

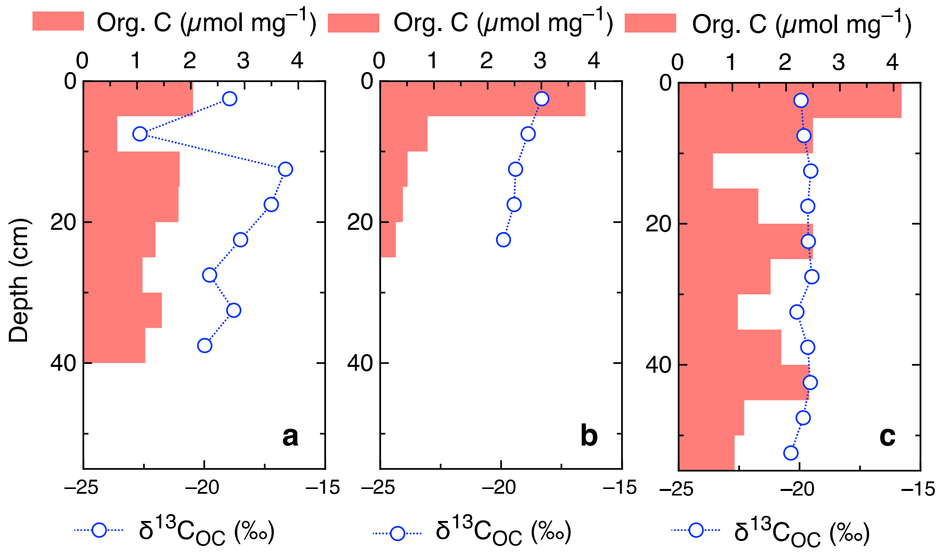


Figure 8 -Vertical profiles of concentration and stable isotope ratio of organic carbon stored in the sediment of **a**) a site with dense *Zostera spp* vegetation and outside shellfish farms (Crique de l'Angle), **b**) a site inside shellfish farm of Bouzigues but with no seagrass coverage, and **c**) a site inside a shellfish farm and under dense *Zostera spp* meadows (Bouzigues ZOST).

The OC content at the topmost layer was about twice as high inside (b, c) than outside (a) shellfish farms, presumably due to OC inputs in the form of pseudofaeces from farmed oysters. However, the OC content in subsurface layers in sediments was higher in *Zostera* spp. meadows (a, c) than a site without seagrass coverage (b). The latter fact suggested that OC derived from *Zostera* spp. and associated algae was refractory and persisted for a long term inside sediments contributing effectively to carbon sequestration, compared to the OC derived from pseudofaecal deposition. The concentration of calcium carbonate (inorganic carbon) in sediment was also different between the inside (60% – 80% of dry weight) and outside of shellfish farms (30% – 50%), reflecting accumulation of oyster shell debris inside the farms (ANOVA: $F = 106.6$, $p < 0.0001$). Both *Zostera* spp. vegetation and the accumulation of carbonates would contribute to the reduction of mineral sediment resuspension and siltation, thereby improving growth conditions for oysters.

In the Japanese site, the experiment of oyster spat cultivation on both the tidal flat with *Zostera* spp. seagrass vegetation and the offshore floating raft without seagrass vegetation exhibited some results (Hori et al. 2018). Oyster spats cultivated on the tidal flat had higher meat part ratio and stable carbon isotope ratios than spats cultivated in the area without seagrass vegetation (Figure 9). These results suggested that trophic contribution of seagrass vegetation occurred. The seagrass trophic contribution was well known and reported as interactions between seagrasses and filter-feeding bivalves in various seagrass meadows from temperate to tropical regions of the world (Morimoto et al. 2017).

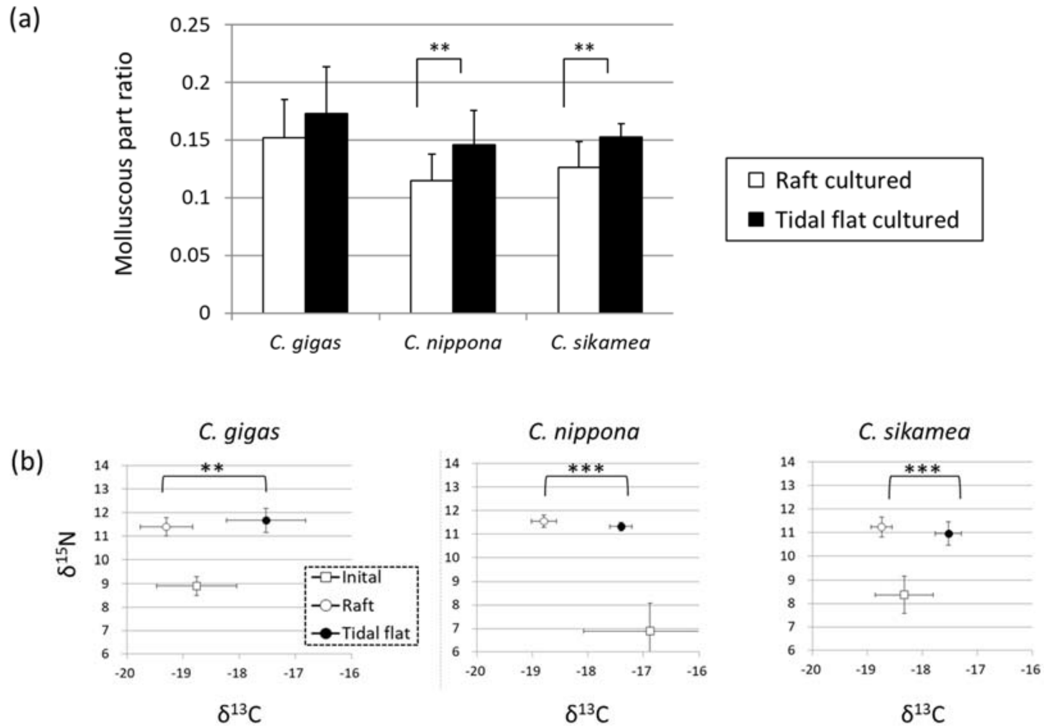


Figure 9 - Comparison between tidal flat and raft cultured spat growth of three species (*Crassostrea gigas*, *C. nippona* and *C. sikamea*) in the Japan site using **a**) the ratio of mollusks part weight (gDW) to total (mollusks part and shell) weight (gDW) and **b**) carbon and nitrogen stable isotope composition of each oyster species. Open squares indicate initial conditions. Significant p-values are represented by asterisks: *$p<0.05$; **$p<0.01$; ***$p<0.001$. These figures were arranged from Hori et al. (2018).

Seagrass meadows might also contribute to the trophic status of ecosystem components other than farmed oysters, such as indigenous fish populations. Figure 10 showed that the presence of intense oyster farming in Thau Lagoon caused a trophic shift of the indigenous fish *Atherina boyeri* from strong dependence on planktonic resources (pelagic channel) to more extensive exploitation of resources derived from seagrasses and their microepiphytes (benthic channel). This fact suggested that seagrasses and microepiphytes subsidized *A. boyeri* with food source when the planktonic resource was exhausted by active filter feeding of farmed oysters. Such a feature could be regarded as an ecosystem function of *Zostera marina* meadows beneficial to the overall fisheries production of Thau Lagoon.

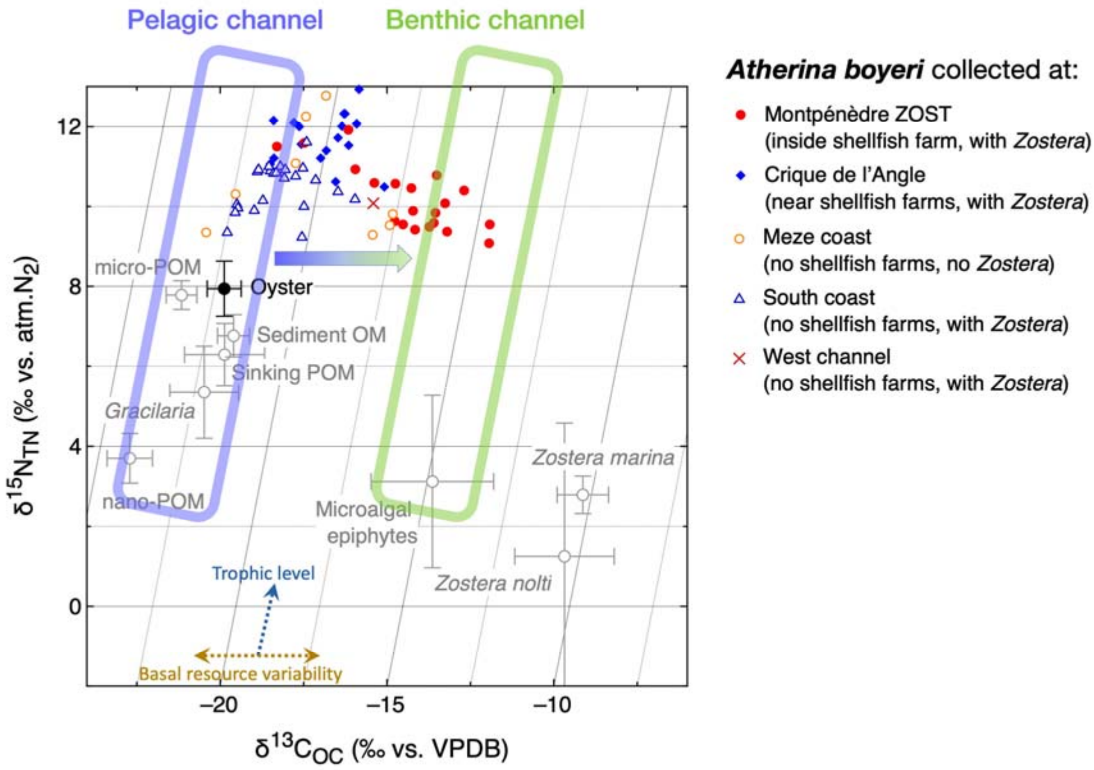


Figure 10 - Stable carbon-nitrogen isotope ratio diagram for representative ecosystem components of Thau Lagoon, including the indigenous fish *Atherina boyeri*. Different color symbols represent *A. boyeri* individuals collected from five different sites. Individuals collected from inside or near shellfish farms (Montpénèdre ZOST and Crique de l'Angle) tended to show higher $\delta^{13}C$ (i.e. higher dependence on the benthic trophic channel) than those collected at sites far from shellfish farms.

3. Description and comparison of the dynamics of socio-ecosystems of shellfish-exploited coastal areas under oligotrophication.

We described and compared the dynamics (1970-2016) of both socio-ecosystems under oligotrophication, following an interdisciplinary framework approach, as outlined by Hori et al. (2018). The aims were to highlight the links between ecosystem regime shifts and modification of management compromises and to identify human well-being of societies living around Thau lagoon and Hiroshima bay.

A common analysis of governance and institutions was started by the French-Japanese team during the SAKURA-project and highlighted some similarities of management actions and social perception of ecosystems degradations during the study period (Hori et al. 2017). Our initial results highlighted the importance of regional and local management measures carried out in response to eutrophication issues on both ecosystems. The local management actions performed since the 1990s were mainly focused on programs of regeneration of seagrass in the Hiroshima Aki Bays, while in the Thau Lagoon they mainly concerned efforts towards the improvement of the watershed's depuration system (Derolez et al. 2019). This analysis will be finalized and extended to include a study of the evolution of ecosystem services provided by both ecosystems and the evolution of the forms of social demands, which can target consumption and/or conservation.

A study had been carried out on Marine Protected Areas (MPAs) located at the east of the Seto Inland Sea (Hinase Bay) in Japan to evaluate the benefits people enjoyed from their coastal ecosystem, based on satisfaction levels of human well-being defined by the Millennium Ecosystem Assessment (Tsurita et al. 2017). This study showed that restoration activities favoring the regrowth of seagrass lead to an expansion of social networks. It also highlighted that mixed management systems could lead to flexible and long-term efforts for improving food security, livelihoods, and the marine environment. Such methods could be applied in Thau Lagoon/France and Hiroshima Aki bays/Japan to identify and compare the human well-being of societies living around both sites.

4. Conclusion and Perspectives

As part of the SAKURA project, the French-Japanese collaboration allowed: 1) comparisons of long-term time-series, 2) expertise exchanges about modelling tools for the management of shellfish-exploited ecosystems under oligotrophication and global change, 3) to carry out field experiments on oyster/*Zostera* spp. interactions in Thau Lagoon and Hiroshima Bay, 4) transfers of expertise from Japan to France about social-ecological systems (SES) mapping that will be purchased from 2019. The SAKURA project improved international knowledge and expertise on the influence of oligotrophication processes on the ecological status of shellfish-exploited-ecosystems and on oyster life cycles (reproduction, recruitment, growth, production). Moreover, this project allowed the start of a research collaboration focused on the impact of submarine groundwater's discharges (SGD) on the functioning of Shellfish-Exploited-Ecosystems. Now, the French and Japanese partners want to deepen the interdisciplinary approach and the knowledge of this major sea and coastal challenge by expanding their partnership in the framework of Sustainable Development Goals. This openness to the international community will make it possible to address more holistically the conservation of biodiversity and the sustainable use of resources in the changing coastal seas.

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References

Bec B, Derolez V, Soudant D, Cesmat L, Pete R, Richard M (2018) Projet CAPATHAU : Capacité Trophique de la lagune de Thau. Livrable I. Evolution temporelle de l'état écologique de la lagune de Thau et des performances des coquillages en élevage au regard de la réduction des apports issus du bassin versant. 157p.

Collos Y, Bec B, Jauzein C, Abadie E, Laugier T, Lautier J, Pastoureaud A, Souchu P, Vaquer A (2009) Oligotrophication and emergence of picocyanobacteria and a toxic dinoflagellate in Thau lagoon, southern France. J Sea Res 61:68–75

Derolez V, Bec B, Munaron D, Fiandrino A, Pete R, Simier M, Souchu P, Laugier T, Aliaume C, Malet N (2019) Recovery trajectories following the reduction of urban nutrient inputs along the eutrophication gradient in French Mediterranean lagoons. Ocean Coast Manag 171:1–10

Derolez V, Soudant D, Richard M, Lagarde F, Chiantella C, Malet N (2017) Restoration trends of the Thau lagoon's water ecological status and phytoplankton communities in response to changes in anthropogenic nutrient inputs. Poster. In: COAST Bordeaux 2017 "Evolution systémique et de la biodiversité des environnements côtiers et littoraux sous la pression du changement climatique, des facteurs naturels et anthropiques locaux". 7 au 10 November 2017, Bordeaux.

Hori M, Hamaoka H, Hirota M, Lagarde F, Vaz S, Hori J, Makino M (2017) Application of the coastal ecosystem complex concept toward integrated management for sustainable coastal fisheries under oligotrophication. Fish Sci 84:283

Kishi MJ, Oshima Y (2008) The Role of Benthos and Epiphyte on the Material Cycle in Akkeshi Lake, Japan. In: Mohanty P.K. (ed) Monitoring and Modelling Lakes and Coastal Environments.

Springer Netherlands, Dordrecht, p 151–158
Lagarde F, Richard M, Bec B, Roques C, Mortreux S, Bernard I, Chiantella C, Messiaen G, Nadalini J-B, Hori M, Hamaguchi M, Pouvreau S, Roque d'Orbcastel E, Tremblay R (2018) Trophic environments influence size at metamorphosis and recruitment performance of the Pacific oyster. Mar Ecol Prog Ser 602:135–153
Lagarde F, Roque E, Ubertini M, Mortreux S, Bernard I, Fiandrino A, Chiantella C, Bec B, Roques C, Bonnet D, Miron G, Richard M, Pouvreau S, Lett C (2017) Recruitment of the Pacific oyster Crassostrea gigas in a shellfish-exploited Mediterranean lagoon : discovery , driving factors and a favorable environmental window. Mar Ecol Prog Ser 578:1–17
Lamb JB, Water JAJM Van De, Bourne DG, Altier C, Hein MY, Fiorenza EA, Abu N, Jompa J, Harvell CD (2017) Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science (80-) 355:731–733
Morimoto N, Umezawa Y, San Diego-McGlone ML, Watanabe A, Siringan FP, Tanaka Y, Regino GL, Miyajima T (2017) Spatial dietary shift in bivalves from embayment with river discharge and mariculture activities to outer seagrass beds in northwestern Philippines. Mar Biol 164:1–16
Pete R, Guyondet T, Cesmat L, Fiandrino A, Bec B, Richard M (2018) Projet CAPATHAU : CAPAcité trophique de la lagune de THAU. Livrable 2. Description et évaluation du modèle GAMELag-Conch : modèle d'écosystème lagunaire exploité par la conchyliculture, adapté à la lagune de Thau. 48p.
Pete R, Richard M, Guyondet T, Cesmat L, Derolez V (2018) Projet CAPATHAU : CAPAcité trophique de la lagune de THAU. Livrable 3 – Évaluation de la capacité de charge écosystémique de la lagune de Thau : Modélisation de scenarios de gestion. 39 p.
Pouvreau S, Maurer D, Auby I, Lagarde F, Gall P Le, Cochet H, Bouquet A-L, Geay A, Mille D (2016) VELYGER Database: The Oyster Larvae Monitoring French Project. http://doi.org/10.17882/41888
Tsurita I, Hori M, Makino M (2017) Fishermen and conservation: sharing the case study of Hinase Bay, Japan. In: Marine protected areas : Interactions with fishery livelihoods and food security, Westlund L.p 43–50
Yanagi T (2015) Estuaries of the World, Eutrophication and Oligotrophication in Japanese Estuaries. The present and future tasks. Springer, Kobe/ Japan