COSELMAR

COMPREHENSION OF THE MARINE AND COASTAL SOCIO-ECOSYSTEMS
FOR RISKS PREVENTION AND MANAGEMENT

A program presented by the federation of research CNRS
University Institute of the Sea and Littoral (IUML)

Scientific review
2013-2017

UNIVERSITÉ DE NANTES

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Région PAYS DE LA LOIRE


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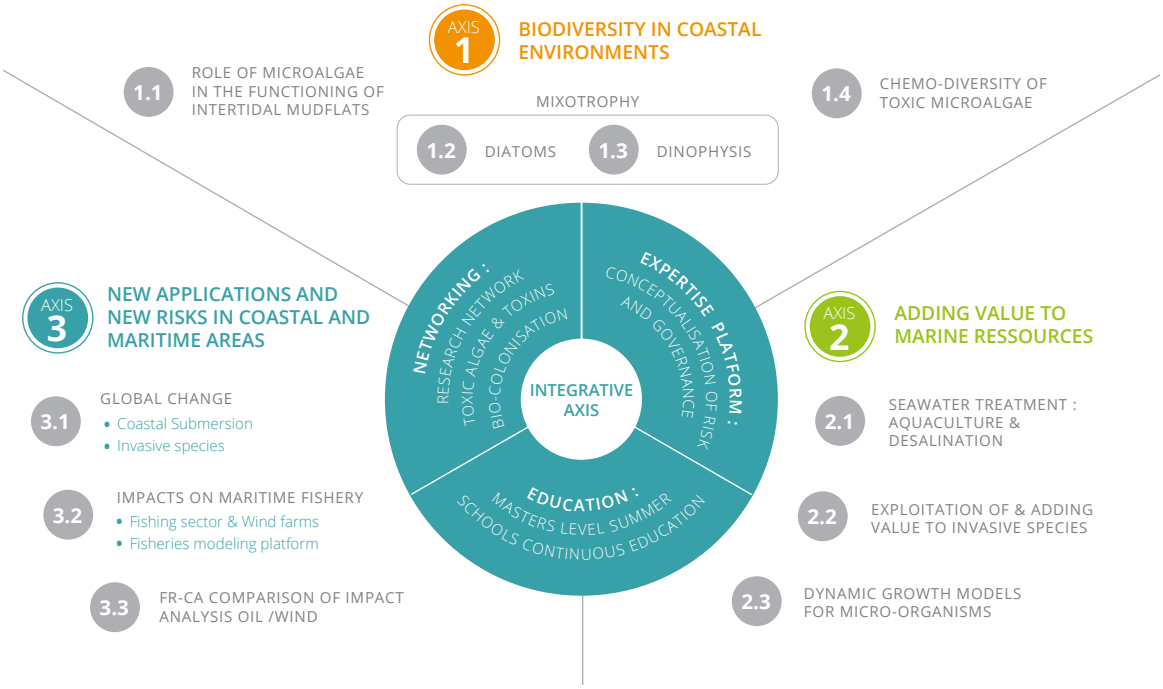
COSELMAR, a 4-year project financed by the Région des Pays de la Loire at 2.1 M€, officially started on the 7th January 2013.

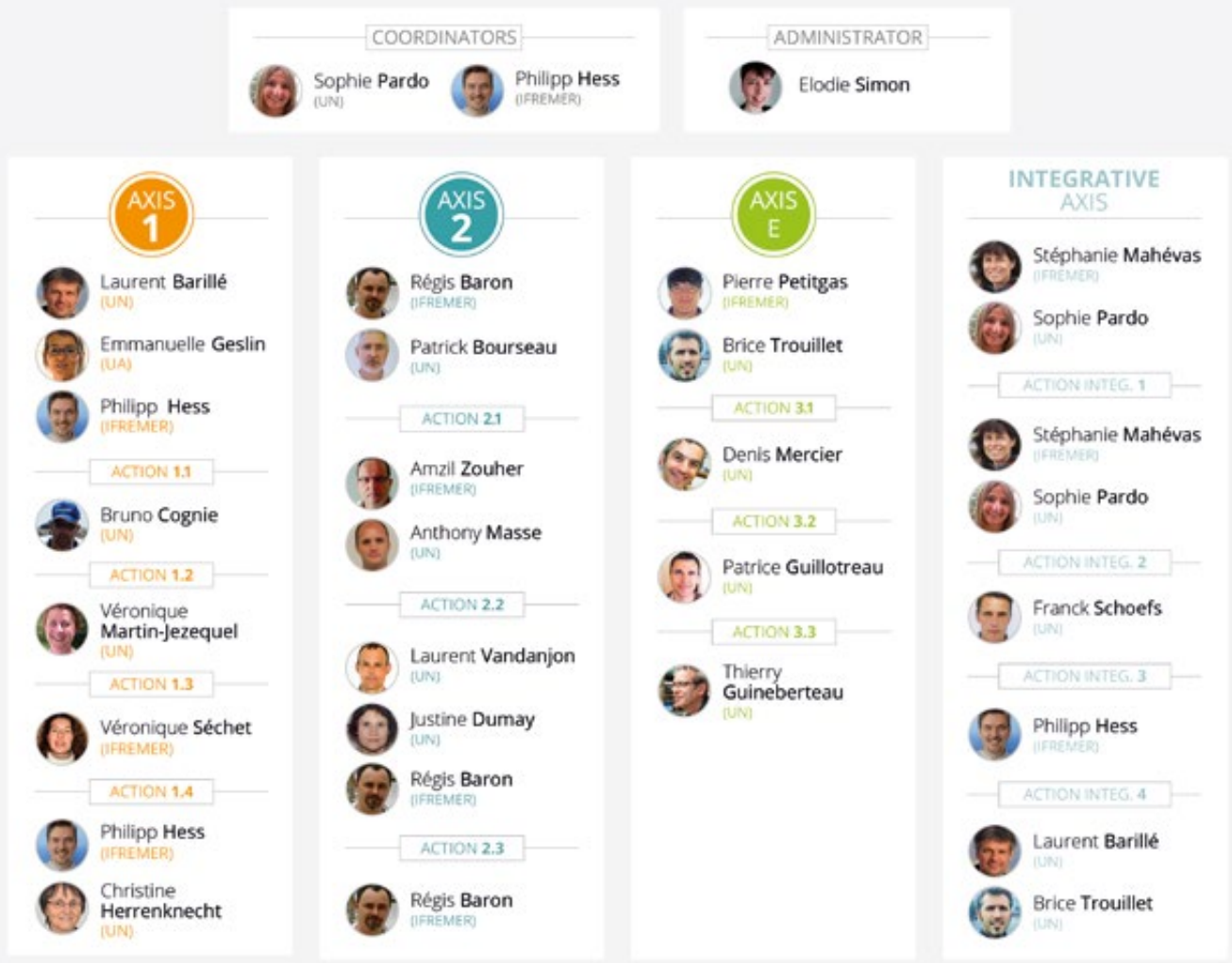
Five research units of IFREMER and 11 laboratories of the Université de Nantes collaborate with academic partners, as well as with national and international companies. The aim is to achieve a better understanding of the marine and coastal ecosystems and the associated resources.

The project also provides insights into risk management and prevention of natural events and anthropogenic impacts.

One of COSELMAR's main objectives is to integrate and promote the interdisciplinary research from environmental, engineering and social sciences in order to build expertise on potential risks of coastal and marine zones.



The COSELMAR coordination team



This report was prepared by
the coordination team and T. LEBEAU (UN),
V. TURPIN (UN) and F. MONDEGUER (Ifremer)

Datas about the project

BUDGET

2,1 Mio €

PROJECT DURATION

2012 2013 2014 2015 2016

4 YEARS

IFREMER
5 LABORATORIES

UNIVERSITÉ DE NANTES
11 LABORATORIES

UNIVERSTÉ D'ANGERS
1 LABORATORY

ASSOCIATED PARTNERS
12 LABORATORIES

6 PhDs

3 TECHNICIANS OR ENGINEERS
employed in the project

10 POSTDOCTORAL RESEARCHERS

x1
INTERNATIONAL CONFERENCE
in June 2016
OCEANEXT

x7
INTERDISCIPLINARY WORKSHOPS

x2
INTERNATIONAL SUMMER SCHOOLS
organised in 2015

AXIS 1

Biodiversity and the marine littoral environment

Microalgae are the basis of the pelagic and benthic food webs. They play a major role in coastal systems that have complex functioning and multiple interactions between organisms and physico-chemical factors. They are used by filtering organisms such as bivalves and represent a very significant part of their diet.

However, anthropogenic pressures affect these coastal ecosystems through changes in the biomass and structures of algal communities, e.g. toxic microalgal blooms, which can accumulate in species consumed by man and present a risk to public health.

In the benthic compartment, microalgal communities are grouped under the term microphytobenthos. These benthic microalgae have been the subject of descriptive approaches, but their functional role and their interactions with many links in the ecosystem remain to be elucidated.

For microalgae in the water column or mud flats and microphytobenthic species, we wanted to emphasize the functional dimension of these organisms: their trophic role, toxin production, biotic interactions (allelopathy, links with invasive species such as wild oysters), and abiotic interactions (links with nutrient flows).

Axis 1 was organized in 4 complementary actions.

ACTION 1.1
The role of microalgae in intertidal mud flats: interactions with benthic biodiversity

This action was based on numerous field campaigns, and its originality was due to the analysis of spatial interactions between organisms in an intertidal mudflat using satellite remote sensing. The working hypothesis of this action was that wild oyster reefs would structure benthic microalgal populations and the associated trophic network by top-down control. This analysis was supplemented by that of microalgae/primary consumer interactions. The status of the wild oyster as an invasive species was also taken into account at the legal level.

SYNTHESIS OF ACTION 1.1

The ecosystems exploited by man are extremely complex. It is necessary to understand the effects of anthropogenic stresses on the stability of these ecosystems and the services they provide, for example through aquaculture and fisheries. The effects (positive or negative) of invasive species on marine communities are often reported, but engineer species (e.g. *Crassostrea gigas*) have particularly important impacts on their host ecosystems. For example, oyster farms and reefs are associated with biofilm development by microalgae (microphytobenthos, MPB), which can reach a very high biomass. These are the dominant primary producers in the intertidal mudflats, although their exact link with oysters is not clearly understood. As part of Action 1.1 of the COSELMAR program, we carried out a BACI (Before After Control Impact) study with the elimination of a wild oyster reef. A high spatial resolution sampling, corresponding to an area of more than 750 m^2, was carried out in the immediate vicinity of a wild oyster reef in the Bay of Bourgneuf (France). We sampled

the spatial distribution of benthic microalgae and macrofauna such as bivalves, gastropods and annelids, as well as environmental parameters related to sediment. We then used geostatistical mapping and spatial correlation tests to determine whether the distribution patterns were true or not. Our hypothesis was that the presence of oysters enabled the development of a high biomass of microalgae.

Initially, samples in the vicinity of oyster reefs revealed high MPB biomass (➔ *Fig. 1A*) and high levels of sediment organic matter. This suggests that oysters have a direct influence on mudflat communities, by enriching the environment through their production of feces and pseudofeces. This mechanism may represent a means by which oysters stimulate their own food and thereby their own biomass, a phenomenon that clearly appears favorable to oyster farming. However, other processes also seem to be involved. For example, oysters can disrupt the local hydrology, leading to increased sediment, nutrient and microalgae deposits.

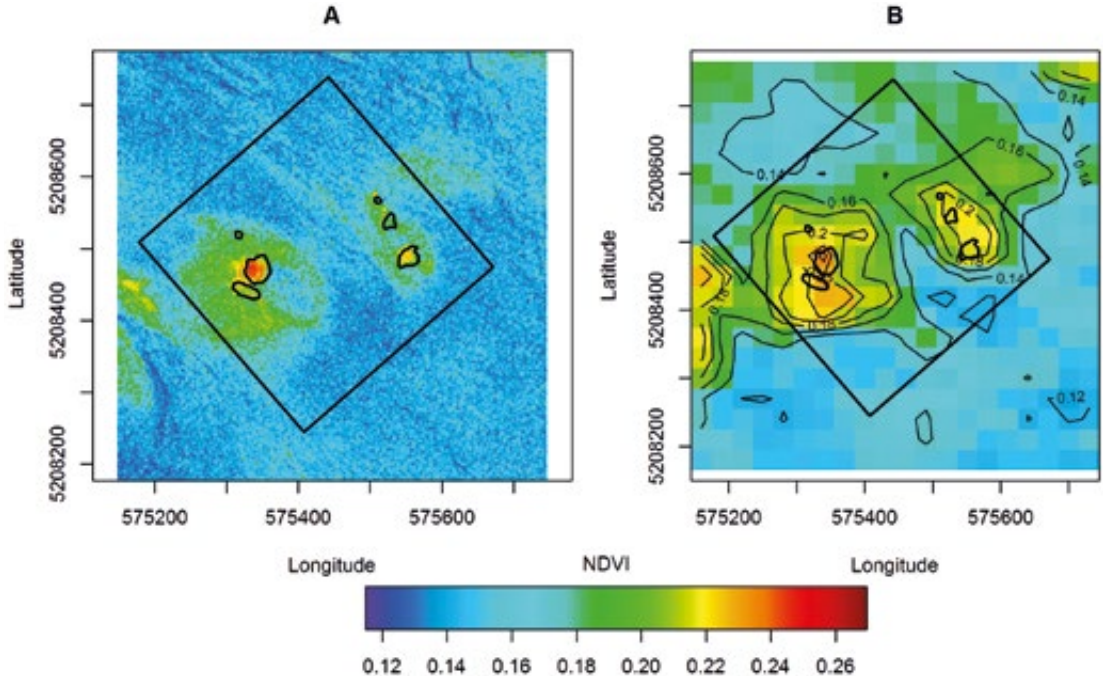


Figure 1. Microalgal biomasses estimated by a vegetation index (NDVI) from satellite images during the study: (A) summer 2013, before the oyster reef destruction, and (B) summer 2014, after the destruction. The heat maps show the high values in warm colors. The black square delimits the sampling grid on the ground. In this square, the areas in black correspond to the oyster reefs. The projection is in WGS84 UTM30.

Oyster reefs also affect the biodiversity and animal biomasses of the mudflat (➔ *Fig. 2A*) within a radius of a few tens of meters. There is a lack of large individuals of each species and a negative relationship between the abundances of microalgae-consuming species and those of the microalgae themselves, whereas we expected the opposite result. This suggests that oysters exercise local control over animal assemblages. We hypothesize that this is an indirect control by providing shelter for predators (such as crabs) from benthic macrofauna in mudflats.

The oysters would thus convert a system controlled by the availability of microalgae (bottom-up) into one controlled by top-down predators. This modification of the trophic chain, with the passage from predation by fish and birds to predation by crabs, could pose a threat to local fisheries and bird conservation efforts.

Since the balance between these two mechanisms of oyster impact on mudflat communities is important for stakeholders, we manipulated the sampling area in order to collect evidence of the existence of one or more other processes. An oyster reef (on the right of each figure) was incinerated with straw, nine months

after initial sampling. Three months later, the same sampling design was used to compare all variables. An overall increase in the NDVI Vegetation Index (microalgal biomass estimator) suggests an overall increase in microalgal biomass. More importantly, the original (2013) distribution pattern of microalgal biomasses decreasing with their distance from reefs (➔ *Fig. 2A*) is only maintained for the untreated reef. This suggests that the elimination of oysters is the cause. The relationship between benthic macrofauna and microalgae disappears completely, for both reefs, whereas it was very strong before incineration. For example, the biomass of a small bivalve, *Macoma balthica*, decreased from 70.3 to 0.7 g m^{-2} and that of a larger species, *Scrobicularia plana*, from 92.2 to 1.6 g m^{-2} (in both cases, the difference is highly significant). These changes indicate that the macrofauna biomass has had an overall effect, probably related to the reef treatment.

We concluded that the Pacific oyster had multiple direct and indirect effects on mudflat communities, with both benefits and threats to anthropized systems. Our work helps to highlight the real impact for man of the invasion of intertidal mudflats by the Pacific oyster. By quantifying the broad influence that this species can have on the environment and clarifying the processes, our work helps to inform the bodies involved in the local, national and international management of this invasive species. This is particularly important in the context of global change, which is accelerating its invasion.

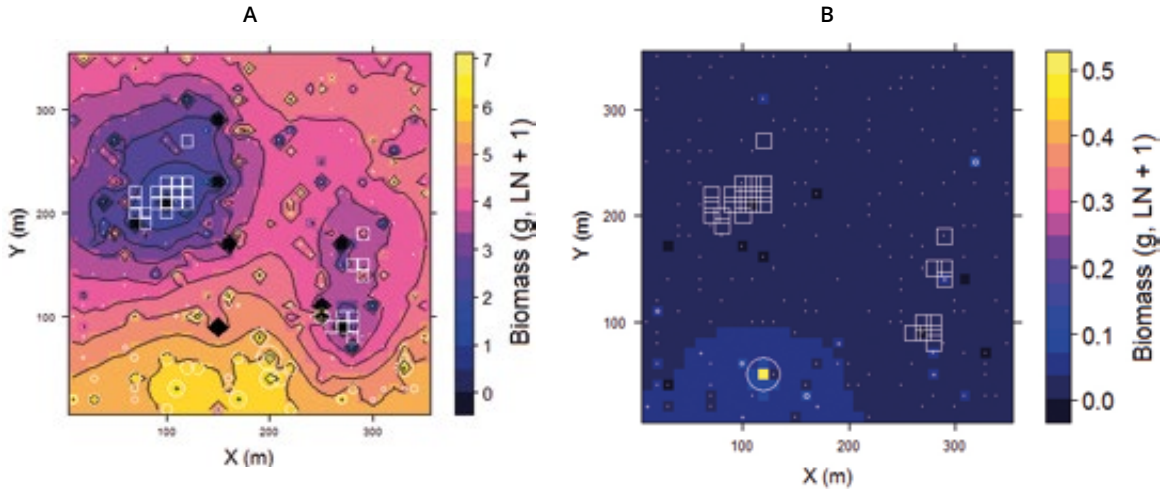


Figure 2. Geostatistical maps of the biomass of bivalve *Macoma balthica* around oyster reefs (white squares indicate the location of the reefs): (A) before (2013) and (B) after (2014) elimination of the reef. Heat maps show the high values in warm colors, with a log-transformed scale bar.

ACTION 1.2
Primary production in pelagic and benthic compartments of coastal systems: diatom autotrophy and heterotrophy

This action was based on laboratory measurements of heterotrophic benthic microalgae. It complements the previous one in that it is interested in the processes likely to explain the spatial structures of organisms inhabiting a mudflat, describing the nature of their biotic interactions. Its originality is particularly linked to taking into account the feedback between primary producers of microphytobenthos and primary consumers, such as suspension-feeders and shorebirds. Experiments were carried out on the products of the particulate and dissolved excretion of oysters and shorebirds to determine whether benthic microalgae had the capacity to use directly the dissolved organic elements released by these organisms.

SYNTHESIS OF ACTION 1.2

Anthropization of coastal systems leads to diverse and large fluxes of nutrients sustaining primary productivity. This production is mainly controlled by predators at the secondary level, but also by interference with other microorganisms (bacteria). We show the complexity of microalgae predation by the main

consumers (birds, oysters, foraminifera) (Jauffrais et al. 2015, 2016 a & b) and the regulation of microalgal growth by satellite bacteria (Jauffrais et al. 2017). The fluxes and relationships are complex, but determine the success and maintenance of microalgae in the system (➔ *Fig. 3*).

Nitrogen is one of the main nutrients that sustains microalgae growth. Nitrate and ammonia are generally considered the major nitrogen sources, but many other nitrogen components that are found in the coastal ecosystem can be assimilated by microalgae. We demonstrated the diversity and the role of

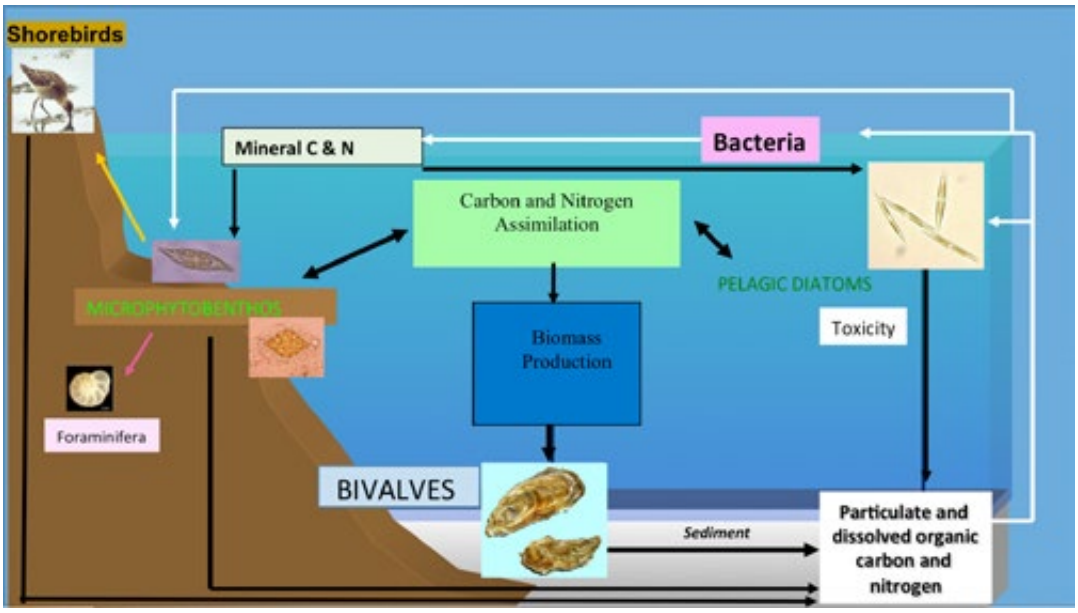


Figure 3. Schematic view of carbon and nitrogen fluxes between the primary and secondary producers in a marine coastal ecosystem

several mineral and organic nitrogen sources to sustain microphytobenthos growth (Jauffrais et al., 2015, 2016a; Rodriguez, 2015) (➔ *Fig. 4*). In addition to mineral forms (nitrate and ammonia), organic components such as urea and amino acids (glycine, glutamine, serine, and arginine) enabled the production of a large biomass (➔ *Fig. 4A*). Some of them (such as urea) induced a higher growth rate than that obtained with nitrate (➔ *Fig. 4B*). We also demonstrated the retroaction of the microalgae predators

Figure 4. Percentage of biomass (A) and growth rate (B) of the diatom *Entomoneis paludosa* grown with several mineral or organic nitrogen sources. Biomass and growth rate obtained with nitrate as nitrogen source are considered as the 100% standard.

(birds, oysters) on the microphytobenthic compartment by growth stimulation. Microalgae used bird feces as the nitrogen source to produce biomass. In the same way, oyster feces and pseudofeces, as well as the dissolved component such as taurine, could be important nitrogen sources for microalgae growth. Even they induced a higher biomass (taurine ➔ *Fig. 4A*) or growth rate (bird feces ➔ *Fig. 4B*) than nitrate as the nitrogen nutrient. The relationships between the primary and secondary levels are thus more complex in the coastal system than only the bottom-up regulation of the microalgae biomass by predation. There is also a potential top-down regulation, which concerns the use by microalgae of nitrogenous nutrients from secondary producers to sustain their growth.

ACTION 1.3
Toxicity of *Dinophysis acuminata* and mixotrophy

This action concerned the dinoflagellate *Dinophysis acuminata* responsible for diarrheic poisoning of mussel consumers, and which produces regular blooms on the coast of Pays de la Loire. This species is characterized by a very special physiology since it acquires its capacity for photosynthesis by sequestering the plastids that its prey, the ciliate *Mesodinium rubrum*, obtains by capturing small microalgae, i.e. cryptophytes, of the *Teleaulax* genus. The originality of this action was to cultivate these organisms in order to feed *Dinophysis* with its main prey and study the effect of this mixotrophy and the variation of irradiance on the physiology and production of toxins.

SYNTHESIS OF ACTION 1.3

Determination of the toxin profiles of *D. acuminata* and *D. sacculus* in culture. The toxin profiles are very different between the two species since our clone of *D. acuminata* produces only okadaic acid (28.8 pg per cell) whereas this compound was found in only a very small quantity in *D. sacculus*, which mainly synthesizes pectenotoxin-2 (➔ *Fig. 5*). This profile, consisting mainly of pectenotoxins, was found in the new 2016 isolates of *Dinophysis sacculus* from the Arcachon basin and in *D. sacculus* from the Thau lagoon.

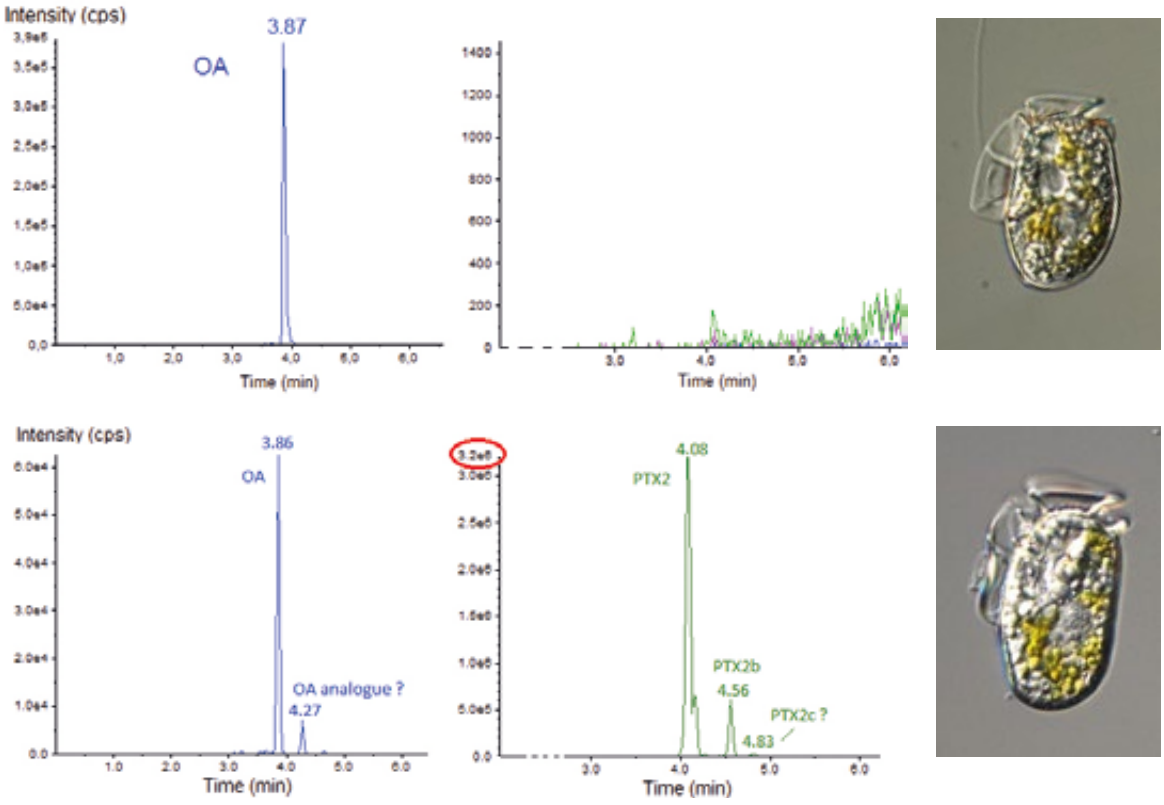


Figure 5. LC-MS/MS Chromatograms of cellular fractions of *Dinophysis acuminata* (above) and *D. sacculus* (below).

Growth and photo-acclimation of the cryptophyte *Hemiselmis* sp. Growth conditions control the physiology of different organisms. We grew the cryptophyte Hemiselmis sp. of the Bay of Vilaine at various nitrogen limitations in a chemostat and at 3 luminous intensities in semi-continuous culture. We studied several aspects of the physiology of this cryptophyte (growth rate, size, pigment composition, carbon and organic nitrogen, photosystem 2 activity = PSII). The physiological responses to the availability of nitrogen and light are very different. The PSII activity increases with light intensity whereas it is not affected by the availability of nitrogen, which shows that it is not a good indicator of nitrogen limitation, photosynthetic activity or even of growth. The nitrogen limitation causes a massive decrease in the phycoerythrin content (PC) while this is not affected by light.

Influence of nutrition on the growth and physiology of *Dinophysis sacculus*. We also studied the influence of nutrition on the growth and physiology of *D. sacculus*. We showed that *D. sacculus* is unable to grow in the absence of prey (➔ *Fig. 6*) while still retaining functional plastids. We also showed that *Dinophysis* could survive for very long periods without prey, and grow again when prey became available. These results provide a better understanding of the spatial and temporal distribution of *Dinophysis* in the natural environment.

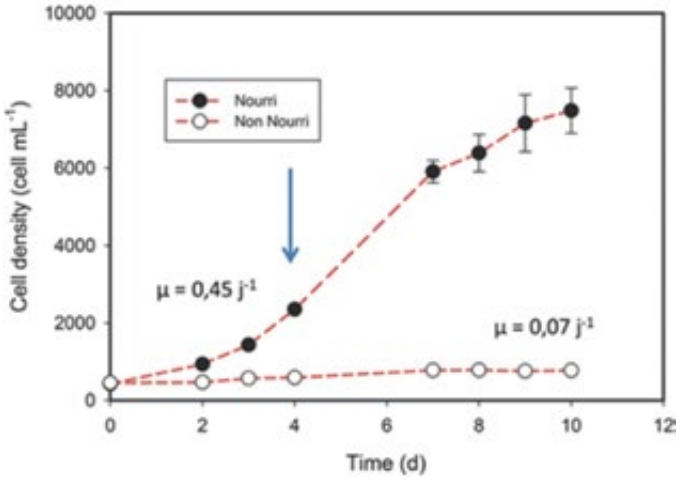


Figure 6. Growth of *Dinophysis sacculus* in the presence of prey.

Influence of light on the growth and physiology of *Dinophysis sacculus*. To date, two levels of irradiance have been tested, 80 (LL) and 200 (HL) µmole m^{-2} s^{-1}, on the three organisms of the trophic chain of *Dinophysis* sp. After a two-week acclimation period, the *Dinophysis* cultures were inoculated at a concentration of 500 cells mL^{-1} and fed daily for five days with a ratio of one *Mesodinium* cell to one *Dinophysis* cell. (These conditions are identical to those of the previous feeding experiment). In order to study several aspects of the physiology of *D. sacculus* (growth rate, size, pigment composition, carbon and organic nitrogen, photosystem 2 activity = PSII), samples were taken for the analysis of liposoluble pigments (chlorophyll a and c2, alloxanthin, monadoxanthin, crocoxanthin and alpha-carotene), phycobiliproteins, toxins (okadaic acid and pectenotoxins), and cellular metabolites. The PSII activity of the three organisms of the trophic chain of *Dinophysis* was also followed at low and high light in order to improve the understanding of this complex mechanism of kleptoplastidy and its temporality.

ACTION 1.4
Chemical diversity of algal toxins

This section focuses on the chemical diversity of algal metabolites and toxins as evidenced by non-targeted techniques, especially liquid chromatography coupled to mass spectrometry (LC-HRMS), and passive sampling and screening of databases for marine natural products. A multi-toxin method was developed to compare the impact of different sample matrices (biological and passive sampling) on non-targeted analysis. A database was constructed

specifically for algal toxins to facilitate rapid screening of various matrices (passive samplers, bivalve mollusks, fish and other seafood). This approach enabled a more comprehensive appreciation of the risks algal metabolites pose to seafood safety.

SYNTHESIS OF ACTION 1.4

Construction of a database for algal toxins. A systematic literature review on the evolution of toxic microalgae at a global scale was conducted and published as a book in both English and French (Lassus et al., 2016). From this knowledge base, toxins produced by these organisms were catalogued and entered in a database. This database contains information on each compound including its exact mass, structure, and where possible mass spectral data. The database now contains more than 500 toxins and associated data, which enables the screening of samples for these 500 compounds. The database was also entered into instrument software (Agilent), which further accelerates the speed of screening for the potentially toxic contents of samples.

Development of a non-targeted method of analysis based on high resolution mass spectrometry. The method developed in this project is based on liquid chromatography coupled to high resolution mass spectrometry using a quadrupole – time-of-flight hybrid technology (LC-Q-ToF-HRMS). This technology is well-known for its specificity and ability to run non-targeted analyses, i.e. without assuming the presence of specific contaminants. The method was internally validated for known toxins (Zendong et al., 2014 and 2015); available standards are well separated and detected (➔ *Fig. 7*).

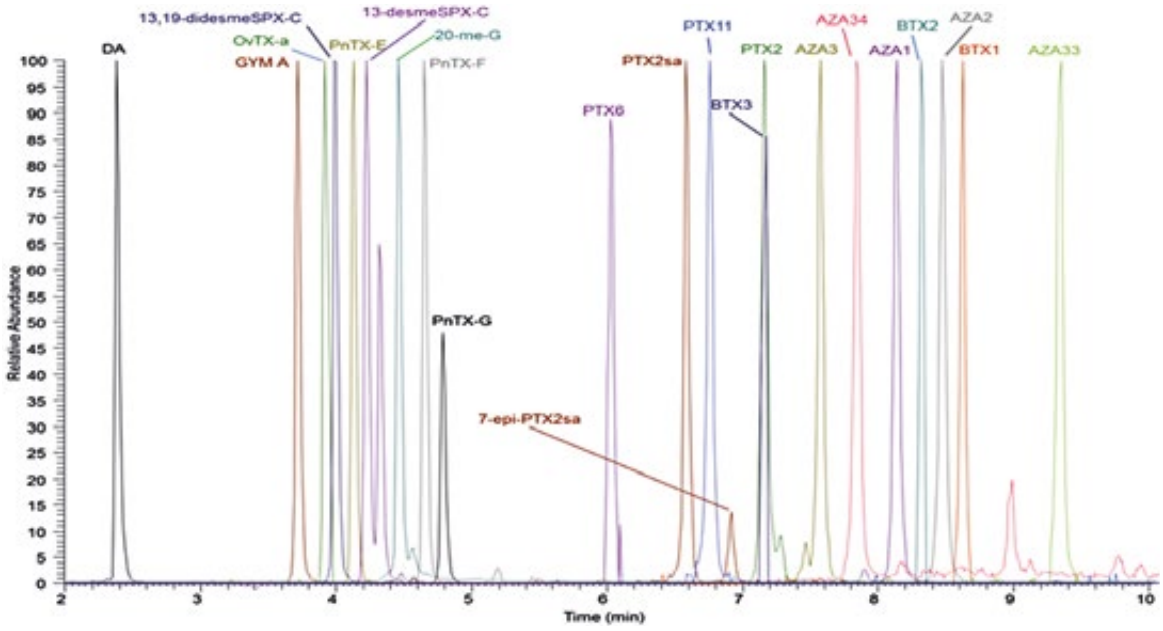


Figure 7. Chromatographic separation of known lipophilic toxins by the non-targeted method developed in this project (based on liquid chromatography coupled to high resolution mass spectrometry, UHPLC-HRMS)

Comparison of different mass spectrometers and matrix effects in biological matrices and passive samples. Different mass spectrometers, including the latest generation high resolution instruments, demonstrated sufficient sensitivity to detect the majority of lipophilic toxins, especially those currently regulated in Europe (Zendong et al., 2015). The method was applied to different types of sample and was particularly optimized for passively sampled seawater. The passive sampling approach enables a two-fold reduction in the complexity of the matrix: (i) passive samples contain fewer compounds than natural biological samples, such as mussels or oysters, and (ii) algal metabolites are not biotransformed by passive samples whereas they are transformed by e.g. traditionally analyzed mollusks. This last point also enables toxins found in extracts of passive samples to be linked more easily with the causative microalgae.

Thus, the project was able to evidence the occurrence of toxins with a rapid action (pinnatoxins) to its causative organism, *Vulcanodinium rugosum*, in the Ingril Lagoon in the Mediterranean (Zendong et al., 2014). The simplification of the matrix also results in fewer matrix effects compared to the classic analysis of shellfish, which again increases the quantitative reliability of the approach. A very recent study on the molar response factors of analogues of lipophilic toxins shows the applicability of the method to compounds for which no calibrants are available and reinforces the approach in principle (Zendong et al., 2017).

Applications of the developed approach to French and Nigerian coastal environments. The combined approach of passive sampling and high resolution mass spectrometry (HRMS) has been applied to different coastal waters, including France (➔ ***Fig. 8***) and Nigeria.

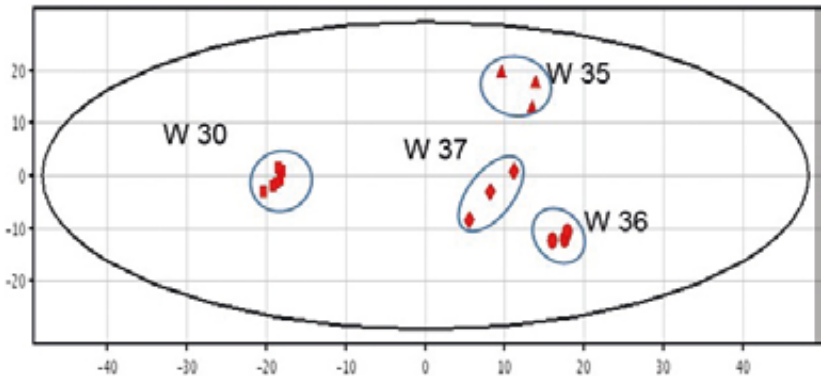


Figure 8. Analysis of the principal components from non-targeted mass spectral data derived from extracts of passive samples originating from Scoré (near Concarneau, Brittany). The compounds identified in replicate samples each week (summer 2013) clearly differentiate separate weeks in this location (mostly due to a bloom of *Dinophysis* during week 35).

Studies in France and Nigeria are also coherent in that they enable chemical differentiation of each site from neighboring sites as well as each week from the previous week. This finding also suggests rapid environmental changes occurring in coastal waters (Zendong et al., 2016a and b). In Nigeria, wet and dry seasons were easily distinguished by non-targeted chemical profiles as well as the coastal waters influenced by the freshwater input of the river Niger compared to more saline areas where a diarrheic toxin (okadaic acid) was found for the first time in our studies (Zendong et al., 2016a). Due to simultaneous sampling of the water column for microalgae, the results from the passive samples could be linked to the presence of *Dinophysis caudata*.

Next page: **figure 9.** practical-field work in the mudflat during the summer school, september 2015, to illustrate different sampling techniques

AXIS 2

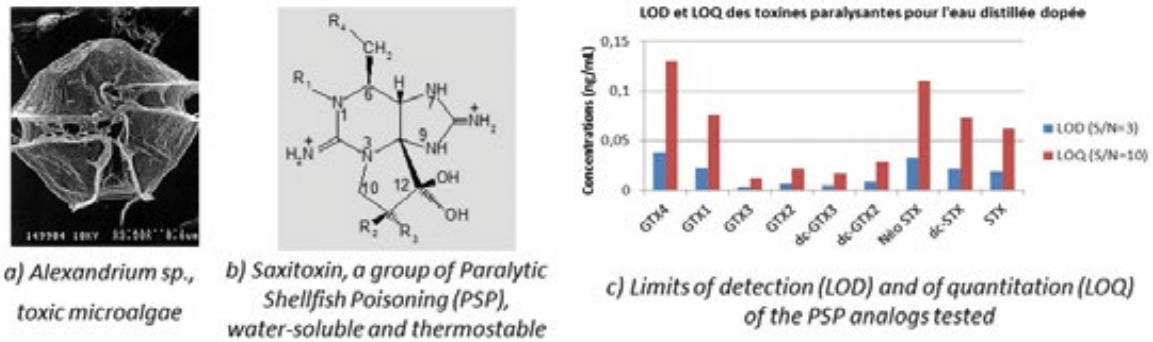
Exploitation of and adding value to marine resources

The context of Axis 2 is the sustainable exploitation of marine resources, the research effort within COSELMAR being focused on the prevention of risks for health or the environment (Actions 2.1 and 2.2) or the development of tools to analyze these risks (Actions 2.3).

ACTION 2.1
Production of safe seawater in the presence of harmful algal blooms

During harmful algal blooms (HAB), seawater may be particularly loaded with particulate, colloidal and polymeric matter (microalgal cells, excreted polysaccharides). It may also contain toxins for some strains such as *Alexandrium* sp. (➔ ***Fig. 10A***) which produces and releases saxitoxin-like toxins, also known as PSP (Paralytic Shellfish Poisons, ➔ ***Fig. 10B***), which have led to many bans on the marketing of shellfish. The aim is therefore to prevent a health risk in the production of freshwater or aquaculture pond water from contaminated water. The performance of membranes was studied, in terms of the retention of toxic microalgae or their toxins and membrane fouling. Membrane fouling could result in a lower income and could also lead to a high economic risk for the sectors concerned, and even disorganization in the case of shellfish farming.

The work was carried out in collaboration between the laboratories PHYC, Ifremer, (analysis and implementation of toxins) and GEPEA, University of Nantes, (granular filtration and membrane filtrations), firstly on the development of a method to quantify PSPs dissolved in sea water in order to measure the concentrations of toxins throughout the seawater desalination chain. This was a critical point of action, poorly documented in the literature, the analysis being technically difficult because of the hydrophilic nature of the PSPs and their strong dilution in sea water. The method developed is based on concentrating the toxins by lyophilization followed by an analysis (identification and quantification) by fluorescence chromatography. Ten PSP analogues



a) Alexandrium sp., toxic microalgae

b) Saxitoxin, a group of Paralytic Shellfish Poisoning (PSP), water-soluble and thermostable

c) Limits of detection (LOD) and of quantitation (LOQ) of the PSP analogs tested

Figure 10. A) A species of toxic microalgae, **B)** one of their toxins, **C)** detection and quantification limits of paralytic toxins.

were tested. Detection and quantification limits (LD and LQ) varied according to the toxins and were always very low (0.01 and 0.3 µg/L for the most toxic analogue, STX ➔ *Fig. 10c*). A method of concentration by adsorption was also tested. Although it does not provide a quantitative determination of toxins, tests carried out on about 15 adsorbent materials showed the value of the method not for analytical purposes but for the recovery of toxins in seawater during HAB. These toxins may be of interest for pharmaceutical (vaccine) or medical (neurology) applications.

A drop in performance of the various steps of the desalination chain (➔ *Fig. 11*) was then evaluated on synthetic seawater during HAB. Under the conditions tested, the two pretreatments for removing the particulate, colloidal and polymeric fractions by granular filtration and ultrafiltration continue to perform their protective role, but with difficulty. Thus, the clogging of the UF membranes increases, resulting in a decrease in the flow rate of processed water, and the quality of the water leaving the UF fluctuates around the limit value recommended by manufacturers for feeding the modules of reverse osmosis (i.e. a silt density index, SDI, of 3). In periods of intense bloom, the protocols for cleaning UF membranes by backwashing will therefore probably need to be intensified. Furthermore, the retention capacity of reverse osmosis membranes (Dow Fimtec SW 30 membrane spiral wound module 2540) artificially aged by exposure to highly chlorine-laden water was tested by filtering seawater highly enriched with PSPs (0.06 to 0.20 µ mol/L). Toxin contents in the permeate downstream of the RO membrane remain below detection limits. Thus, under the conditions tested at least, it appears that RO membranes can effectively retain STX toxins even after long periods of operation.

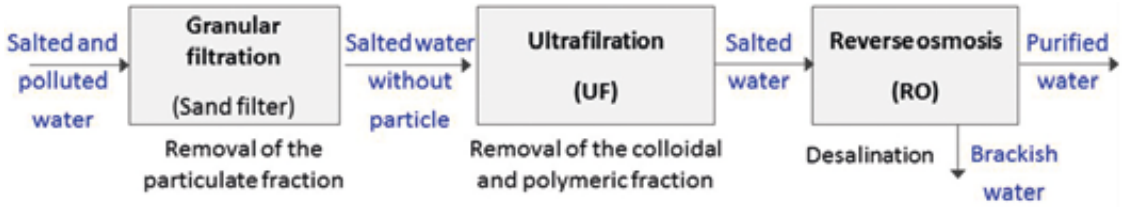


Figure 11. A typical seawater desalination unit.

The last part of the work deals with the feasibility of concentration and pre-purification by membrane processes of compounds present in sea water during HAB, namely toxins and exopolysaccharides, with a view to their valorization. The toxins were concentrated by a cascade of 3 operations, UF in diafiltration mode, then "loose" RO in concentration mode and then diafiltration. The toxins could be pre-purified satisfactorily but their concentration must be further optimized, particularly by increasing the number of diavolumes during the first recovery step.

Moreover, the exopolysaccharides (EPS) contained in a culture supernatant of the red microalga *Porphyridium cruentum* (0.26 g EPS/L) were concentrated by microfiltration (tubular membrane TAMI, MF 0.14 µm) and then desalted by diafiltration. The results are encouraging since an EPS concentration factor of 8 to 10 times was obtained with relatively high permeation fluxes and EPS retentions, and an acceptable EPS quality (protein level lower than 6%, and reduction of 95% of the conductivity after diafiltration).

ACTION 2.2
Valorization of invasive species, macroalgae or crustaceans

The aim here is to prevent an environmental risk by valorizing invasive species in order to limit their proliferation in the absence of preventive solutions. The species considered are two red and brown algae and one crustacean (*Grateloupia turuturu*, *Sargassum muticum* and *Polybius henslowii*, respectively ➔ *Fig. 12*). Valorization consists of producing different fractions from the treated biomass of interest to the cosmetics, food and feed, agriculture and energy sectors.

For all three species, the approach consisted of (i) putting in place the analytical tools for the biochemical characterization of the biomass in order to identify and quantify the compounds of interest and then to determine the physico-chemical properties and the nutritional, biological or techno-functional properties of the compounds or fractions produced; and

Figure 12. The invasive species treated, the seaweeds *Grateloupia turuturu* and *Sargassum muticum*, and the crustacean *Polybius henslowii*, and their main compound of interest.

(ii) to develop the process (➛ *Fig. 13*). The strategy adopted was to maximize the solubilization of the biomass and then to fractionate the compounds of interest in the aqueous phase. The use of gentle and eco-friendly processes (enzymatic hydrolysis, membrane filtration) was favored as part of a biorefining logic, in which the extraction conditions of the main valuable compound (the «target» compound) must not impede the valorization of the other biomass components. Here, the targets are *G. turuturu* R-Phycoerythrin (R-PE), a purple pigment used as a fluorescent marker for various analytical techniques, *S. muticum* phlorotannins, phenolic compounds with strong antioxidant activities, and the chitin of *P. henslowii*. The other compounds monitored are proteins and polysaccharides (sugars).

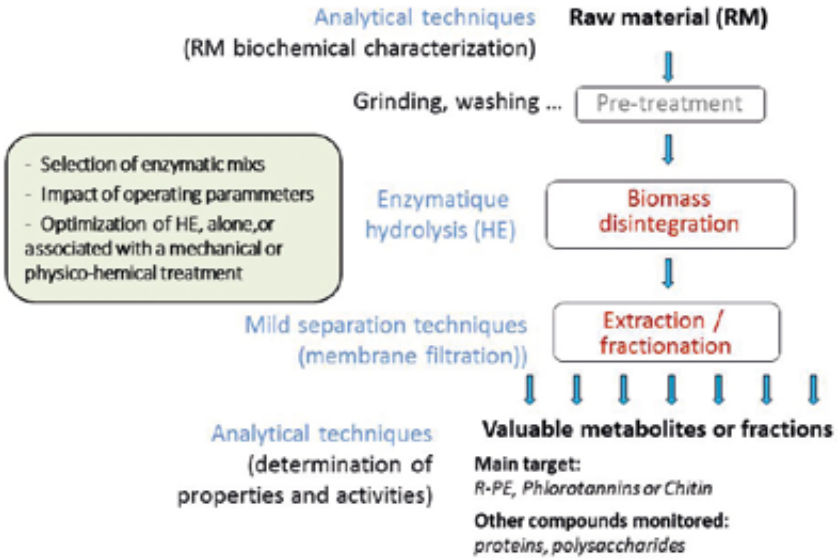


Figure 13. The approach implemented in Action 2.2.

SEAWEEDS

Work on *G. turuturu* was carried out in a collaboration between the laboratories BRM, Ifremer, and MMS, University of Nantes, as part of Cécile Le Guillard's thesis, and that on *S. muticum* at GEPEA and MMS in collaboration with the LEMAR (UBO) and LBCM (UBS). Regular exchanges took place between the 3 partners of the action on the protocols of solubilization by enzymatic hydrolysis and the comparative analysis of the hydrolysis performances of a red alga and a brown alga. The work consisted mainly of completing the pool of analytical techniques already available and developing and optimizing the biomass destructuring step by enzymatic hydrolysis. In addition to these two aspects, which will be the only ones detailed herein, tests were also carried out on the influence of pre-treatments (seaweed washing, grinding technique) on the hydrolysis yield, the fractionation of the compounds in aqueous phase by membrane filtration, the intensification of *S. muticum* hydrolysis in an extruder, and the destructuration of a green microalga, *Parachlorella kesleri*.

CHARACTERIZATION OF THE RAW MATERIAL

Building up efficient and robust biorefining schemes requires a thorough knowledge of the biochemical composition of the seaweed as well as its variations with seasons or life cycle stages. Biochemical assay methods are precise but numerous and tedious (dry and mineral materials, total polysaccharides and uronic acids, lipids, sulfated or phenolic compounds, etc.). Therefore, a faster qualitative method using infrared spectrometry (medium infrared, 400-4000 cm^{-1}) was developed to evaluate the seasonal variations in the composition of *S. muticum*. The method provides representative spectra of the overall biochemical composition of the seaweed. Multidimensional statistical processing of the data by ACP of the IR spectra makes it possible to group seaweeds by class of neighboring biochemical compositions, which correspond to the harvesting seasons. In addition, for some metabolites of interest such as sulfated compounds, a correlation between the biochemical composition of the seaweed and the physiological stage can be demonstrated (➔ ***Fig. 14***). The method can also qualitatively evaluate the performance of the extraction of two families of polysaccharides of interest from *S. muticum*, alginates and fucoidans: the comparison of the IR spectra of these compounds extracted from *S. muticum* with those of pure commercial compounds showed degrees of similarity close to 80%, indicating a very good selectivity of extraction.

Given the interest of this approach, an interesting prospect would be to develop a quantitative method for rapid quantification in the liquid phase of the main biomass compounds (proteins, carbohydrates, etc.), as already done on microalgae (Pistorius 2009, Wagner 2010, Mayers 2013).

ENZYMATIC HYDROLYSIS (EH)

The methodology was developed on *G. turuturu* and then transposed to other red algae including *Chondrus crispus* and to *S. muticum*. The first trials on *G. turuturu* made it possible to select enzymes of the glycosidase type thus maximizing the extraction of non-denatured R-Phycoerythrin (R-PE being a thermosensitive molecule) and the solubilization of the algal matrix. Coupling the enzyme treatment with a physical treatment by ultrasound (US) improved the extraction yields, probably because it limits the viscosity induced by the release of the parietal polysaccharides contained in the algae. The EH-US coupling was then optimized by experimental design, using four operating parameters (EH temperature T, power PUS of the applied ultrasound, flow rate Q between the enzymatic reactor and the ultrasonic tube, duration D). The results show that the conditions favorable to the extraction of R-PE are different from those maximizing the solubilization of the dry matter (DM): whereas the solubilization of the alga is favored by high hydrolysis temperatures, US power and processing time (T = 40°C, P_{US} = 400 W,

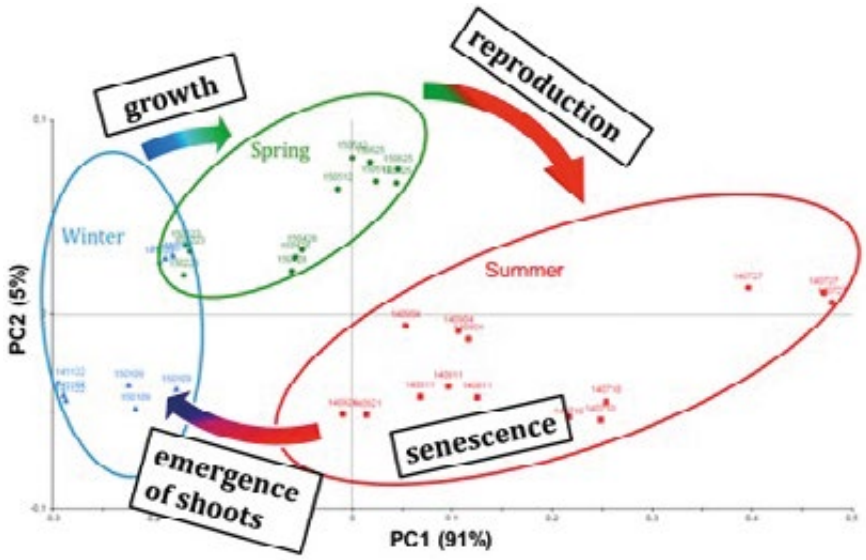


Figure 14. *Sargassum muticum*: Identification of classes of neighboring biochemical compositions corresponding to harvest seasons, and their relation to the physiological stage of the seaweed.

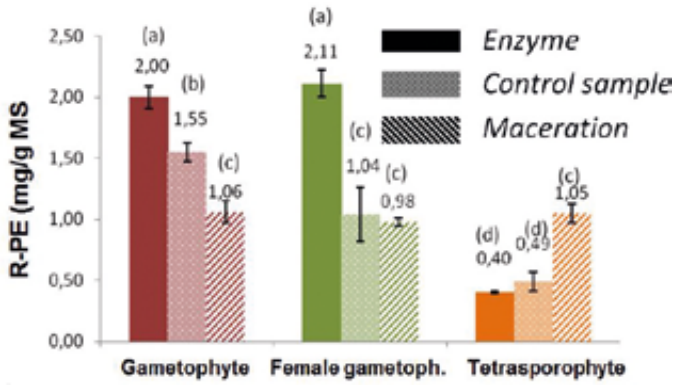
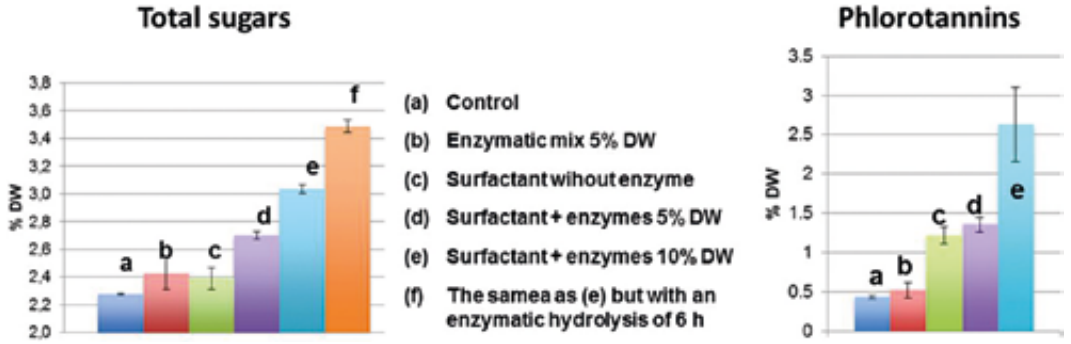


Figure 15. *Chondrus crispus*: The enzyme mix selected to solubilize the gametophytes (k-carrageenase + cellulase) is unable to solubilize the tetrasporophytes (this figure), whereas a mix (cellulase + protease) is able to solubilize it (results not shown).– Solubilization process: Enzyme = Enzymatic hydrolysis; Maceration = Aqueous hot extraction (conventional method); Control: Extraction under hot hydrolysis conditions (temperature and pH).

D = 360 min), these conditions denature R-PE while the optimal conditions for R-PE extraction are milder (T = 20°C, P_{US} = 300 W, D = 210 min). These results call into question the initial strategy (maximizing biomass solubilization) and suggest considering instead a two-stage treatment composed of the non-denaturing extraction of R-PE at low temperature and moderate power, followed by the extraction of other compounds (proteins and sugars) at higher temperature and power.

Prospective work on *C. crispus* showed that the biological variation in the parietal composition played an important role in the efficiency of enzymatic hydrolysis (➔ ***Fig. 15***). The figure also shows the superiority of enzymatic hydrolysis compared to hot maceration, which is a classic solubilization method.

For the solubilization of the brown alga *S. muticum*, a mix of glucosidase, protease and alginate lyase activities was used because some of the *S. muticum* phlorotannins are insoluble, being linked to the proteins as well as to the cellulosic polysaccharides of the wall, fucoidans and alginates. However, optimization of enzymatic hydrolysis alone made it possible to solubilize only a very small amount of phlorotannins and total sugars, even with large doses of enzymes (5% w/w ➔ ***Fig. 16 columns c***). Among the different solutions tested to increase solubilization, the use of a detergent mainly "boosted" the action of enzymes. Of the 4 anionic detergents tested, only Triton X 100 had a marked effect (➔ ***Fig. 16 columns e***; according to the literature, this detergent blocks the unproductive bonds between the enzyme and the substrate during polysaccharide hydrolysis, which



Effect of addistion of Triton X (an anionic detergent) 0.5% vol., on the solubilisation of total sugars and phlorotannins - hydrolysis duration, 3 h, except for for (e), 6h.

Figure 16. The coupling of enzymatic hydrolysis and detergents favors the solubilization of dry matter and phlorotannins (*S. muticum*).

increases the effectiveness of enzymatic hydrolysis). The solubilization levels, however, remain low even for high enzyme concentrations and durations (10% w/w and 6 h ➔ ***Fig. 16 columns f***), which can be attributed to the very high strength of brown seaweed tissues.

Conclusions and perspectives: Although industrial stakes are not currently well developed in the French region of Pays de la Loire, seaweeds are nevertheless a resource for the future as a potential source of compounds of marine interest, in particular proteins for food, feed and marine molecules with specific properties. Their biorefining encompasses major scientific issues, and the necessary skills are available within the IUML in Nantes and Saint-Nazaire. On the dynamics of the action carried out in COSELMAR, two subjects were defined, one of which, financed under an AAP Smidap, will start in September 2017.

CRUSTACEAN

This part of this action was aimed at understanding some generic aspects of biorefining by hydrolysis for a "crustacean shell" support with a complex polysaccharide-protein and mineral arrangement as well as the case of macroalgae. The work was based on the knowledge of Ifremer and GEPEA on shrimp shell biorefining. Several crustaceans were processed, including two invasive species. The first, initially programmed in the COSELMAR project, is *Polybius henslowii*, an invasive swimming crab on our coasts, which creates damage for fishermen, and the second is *Lubinia dubia*, an invasive crab of the Gulf of Gabes, studied by a Tunisian laboratory, which enabled a Tunisian doctoral student to be invited for 3 months.

The work of this sub-action was mainly carried out in the framework of the post-doctoral work of M. Socol and during the stay of the Tunisian doctoral student W. Rijba. The post-doctoral work included both experimental work to transpose the work on shrimp to crab and modeling of the kinetics of demineralization and deproteinization, including the notion of peptide molecular weight distribution in the aqueous fraction. This modeling work led to two publications. Work on the analysis, formulation and comparison of the demineralization and deproteinization kinetics of shrimp and crab shells showed a marked difference between the two with a higher mineralization level in crab, which requires further purification of the solubilized chitin with a slightly reduced degree of deproteinization and a relative amount of minerals even with the same demineralization level.

ACTION 2.3
Estimation of Microbial Growth Dynamics – Microbial interactions

The initial objective of this action was to develop models for estimating microbial growth dynamics, for monocultures or microalgae-bacterial co-cultures, using simple and automatable measurements, in particular optical microwell density readings on plates (Bioscreen C system). After some preliminary experiments (A. Lamer's internship), an improvement in the practices was proposed in monoculture. Conversely, the use of Bioscreen in co-culture proved to be more than delicate in most cases. Thus, the rapid acquisition of a very large number of data for the dynamic modeling of microbial interactions could no longer be the main objective of this work. The latter was therefore re-evaluated during the project.

The choice was made to focus our attention on obtaining additional data for modeling work on the co-culture of a diatom (*Haslea ostrearia*) associated with a diatomaceous growth-promoting bacterium of its environment. The determination of the most favorable bacteria was an integral part of the work. This point necessitated numerous investigations because the incomplete knowledge of the ecological characteristics of this marine diatom complicates its culture. More specifically, the bacterial ecosystem in the oyster-clays where *H. ostrearia* develops remains unknown. The diatom is an important microalga for regional oyster culture since it is responsible for the greening of oysters in connection with the production of its pigment marennine. This work was carried out within the framework of the CDD of Alexandra Lepinay.

The structure of this bacterial community was analyzed using PCR-TTGE before and after the isolation of the *H. ostrearia*-associated bacteria (from the biofilm associated with the microalgae) and present in the water column. The results are obtained from 4 different sites in order to distinguish the relative part of the biotope and biocenosis and to describe the temporal dynamics of the structure of the bacterial community at two time scales (2 weeks vs. 9 months). The bacterial structure of the phycosphere differs greatly from that of the sediment of the oyster clay (➔ ***Fig. 17***). Furthermore, the degree of similarity between bacteria derived from biofilm and those suspended in the water column (culture medium) does not exceed 10%. In contrast, similarities within the biofilm bacterial community are greater than 90%, irrespective of the geographic origin of the isolate,

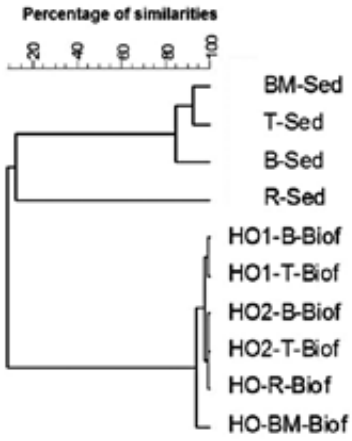


Figure 17. PCR-TTGE analysis of the bacterial community structure of sediment samples (Sed) from oyster-clay samples and the structure of the bacterial community from biofilm samples (Biof) after isolation from several localities (B: Bouin, BM: La Barre-de-Monts, R: Re island, T: La Tremblade) of H. ostrearia grown in the laboratory in ES 1/ medium.

while similarities are lower for suspended bacteria. At the level of the culture cycle under laboratory conditions, the bacterial community depends on the growth stage. When the *H. ostrearia* culture is maintained by transplanting for 9 months, a change in the bacterial structure is observed from 3 months, followed by its stabilization (70 to 86% similarities). On the basis of these results, a first outline of the relationships between *H. ostrearia* and its surrounding bacteria can be sketched, leading to a better understanding of the ecological function of this marine diatom.

The bacteria isolated from monospecific cultures of the marine diatom *H. ostrearia* were therefore tested in co-culture in order to evaluate their possible influence on the growth parameters of the microalgae. Several bacterial strains showed in co-culture that they can significantly increase the maximum growth rate and the maximum biomass produced in comparison with a monoculture (e.g. 15% increase in the maximum biomass for isolate B22 (➔ ***Fig. 18***). Thus, on these performance criteria, several strains were retained for taxonomic identification. Isolates B5 and B10 were identified as *Saccharospirillum* sp. while B22 belongs to the genus *Rhodobacter*. The geographical origin of *H. ostrearia* does not influence the growth performance of the alga and a given bacterial isolate will result in the same algal growth performance regardless of the origin of the alga. Only 8 bacteria from the thirty isolates produced indole

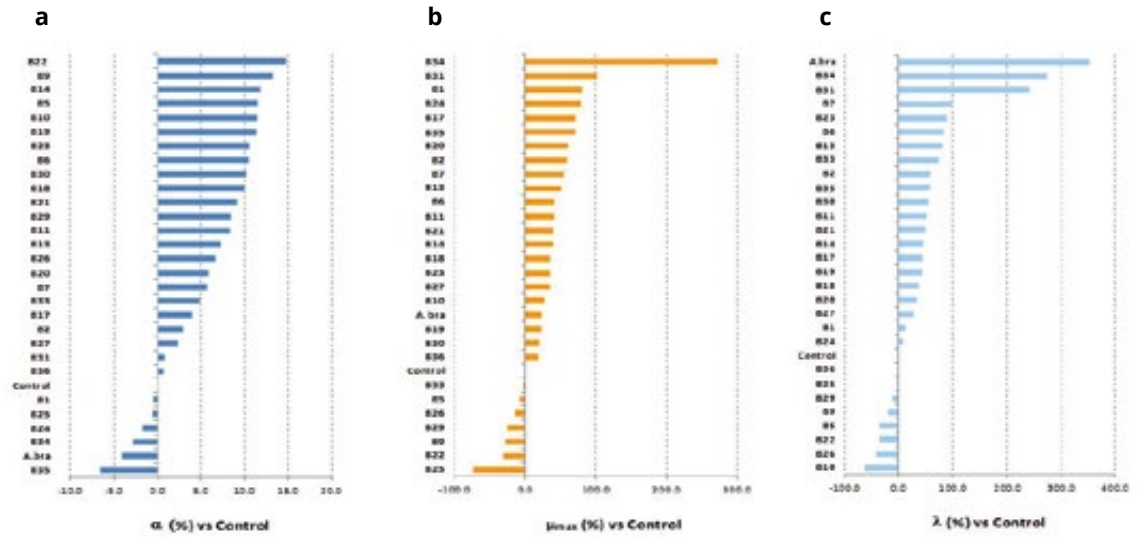


Figure 18. (a) Maximum latency (λ), (b) maximum growth rate (μmax), and (c) maximum biomass in stationary growth phase (α) of *H. ostrearia* (La Barre-de-Monts) co-cultivated with each of the bacterial isolates or *A. brasilense* (A. bra). The mean values are given in % with respect to the control (*H. ostrearia* monoculture).

acetic acid (IAA) and increased the growth performance of the algae. However, other bacteria that do not produce IAA are also capable of increasing algal growth. The metabolic fingerprint (non-targeted approach) was used to observe the metabolic profile of the extracellular compounds synthesized by the algae in the presence or absence of a bacterial isolate. The number of compounds specific to the different associations is about ten and only three are specific to a positive effect on the growth of *H. ostrearia* in the presence of bacterial isolate.

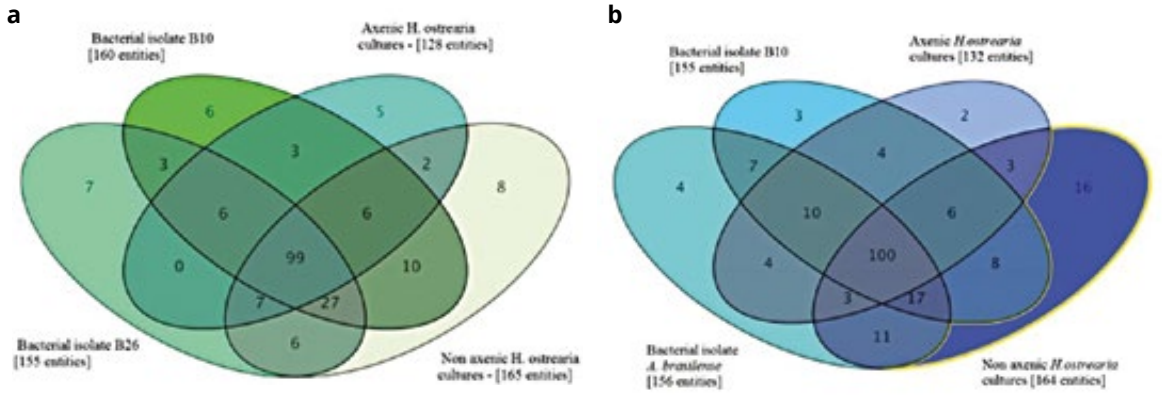


Figure 19. Venn diagrams showing common and specific compounds: (a) *H. ostrearia* cultures from the Ile de Ré associated with growth-promoting bacteria (B10) or growth-inhibiting bacteria (B26) and compared with axenic or non-axenic monocultures; (b) *H. ostrearia* cultures from La Barre-de-Monts associated with growth-promoting bacteria (B10) or growth-inhibiting bacteria (*A. brasilense*) and compared with axenic or non-axenic monocultures.

AXIS 3

New risks and new use of maritime and coastal spaces

At the origin of the formalization of this axis of the COSELMAR project were a lack of awareness of the risks linked to or amplified by the many changes affecting maritime and coastal spaces (new uses, climate change, etc.), both in their forms and their effects on coastal territories, as well as the questions posed by the current implementation of maritime spatial planning measures affecting maritime fisheries in particular, whose complex operation requires an interdisciplinary approach. Thus, the objective of this axis was to try to understand these risks qualified as "new" insofar as they are linked to one or more changes taking place on the scale of a given territorial system. In particular, the aim was to identify, in an integrated and interdisciplinary way, the elements of risk definition and to model the key mechanisms of risk emergence and control, with a view to managing maritime and coastal space. This situation therefore involved a wide range of disciplines (public administration, law, economics, geography, history, sociology, as well as biology and ecology), whose approaches and contributions this axis wished to structure.

After a little more than four years, the results in each of the following actions show that both the scientific objectives and the structuring of the research have been achieved. This is evidenced by a number of important milestones that have marked the progress of this axis:

- *the academic valorization plan: more than 30 articles in peer-reviewed journals, a dozen book chapters, nearly 100 papers mostly in international scientific symposia, some twenty thesis and masters dissertations, the transfer of research products into a wide range of training courses, including a master's degree at IUML, the setting up of a summer school on maritime spatial planning (see the integration axis);*
- *in terms of non-academic valorization: a very large number of dissemination actions ("general public" symposia, interviews on television or radio broadcasts, round table discussions, science cafés or even public meetings), active participation in the broadcasting activities of the integration axis (Les Eclaireurs, 3 minutes for COSELMAR);*
- *in the structuring of research: numerous seminars and workshops that have enabled issues to be worked on at the interface between several disciplines, more than half of the publications involving researchers from several disciplines, editing and/or participation in peripheral projects arising from collaborative or increased collaborations within the framework of COSELMAR, co-direction of university work (theses, masters);*
- *in terms of relationships with "civil society": the work carried out under this axis has systematically involved professionals (fishermen in particular), local authorities, government departments and various bodies working on issues (e.g. ZIP committees in Quebec) and, in so doing, has helped to deepen relationships with civil society and to integrate their needs and expectations as early as possible.*

In order to appreciate more concretely the many achievements resulting from the work carried out within this axis, these are detailed below action by action.

ACTION 3.1

Action 3.1 (Effects of global changes on coastal territories) analyzed the risks of sea submersion in the context of the effects of global changes on coastal territories. A spatial delimitation of marine submersion hazard zones was carried out on the basis of the knowledge of old and recent events affecting the Pays de la Loire coastline. It incorporated the sea-level rise scenarios of +60 cm up until 2100. It continued mainly through a multi-scale mapping of the issues in the submersible zones and an economic cost-effectiveness analysis. It ended with proposals for a strategy to reduce the vulnerability of territories. The cartographic results have been published at the communal or sub-communal level, and at the residential building level for certain municipalities. Quantitative results on the costs of measures to reduce prevention, protection and adaptation have been given.

The most significant advance was the defense of the doctoral thesis of Axel Creach, on November 13, 2015, entitled "Cartography and economic analysis of the vulnerability of the French Atlantic coast to the risk of marine submersion", a two-volume work of 321 p and 249 p, under the direction of Denis Mercier, with the co-supervision of Sophie Pardo. At the heart of this work was the storm Xynthia (2010), which caused a large marine submersion leading to the death by drowning of 41 people. Beyond the hazard, feedback pointed out several causes of this result: the aging of the population of coastal communes, urbanization of low areas, and the unsuitability of buildings toward the risk of marine submersion. Faced with this dramatic event, the State decided to buy back and destroy 1,628 buildings deemed too dangerous (black areas). The objective of the thesis was two-fold: (i) to identify *a priori* areas of danger for the population, (ii) to reflect on the importance of different measures to reduce vulnerability. An index was created to identify areas where the building configuration may present potentially fatal occupant exposure. The Extreme Intrinsic Vulnerability Index (VIE) is based on four criteria: (i) potential water heights inside buildings, (ii) proximity to dikes, (iii) architectural type, and (iv) distance to sheltered areas. The index provided an initial assessment of the vulnerability of seven communes on the French Atlantic coastline and confirmed the exposure of the territories impacted in 2010.

Second, an economic evaluation was carried out in order to compare different possible strategies for reducing vulnerability: (i) protection, (ii) building adaptation, (iii) prevention and awareness, and (iv) relocation. Through the use of Cost-Effectiveness Analysis (CEA), the relevance of each measure was evaluated in terms of the number of lives preserved. This makes it possible to stress the importance of prevention in the policy of reducing vulnerability in coastal communities. This work has been the subject of an intense academic valorization, with an emphasis on international and non-academic media (TV/radio interviews, "general public" conferences).

Axis 3.1 also involved a doctorate (Elie Chevillot-Miot), financed by a ministerial allocation (ED-DEGEST grant), on the resilience of coastal territories to the risk of marine submersion. It followed on from his M2 internship on the vulnerability of the Pays de la Loire region (financed by COSELMAR), and conclusions on the notions of perception, acceptance and resilience of the risk of submersion. The objective of this work was to investigate further the notion of territorial resilience and to arrive at an indicator of resilience. The study sites selected were Charente-Maritime and Somme, in view of their collaboration with CEREMA and their historical, geo-economic and land-use characteristics. This work was thus concerned with the experience and adaptations resulting from a marine flooding event and climate change, from acceptance and initial perception of risk, to know-how in the event of a crisis, and access to information about the risk of marine submersion. This complementary, more societal-based approach has helped to build a more comprehensive understanding of the risk of marine submersion.

Although geographically driven, this action was the opportunity to develop and intensify fruitful collaborations with other disciplines: with economists (S. Pardo and P. Guillotreau, LEMNA, University of Nantes) within the framework of Axel Creach's thesis on the statistical aspects and cost-effectiveness analyses, with a civil engineer (E. Bastidas-Artega, GEM, University of Nantes), on the quantification of the scenarios in the economic part of the thesis work of Axel Creach, and with a historian (T. Sauzeau, University of Poitiers), for historical research about the island of Noirmoutier and the diachronic analysis of the evolution of the buildings in zones at risk.

ACTION 3.2

Action 3.2 (Changes and risks in the marine fisheries sector) of the COSELMAR project made it possible to

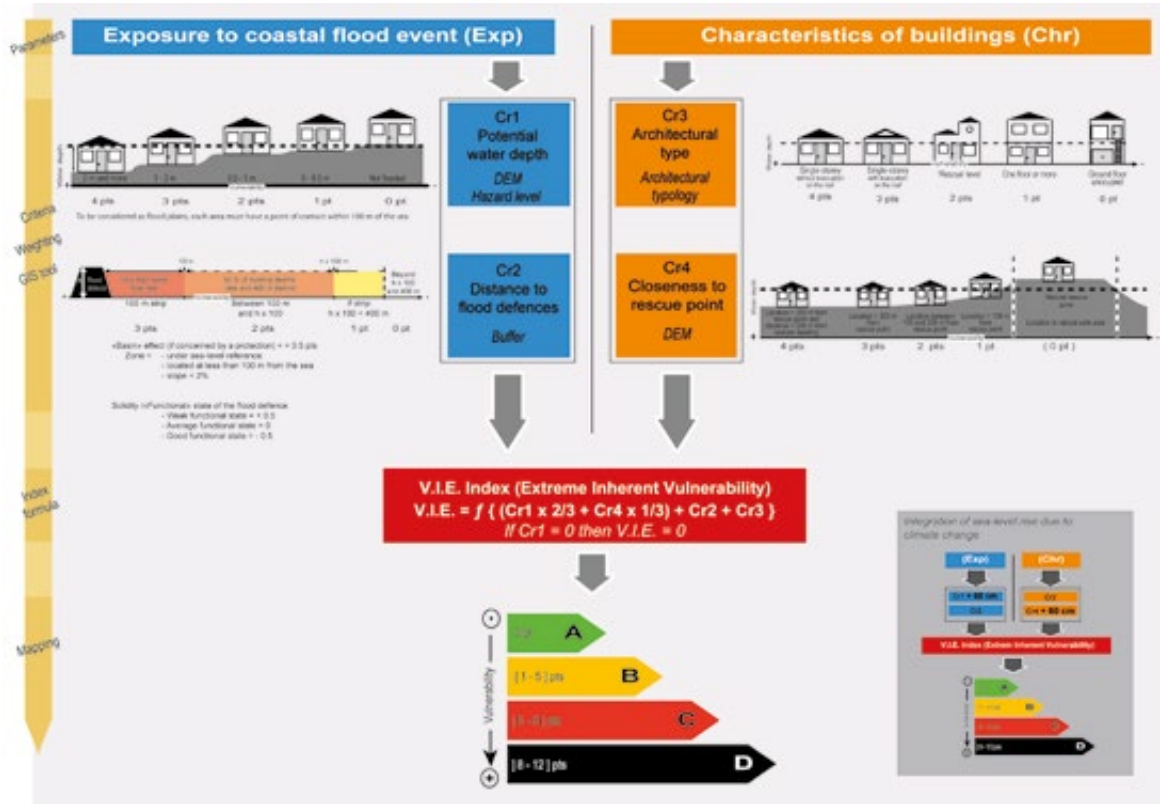


Figure 20. Methodology of the V.I.E. index, presenting the criteria used and their definition and weighting, the formula used and the vulnerability classes.

answer many of the scientific questions posed at the origin of the project. During the lifetime of the project, this led to the production of a large number of scientific articles (29), book chapters (10) and communications at conferences (87), as well as several promotional activities aimed at the general public (15), master (15) and doctoral (4) theses, one of which is financed by the COSELMAR program and has not yet been defended (a list of these productions is attached).

Among the overall results achieved under Action 3.2 are some major contributions to the various issues raised.

Sociological research on occupational temporalities and domestic adjustments revealed the link between the special features of artisanal fishermen's work through two types of specific family arrangements. The work on organizational and professional dynamics focused on the process of socialization and the learning of risks, attesting to a strengthening of the credit granted to the traditional experts and know-how of fishing. Understood as a resource to face uncertainties and to ensure the best tide, the over-valorized professional credit nevertheless discriminates against those who do not have it, namely the least integrated into marine fishing. The particular relationship with wages in the fishing sector - the shared wage - with risk-taking collectively accepted by the crews with a view to maintaining a satisfactory level of remuneration leads to the intensification of work on board, the generalization of riskier fishing practices, and the reduction of on-board crews. These risks are accompanied by significantly higher accident and mortality rates than all land-based sectors, including construction.

One result highlights the individual role of seller and buyer in price differentials, which vary by species, and their pairing, in addition to the traditional characteristics of the product (species, size, presentation, quality) and their seasonality. An original measurement test of the Single Price Law (price convergence between fish markets for an identical product) was constructed to identify the spatial distribution of regional markets.

Figure 21. St Gilles Croix de Vie Auctions.

Regional assemblages were thus built on the basis of this original test, demonstrating the remarkable convergence in price of 8 species (monkfish, langoustine, sole, Saint Pierre, cuttlefish, etc.) for the majority of fish markets in the ports facing the Atlantic, with the notable exception of Dieppe and Fécamp. These auctions differ markedly from the prices displayed on the Mediterranean coast, thus showing a border effect between the two main coasts. The fish auction has evolved significantly over the past ten years and Internet sales have contributed significantly to the price firming thanks to distant buyers. The physical sales are thus tending to regress in favor of these dematerialized sales and some ports now sell all their goods to distant buyers. This trend is likely to strengthen in the coming years, with the creation of hubs in the zone behind the coast, which will lead to mass-market distribution logistics in order to increase efficiency in the territorial distribution of fishery products. Nevertheless, the paradox of the decline in prices during the day for the same product sold at auction continues and constitutes a risk for the seafarer according to his place in the order of sales. The COSELMAR project explained the origin of this decline by decomposing the effects of time (influences of the seasons, the day of the week) and the categories of buyers represented (wholesalers, purchasing centers, retail fishmongers). In parallel with this organization of the auction market, new forms of marketing via short circuits are emerging and have been studied by researchers at COSELMAR. In light of the special features of these short circuits, the survey carried out also emphasizes the exceptional character of the Yeu-Mainland AMAP, which for the time being does not seem to constitute a transferable model from which the short circuits to fishing could develop in the Pays de la Loire region with a view to securing the income of artisanal fishermen.

A major challenge for the future of the marine fishing profession concerns fishery governance and climate change in relation to its effects on marine ecosystems. A geo-prospective exercise has been carried out to stimulate debate around possible developments in fishery governance in the Bay of Biscay. The value of foresight for action research has been demonstrated in environmental and social sciences. On the other hand, the question of the possibilities and methods of spatializing foresight with the stakeholders remains an open question, despite recent developments. A series of cycles of individual interviews and group workshops was conducted, respecting the different stages of foresight (i.e. diagnosis, hypotheses about the future, discussion of possible futures). Spatialization times were also proposed to stakeholders in which participatory expression tools, such as mind maps and graphic representations, were used. Moreover, the discourse and debates of stakeholders were analyzed using grids highlighting the spatio-temporal contents of the narrative (Tissière et al. 2017, Tissière et al. 2017b, Tissière et al. submitted). Finally, the scenarios were simulated in the ISIS-Fish model, characterized by the flexibility of hypotheses, spatial meshes and time steps (Provot et al. submitted). At the same time, an original tool (called I-ADApT) for assessing responses to global change problems affecting marine ecosystems was designed and applied to some twenty marine ecosystems around the world, supported by colleagues (Human Dimensions group of the IMBeR-Integrated Marine Biosphere Research program). The synthesis of the cases studied is presented in a book to be published by Routledge in 2017, and the database generated should be enriched with new cases in the years to come in order to propose a typology useful to decision-makers. Such a typology will enable them to identify and evaluate the chances of success of the strategic options envisaged in the face of a major crisis affecting the marine socio-ecosystems exploited.

Interdisciplinary meetings marked the highlights of research Action 3.2, such as the holding of seminars, colloquia, workshops and summer universities. These include the seminar at the Ange-Guépin House of Human Sciences on 15 July 2014 on the integration of research on change and risk in the fishing sector, the International Summer School on Maritime Spatial Planning, in collaboration with the Marine Spatial Planning Research Network, which

brought together 23 participants of 17 different nationalities from 1 to 5 June 2015, the moving-2gather conference on marine ecology in December 2015, the 4 workshops on foresight in the field of fishery management in the Bay of Biscay in 2015 and 2016 (thesis by Laurie Tissière) , the OCEANEXT colloquium of 8-10 June 2016, the two symposia of the French Association of Halieutics (Montpellier in June 2015, Nantes in June 2017), the theme of the Nantes colloquium organized by the EMH team at Ifremer entitled "Fisheries and Global Change", the study days of the Observatory of Seafarers' Rights in January 2016 on "Fishing and Fishers, Evolutions and Transformations: Interdisciplinary Approaches" and in June 2017 on the social conditions of fishing, the LEMNA international seminar on societal responses to the problems of global change impacting marine socio-ecosystems in May 2017, the colloquium organized by CENS on "The coveted sea: occupations, uses and regulations" on 8-9 June 2017, the international seminar "Fisheries, Fishers and Marine Spatial Planning" organized by the LETG-Geolittomer on 14-15 June 2017.

ACTION 3.3

Action 3.3 (France-Canada comparative analysis of governance in the face of new risks and coastal and maritime uses), crossing 3.1 and 3.2, analyzed, within the framework of an international comparison between France and Canada, the governance processes at the territorial level faced with the two main risks studied: the effects of global changes on coastal territories and the understanding of the changes and risks facing the marine fisheries sector. The international comparative dimension of this action was based first and foremost on the existence of a Francophone network (UQAR, ENAP, UMCS) linked to the University of Nantes, with the objective of expanding to other universities and provinces, and the relevance of the similarities and differences found. This action was also supported by additional funding (CPCFQ), which preceded the COSELMAR project, and which enabled several years of work sessions involving Quebec and Loire-Atlantique researchers. In addition to the ambition of openness and international structuring, the aim of this action was to build a shared methodology for analyzing governance processes and their possible transformations in this context of "novelty" of risks and uses, based on two thematic inputs (other Axis 3 actions): submersion and fishing activity.

Yannick Leroy's thesis on "Governance of coastal territories subject to change: comparative analysis between France and Canada" is one of the major productions of this action. Co-supervised (Nantes, B. Trouillet - Rimouski, C. Rioux), it helped to consolidate the cross-analysis and the partnership, with research that took place on both sides of the Atlantic. The papers and articles already demonstrate the relevance of this comparison while the thesis itself will be completed by the end of 2017. This thesis, as well as the work undertaken within the framework of the CPCFQ (Standing Commission for Franco-Quebec Cooperation) and partnerships with Francophone universities in Quebec (UQAR, ENAP) and New Brunswick (UMCS) have promoted research involving researchers from both countries and the involvement of stakeholders in the management of coastal territories. Thus, two chosen sites have made it possible to carry out these cross-tabulated analyses: Yeu Island in France and the Magdalen Islands in Canada. These two sites are "subjected" to new uses (projects) at sea, which are revealing and disruptive of governance systems (off-shore wind turbines for Yeu Island, offshore hydrocarbons for the Magdalen Islands), ongoing processes that highlight the permanent features and the notable differences between the two socio-systems. At the same time, Action 3.3 has contributed to a better understanding of the mechanisms specific to the Quebec-Canadian system, as reflected by the thesis (May 2016) of Anne Fauré, one of the Canadian partners, on the ICZM in Quebec.

In addition to research, this cooperation is also represented by a training component, from student mobility to a double-degree project between UQAR (Rimouski) and the University of Nantes (Master of Marine Resources Management and Master GAEM - Geography and Management of Maritime Areas). This Franco-Quebec dynamic linked to Action 3.3 has also contributed to the good positioning of the IUML in Nantes during the implementation of the IFQM (France-Quebec Institute for Scientific Cooperation in support of the Maritime Sector), "launched" at the first congress of the IFQM in Montreal on May 8/9, 2017. This cooperation could soon be concretized around actions related to port governance (T. Guineberteau): participation in the study related to the extension of the Port of Quebec in Beauport Bay (ongoing discussion with Port-Quebec); participation in the organization of a scientific day associated with the AIVP (International Association of Cities-Ports) Meetings, to be held in Quebec City in June 2018.

Beyond the emblematic case of Quebec, Action 3.3 has enabled targeted or comparative research on another scale. Thus, the comparative research of A. Gallais-Billaud (2014 - T. Guineberteau, LETG) on participatory approaches and P. Deschamps (2015 - O. Delfour, CDMO) on maritime rights produced very relevant results on the comparison of Provincial/ Federal with National /European levels, as shown by the presentations and debates at the Europe-Canada Congress held in Nantes in June 2015. Similarly, the work carried out by I. Fortier (ENAP) on the concept of the common good applied to the management of

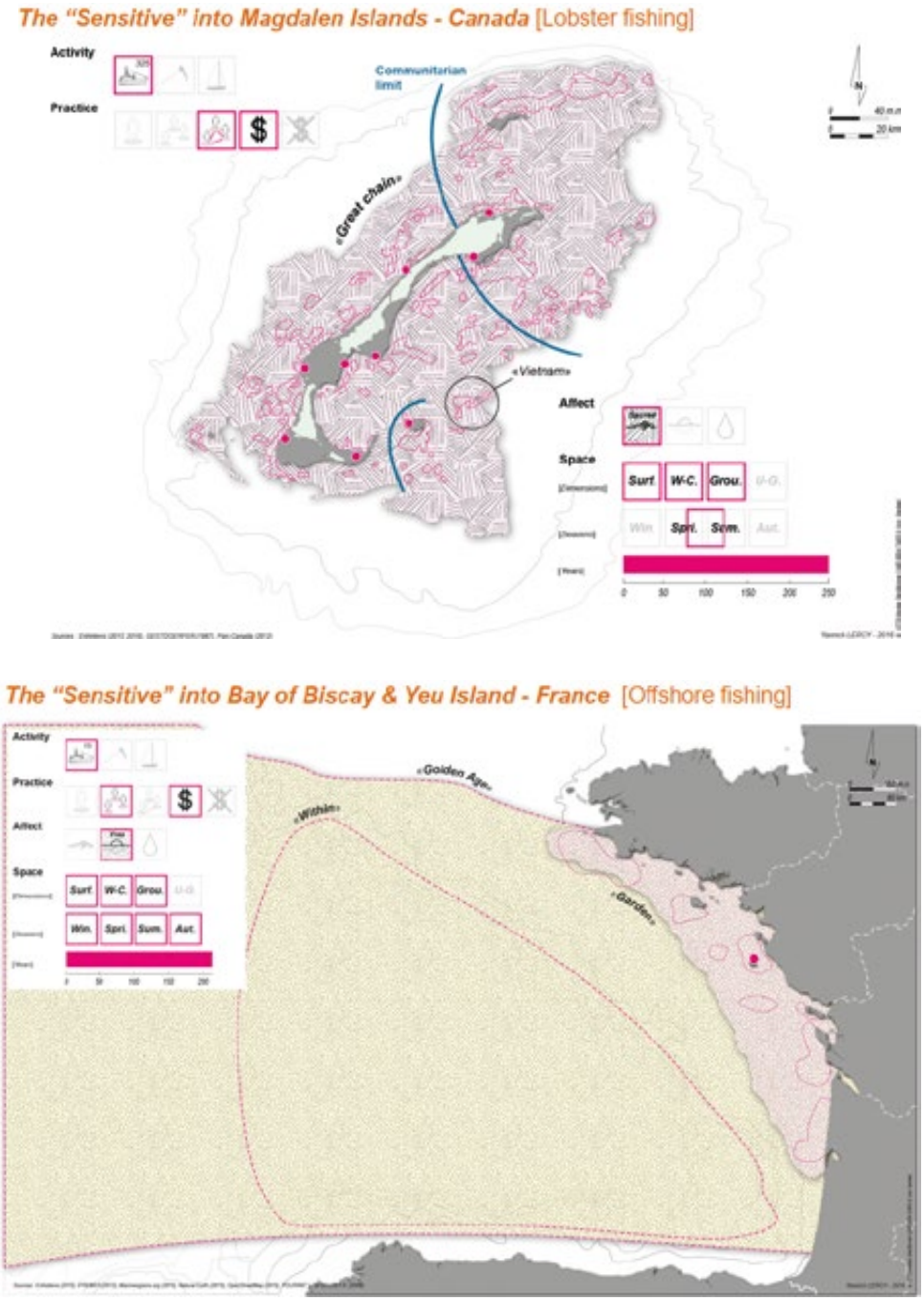


Figure 22. France-Canada comparative analysis: offshore fishing in the Bay of Biscay, off Yeu Island and lobster fishing off the Magdalen Islands.

coastal zones, linked to the Nantes researchers (T. Guineberteau, B. Trouillet) during his reception at the MSH Ange-Guépin (2015,) are fully in line with this objective of comparison. Although comparison was not the selected research topic, the study carried out by M. Coulibaly (2016 - P.-A. Mahieu, LEMNA, in partnership with C. Rioux, UQAR) on the environmental assessment of a marine energy project in Canada fits perfectly with part of the observations made on the sites of Yeu Island and the Magdalen Islands where the energy issue is omnipresent in projects for new uses at sea. Research that is currently being finalized by L. Trichet (2017 - T. Guineberteau, LETG) is a comparative analysis of the management of coastal zones around the Gulf of St. Lawrence. This internal comparison in Canada thus crosses the situations of the various maritime provinces of Eastern Canada, with methods and results that should *a priori* be extended beyond this single geographical area. On the other hand, we have not been able to integrate the West coast, i.e. British Columbia, into our work, with the distance itself being the first hurdle.

In line with the objectives set out at the launch of the COSELMAR program, Action 3.3 ends with the logic of enlargement and prospects going beyond the Franco-Canadian comparative framework, like the priority themes of Axis 3. On the one hand, the research currently being carried out by J. Dilasser, a contract researcher in the COSELMAR program, is an essential feedback and methodological point on the international comparative study for future research. On the other hand, the international workshop "Coastal governance" programmed at the MSH of Nantes on 12 and 13 June will bring together partners from Ivory Coast, Gabon, Morocco, Senegal and France. Some 20 experts will work on the theme of governance in relation to the three predefined targets - research (including action research), training (including continuing education), and publication (including popularization) - thus contributing to the emergence of an international network, francophone at this stage, on the governance of coastal zones.

AXIS 4

Integrating axis

The objective of the COSELMAR project was to increase the structuring of the consortium and its international influence, through three actions: a reflection on transdisciplinarity and the creation of a platform for integrating knowledge about risks, the governance of marine resources and spaces; networking of researchers from the federation "Institut Universitaire Mer Littoral"; spreading influence at the training level. Among these transversal actions, two have also produced significant scientific results.

ACTION 4.1
Prospective

Objectif : To propose a transdisciplinary representation of the socio-ecosystem of the Bay of Biscay and to identify future research topics.

One of the scientific objectives of COSELMAR was to carry out a reflection in order to improve multidisciplinary integration and to sketch the beginnings of a real transdisciplinarity. Several actions have been implemented: multidisciplinary scientific facilitation throughout the project in the form of workshops, the construction of a common language around the fundamentals of the project (risks, governance, socio-ecosystem, model, etc.), and the creation of a computer platform for knowledge integration. A reflection on ontology as a tool to help this multidisciplinary integration of knowledge was initiated but did not reach the scale of the project due to a lack of time and of skills within the consortium. In this process, foresight has become a relevant and constructive approach in order to carry out this reflection and initiate new transdisciplinary research topics. The theme of foresight launched at the scale of the project is the following: "What is the future of research on marine and coastal environments and especially in the Bay of Biscay?"

WORK STAGES AND PRODUCTIONS

The COSELMAR foresight was built in three stages: 1) training researchers in foresight; 2) application to a research topic of the project, well defined and relevant for a foresight exercise, and which formalizes a major issue in the Bay of Biscay (governance of fisheries in the Bay of Biscay [Laurie Tissière, Action 3.2]); 3) exploitation of the scenarios produced during the geo-foresight of the governance of fisheries of the Bay of Biscay as a starting point for foresight at the scale of the project. The special feature of this exercise at the scale of the research project is the deconstruction (and not the construction) of scenarios to bring out themes/research questions. In 2017, three foresight workshops brought together researchers in charge of the COSELMAR axes. During the second workshop, researchers from outside COSELMAR, historians and project coordinators in the social sciences and humanities were involved in the discussions to open up the debate and provide the missing visions from other disciplines to the project.

The scenarios constructed during the geo-foresight of fisheries governance in the Bay of Biscay were modified and expanded in order to understand better the socio-ecosystem of the Bay of Biscay. Discussions on the future of research around this socio-ecosystem led to the definition of new long-term changes in its compartments and uncertain breaks in its dynamics. A series of issues were identified, focusing on research (method, ethics, financing, etc.) and the marine and coastal socio-ecosystem. At the end of the three workshops, we brought together the following elements:

- A transdisciplinary graphical representation of the socio-ecosystem of the Bay of Biscay (➔ ***Fig. 23***)
- A list of seven variables (called critical uncertainties in prospect) that characterize the socio-ecosystem and on which various hypotheses of possible evolutions are based. These hypotheses are broad enough here to allow transdisciplinary links. They can be re-examined more precisely according to the project theme and the disciplines involved.
- Three scenarios relating three possible types of evolution of the Bay of Biscay to 2050: these three

scenarios are based on combinations of assumptions about uncertainties.

- A list of issues, which emerge from reading the scenarios in terms of risks and opportunities for the future. This list is certainly not exhaustive but sufficiently rich and diverse to fuel a wide range of research questions.

From these, transdisciplinary research themes and paths of innovation emerged. The results of this foresight were debated in public during a Serious Game closing the web-series of Les Eclaireurs (popularization and public dissemination of COSELMAR results).

INTERMEDIATE OUTCOMES OF FORESIGHT "WHAT IS THE FUTURE OF RESEARCH ON MARINE AND COASTAL ENVIRONMENTS AND ESPECIALLY IN THE BAY OF BISCAY?"

A graphic representation of the socio-ecosystem of the Bay of Biscay

To initiate discussions on the socio-ecosystem issues of the Bay of Biscay, it was necessary to define clearly the different compartments of this study topic. Figure 23 reads first from left to right, although the interactions inherent in the system, exchanges with related marine and socio-ecosystem systems and the

Figure 23. A representation of the socio-ecosystem of the Bay of Biscay.

spatial heterogeneities of the system do not require unidirectional operation dynamics. The suggested coastline, symbolizing interactions within the littoral, reveals a growing density of human activities along a wide-gradient gradient. The ocean (in white), structured around its biotic and abiotic components and its factors regulating the socio-ecosystem, is the basis (in dark blue) of the production of bio-resources, mineral resources, and physical resources. It also offers a space of life and activity for man. Then, in green, is what man values in this environment in terms of potential, emerging or traditional uses, which are at the origin of sectors (in orange). All this is at the heart of issues of governance and spatio-temporal inter-relationships, imbued with a collective and individual imagination.

List of variables

On the basis of Figure 23, the first step was to identify already evolving socio-ecosystem trends (strong trends in prospect): climate change and other environmental evolutions; evolution of anthropogenic behaviors and pressures on the ecosystem; evolution of modes of governance. In the second phase, the workshop participants imagined events that could create breaks in these dynamics. They were classified into seven different variables:

Variable 1 ➔ Public policies and participation; **Variable 2** ➔ State of the marine environment; **Variable 3** ➔ Maritime economic sectors; **Variable 4** ➔ Scientific monitoring of marine ecosystems and shipping companies; **Variable 5** ➔ Organization of uses at sea; **Variable 6** ➔ Quality of life and social well-being; **Variable 7** ➔ Risk management.

The scenarios

These were constructed at the time horizon of 2050 as exploratory scenarios (neither desirable nor undesirable) and rely on two types of dynamics:

- strong trends: dynamics that one imagines stable over the horizon studied (already underway);
- critical uncertainties: dynamics or variables that are highly uncertain and that raise critical issues for the topic being debated.

These elements were chosen in a "temporary" or arbitrary manner (contingency linked to the people present at the workshops, to the surrounding context, to current events, etc.) to fuel the question of foresight. The space in which the scenarios are presented is the Bay of Biscay, not to restrict the scope of the questions but to give a concrete case study facilitating the questioning and exploitation of the results and limits of the project. Its openness toward the world, and particularly toward related marine areas, and the diversity of its species habitats, forms of governance, uses, etc., make the Bay of Biscay a socio-eco-region relevant to question socio-ecosystems in the widest sense.

List of issues

This list was drawn up on the basis of the above data: scenarios, strong trends, and critical uncertainties. Although not exhaustive, it is currently organized around seven themes:

Issues of **global change**; Issues in **marine sectors**; Issues of **multiple uses of the sea and coastline**; Issues for **the recovery of degraded environments and artificial environments**; Issues about **the imagination of the sea and our representations**; Issues about **the common good and well-being**; **Methodological, monitoring and ethical research** issues.

AN INITIAL FORMULATION OF RESEARCH THEMES/QUESTIONS

An association between critical uncertainties, challenges for the future of marine socio-ecosystems, research topics and the disciplines to be used, proposes an innovative and heuristic path to build new transdisciplinary problems, thus extending the working dynamics of COSELMAR. This resulted in the formulation of five main themes:

- **Design of structures at sea:** what would be the durability of these structures (wear, life cycles, reversibility)? What are the environmental and social impacts/risks (jobs, assets, etc.) of the establishment of large multi-use platforms at sea? What types of uses can be accommodated? What would be their economic profitability? What capacity would the territories need to produce, maintain and transform these structures (provision of maintenance vessels, vessels specialized in their design and know-how)? What is the social acceptability of their emergence and development at sea?
- **Development of a new aquaculture sector at sea** (algae, macroalgae) at the regional scale: what new occupations? How could this be a diversification route for traditional activities (fishing, aquaculture)? Which spaces could be involved and which economic models could be imagined: from

harvesting to intensive culture? What links need to be built with the health and food sectors? What will be the impacts on water quality, landscapes and other uses? Here too, what is the social acceptability of their emergence and development at sea?

- **Multi-use of the sea**, regional policies and maritime planning. How can uses be planned by integrating notions of evolution? How are the relationships of domination of uses at sea expressed? Does the sea provide social, ecological and spatial justice? What is the integration of policies between regions? How far are participatory processes used/usable to manage the sea? What type of democracy is deployed at sea (who will be the "residents", citizens of the sea)? How can the sectors cooperate? What are the tools for decrypting and analyzing conflicts?
- **Future changes** in the state of marine environments and marine societies with respect to global changes (climate, geopolitics, population density): observing climate change in a marine region in relation to global climate change, observing past and present ecological changes, and past and present social changes, evolution of uses and practices with respect to global changes, changes in political positions, regulation directly or indirectly linked to global changes and the economic and geostrategic context.
- **Study of the logic of gains and losses in the marine environment:** the sea, a space by nature moving and impermanent, encourages one to think of the reversibility and the evolution of uses. The coastline fluctuates, and traditional uses evolve in space according to the availability of resources (oyster farming, fishing). There are already wastelands at sea (for example, abandoned oyster tables in the Arcachon basin): how are they valorized? In addition, new uses could be established in a more sustainable way and the desire to plan activities spatially could induce factors of immobilism at sea. How should the logics of gains and losses be considered upstream of the planning? How do we think of these logics in our ways of managing the sea and the coast? What will be the future industrial wastelands (e.g. wind turbine bases)? How can the concept of impermanence be integrated into maritime planning? What is the place of spatial analysis and a real-time management model?

This foresight exercise, which was the culmination of four years of multidisciplinary reflection, helped to consolidate the problems already under way, to clarify certain related issues and to elicit more innovative ideas stemming from truly transdisciplinary questioning. In particular, the theme of gains and losses of the maritime space attracted the greatest number of participants and is a prospect for future transdisciplinary research.

ACTION 4.2
Bio-colonization

Bio-colonization of offshore structures is defined as the fixation and growth of plant or animal marine species on an offshore structure. This subject, at an international seminar held at the University of Nantes at COSELMAR in 2015, was highlighted as one of the main challenges for the maintenance and design of **Renewable Marine Energies, in particular future floating wind turbines.**

By relying on the Institute for Research in Civil and Mechanical Engineering, the Molecules Marine Health Laboratory and the Biolittoral company, the COSELMAR project brought together actors whose complementarity alone can meet this interdisciplinary challenge.

In concrete terms for this vast subject, this action is about initiating work on scenarios of growth of bio-colonization and optimizing the procedures of preventive and curative maintenance, and especially initiating the creation of a national and international network of reflections and exchanges (both of experimental data, means and the conceptualization of approaches) in order to constitute a leading network at the European level on this issue. This work is situated in a dual context of risk analysis: technological risk linked to the cessation of operation or to the breakdown of a structure; environmental risk linked to the biomass produced during cleaning.

SYNTHESIS OF THE RESULTS AND LEVERAGE OF COSELMAR

To answer this question, three priority axes were defined: (1) in situ measurement methods to quantify the thickness of bio-colonization, co-financed by a study with the company TOTAL (2) modeling of the colonization process (3) *in situ* expertise to identify and quantify the dominant species in view of the establishment of offshore wind turbines off St Nazaire.

- (1) : this exploratory and qualitative work has now entered the scientific development phase with an 18-month post-doc co-funded by the University of Nantes and the Irish MaREI project. The **3D measurement protocol for bio-colonization** is now available. Initial tests have been carried out and are conclusive for the cone-type bio-colonization measurement (➔ *Fig. 24*, extracted from a video made during the project): the simulated bio-colonizations are made of cones of known geometry designed to represent the sizes of the barnacle clusters on mussels. We can then access the measurement error of the protocol in the laboratory and under increasingly difficult real conditions.

Prospects and leverage of COSELMAR: as part of the ANR project ABIOP, led by the University on the operational implementation of protocols, a control plate (➔ *Fig. 25*) will be used to calibrate the devices in turbid and actual brightness conditions (passage TRL 4-5 to 6-7).

- (2) : The stochastic model by Gamma process has been finalized. It also makes it possible to simulate the increase in thickness and the variation in roughness.

Prospects and leverage of COSELMAR: the analysis of the results showed a strong dependence on the measurement (previous point) and the definition of roughness. A fault appeared in the standardized definitions, which gave the idea of the WEAMEC project LEHERO-MG, carried out in partnership with the hydroelectricians of the LHEEA. The finalized software is used as part of the SURFFEOL FSI project with STX.

- (3) : A Biocolmar® implantation analysis was carried out in the COSELMAR project as well as the design of the collectors, in partnership with Biolittoral. This **measuring station** will be set up in the SURFFEOL project and COSELMAR partners will benefit from the environmental measurements of this project (two NKE probes) enabling each consortium to take advantage of the progress of the other.

Figure 24. Tests in the Ifremer basin (Boulogne) - Financed by the company TOTAL for the validation of the protocol developed in COSELMAR for the case of mono-color roughness and absence of turbidity

Prospects and leverage of COSELMAR: this structure was set up in June on the site of the Base Michaud, well referenced historically, and will provide on site data for the whole scientific community of IUML (biologists, bio-chemists, hydro-mechanicians...).

Figure 25. 3D reconstitution from 2 images in the case of a "Biocolmar®" plate with various colors and without turbidity (University of Nantes - GeM-MMS-IXEAD-Biolittoral/MaREI (Ireland).

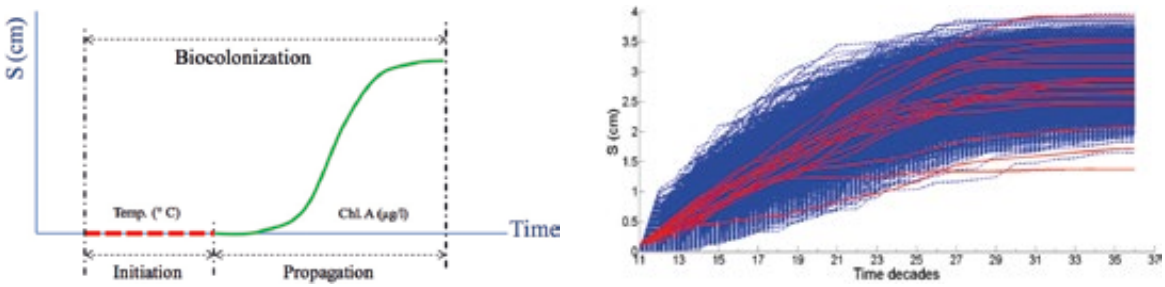
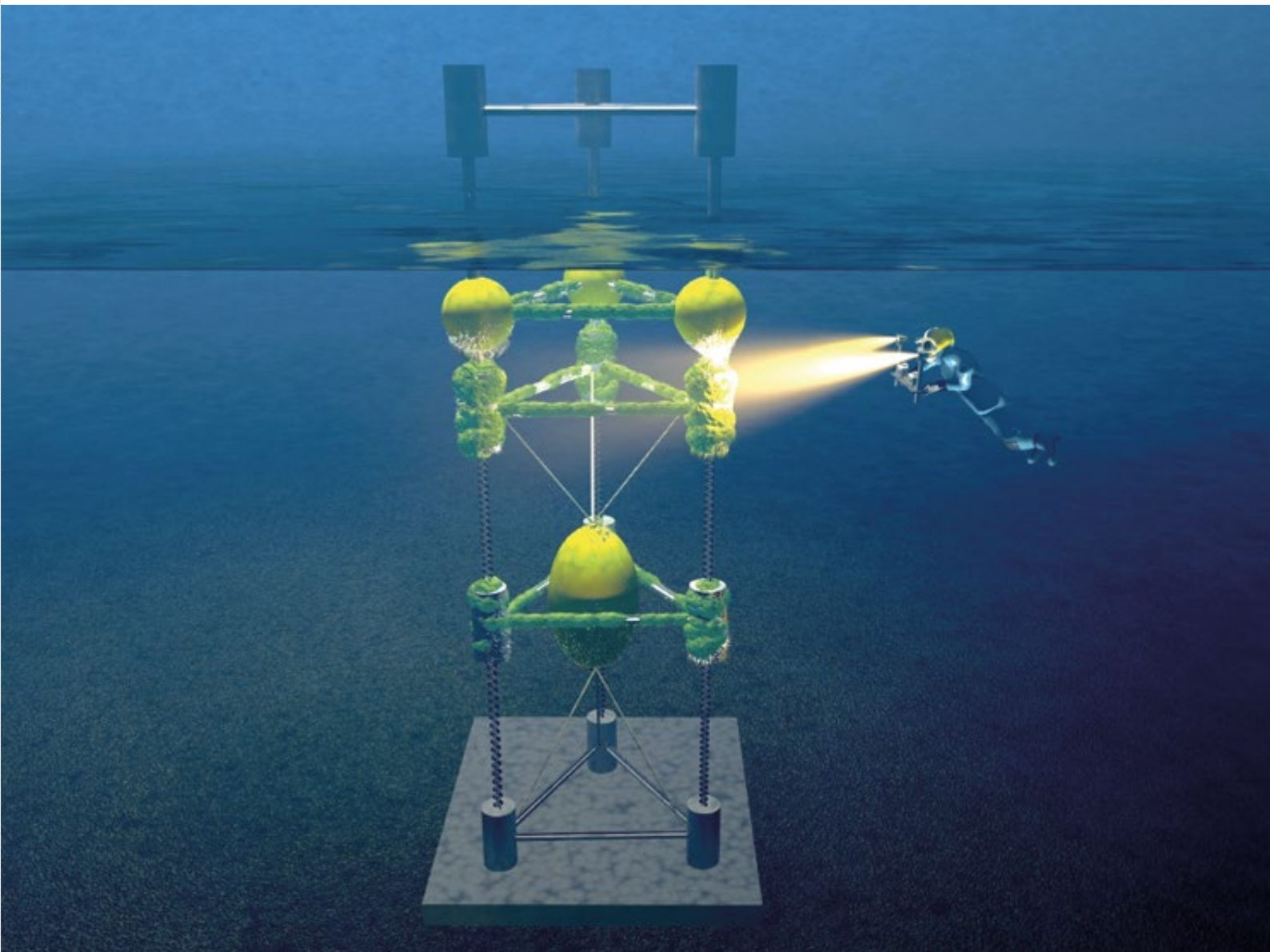


Figure 26. Assimilation of bio-colonization to a three-phase degradation model and representation by a state-dependent Gamma process: comparison with some DEB trajectories..

Figure 27. Patented Biocolmar® and its collectors analyzed within the framework of COSELMAR.



ACTION 4.3
Summer Schools

MARITIME SPATIAL PLANNING AND MANAGEMENT

From June 1st to June 5th 2015, 24 students (doctoral, post-doctoral or master 2) were selected and gathered around international experts on the topic of planning and management of maritime spaces.This summer school has relied on the Marine Spatial Planning research Network (MSPRN).

The participants

No less than 10 different nationalities for these 24 students, 2 of whom are currently studying in Nantes. They come from as varied backgrounds as Colombia, Crete, Spain, Ireland, South Africa, Germany, Italy, Portugal, India and France.

The speakers come from Portugal, France, Spain, Sweden, Germany, the United Kingdom and Ireland. thanks to Andréa MORF, Andreas KANNEN, Gillian GLEGG, Holger JANSSEN, Stephen JAY, Thomas KLENKE, Cathal O'MAHONY, Helena CALADO, Maria DE FATIMA LOPES ALVES, Juan Luis SUAREZ DE VIVERO, and Brice TROUILLET.

The program

The first afternoon was devoted to a field trip (St Nazaire, Le Croisic). The following mornings began with cross-discussions, followed by guest speaker interventions, and practical exercises closed each day.

Cross-Discussion at MSH Ange-Guépin.

Field Trip.

MICROALGAE AND SHELLFISH ECOLOGY IN COASTAL AREAS

From 1st to September 4th 2015, 16 students (doctoral, post-doctoral or master 2) were selected and gathered around international experts on the ecology of microalgae and molluscs in coastal areas.

The participants

No less than 12 different nationalities for these 16 students, 3 of whom are currently studying in Nantes. They come from horizons as varied as Tunisia, Morocco, Indonesia, Germany, Italy, Belarus, Austria, China, Scotland, Portugal, India and France.

The speakers came from Portugal, Denmark, Canada, France, Spain and the USA. Thanks to Lourenço RIBEIRO, Michaël KÜHL, Cédric HUBAS, André MALLET, Nicolas CHOMERAT, Santiago FRAGA, Philippe SOUDANT, Patricia TESTER, Romain GASTINEAU, Sébastien LEFEBVRE, Véronique SECHET, Philipp HESS, Bruno JESUS, Vona MELEDER, Laurent BARILLE, Priscilla DECOTTIGNIES and Bruno COGNIE.

The program

The mornings were devoted to theoretical lessons, while the afternoons allowed to introduce the students to advanced techniques thanks to practical laboratory work. A field trip on the last day allowed them to test their new knowledge in real conditions!

Practical Fieldwork.

Practical work in the MMS labs.

Action 4.4
Creation of a research network on toxic algae and their impacts

This action was the result of a desire to create a national dynamic on research on toxic algae, their metabolites and impacts on coastal and marine socio-ecosystems. Thus this action was in strong connection with action 1.4 on the chemical diversity of algal toxins as well as the idea of increasing the national and international impact of our federation of research through the COSELMAR project.

SUMMARY OF ACTION 4.4 CREATION OF A RESEARCH NETWORK FOR HARMFUL AND TOXIC MICROALGAE

Created at the beginning of 2014 and coordinated by Héléne Hégaret (CNRS, UMR LEMAR) and Philipp Hess (Ifremer, Laboratory Phycotoxins - Littoral Unit), the national research group PHYCOTOX "Microalgae risks to man and the ecosystem" toxic algal efflorescences and their health and socio-economic impacts.

Phycotox
Groupement de Recherche

26 research teams to create a network with complementary competences

The GDR brings together 26 French teams from different organizations, institutes or UMR: CNRS, Ifremer, ANSES, UBO, IRD, Universities of Nantes, Caen, Lille, Bordeaux, Montpellier, Institut Louis Malardé French Polynesia. The GDR involves 14 laboratories of Ifremer. The objective is to create a structured network around the competencies carried in the various teams, diversified and complementary. It is thus intended to facilitate the multidisciplinary approach.

The specific objectives of this GdR PHYCOTOX are both scientific and operational:

- Continue to structure French research on harmful and toxic algae and their toxins. This will allow us to better integrate our projects in GLOBALHAB's internationally structured approaches (2014 - 2023) and thus increase the visibility of French research on a European and international scale.
- Continue to improve interdisciplinary research in order to better prepare French teams for participation in European and international projects.
- To better understand through research the fundamental questions posed by exceptional events or by blooms of a recurring nature, with a view to:
  - Improve knowledge of the diversity and distribution of harmful and toxic microalgae on the French coastline;
  - Improve understanding of the determinism of harmful and toxic microalgae blooms, both pelagic and benthic, to identify factors that promote their proliferation and invasion in sensitive ecosystems;
  - To better understand the link between phenology and toxin production;
  - Identify and characterize phycotoxins, regulated or emerging, that present problems in France or emerge in our neighbouring countries and that could pose problems in the near future;
  - To provide new knowledge on the toxicity of the various toxins observed in metropolitan France or overseas or in adjacent marine ecosystems.
- Better identify and characterize risks to ecosystems and human health, such as:
  - Improve knowledge on the impact of phycotoxins on primary and secondary consumers and on the ecosystem;
  - Better assessment of toxin transfers within the marine ecosystem food web;
  - Through mathematical modelling, provide a better understanding of the mechanisms and factors involved in the potential health risks associated with toxic micro-algae blooms;
  - Better identify the socio-economic impact of harmful and toxic microalgal blooms.

In order to achieve these objectives, it was necessary to improve and to reinforce the interactions between the teams and with the international laboratories by encouraging exchanges and collaborations between laboratory and involving the students trained by the research. This is what the GdR has tried to do in these four years and aims to improve further in the next four years.

Activities and influence of the GDR during the period 2014-2017

This network aims to formulate research priorities and to identify future collaborations for research projects. Four annual meetings and 12 meetings of

the steering committee facilitated this process. For the 4 meetings, some 20 international personalities were invited, which made it possible to increase the visibility of the French community in this field. The creation of the website in early 2014 (http://www.phycotox.fr) made it possible to inform the 140 members and other Internet users on 52 pages on the activities of the network and the generalities concerning toxic algae. About fifteen pages have been added since. Via an email distribution list, members were informed of more than 600 news (including announcements of 10 M2 internships, 13 doctoral theses and 6 post-doctorates directly available within the network). The Governing Board of the GoR presented its candidature to the International Society of Toxic Algae (ISSHA) in October 2014 at the Symposium in New Zealand to host the International Colloquium on Toxic Algae; **this application was accepted and the ICHA conference will be held in Nantes in 2018.** The GdR has also applied for a renewal (granted by Ifremer and in progress for the CNRS).

The research network as an incubator of increased collaboration among French teams

Since 2015, nine collaborations between teams were strongly encouraged by calls for projects. These mini-projects were financed from 2,500 to 7,000 € to facilitate the purchase of consumables.

The research network as an incubator for national and international cooperation

The GdR has indeed enabled many additional projects to come into being. It has encouraged exchange and meetings that were conducive to the search for funding at the regional, national or international level, which has allowed and continues to allow all the research themes to be carried out around toxic and harmful microalgae. Some 40 projects have been proposed between the GdR teams, but also with international researchers, thanks to the different actions put in place by the GdR. Of these projects, 50% are currently underway or accepted, 20% are under evaluation, 25% have been rejected so far, but most will be re-submitted, and 5% are in progress incubation. **Ocean-15** is one of the examples of flagship national integration projects that have been set up under the GdR, bringing together three Institutes of the GoR PHYCOTOX (Ifremer / PHYC, UPMC / LOOV and Anses, Fougères) and a new partner, the GéoAzur laboratory (UMR CNRS, UNS, OCA and IRD). The Ocean-15 project aims to clarify the chemical ecology of Ostreopsis spp. Species, emerging in the Mediterranean, and the effects of the different compounds produced by these species; it uses axes 1, 2 and 4. The **CoClime** project (ERANET for climate services) is a prime example of accepted European projects. CoClime aims to anticipate the effects of climate and global changes on toxic algae, and subsequently the main sectors affected by these phenomena (shellfish farming and tourism).

INTERVIEW

Philipp Hess
Phycotoxins Laboratory, Ifremer

The proliferation of some species of unicellular microalgae, sometimes causing coloured brown, red or green tides, can be toxic to shellfish and fish. In humans, ingestion of contaminated shellfish can cause gastrointestinal or even neurological symptoms depending on the nature of the toxins. Phycotoxins (toxins derived from "algae") are produced in particular by dinoflagellates and diatoms.

Would there be as many toxins as toxic micro-algae?

No, a species (or genus) of toxic microalgae can produce several types of toxins. More than 5,000 microalgae are known, 174 of which are toxic or harmful (described in our work). It is important to monitor and predict possible blooms or blooms of the marine phytoplankton through regular monitoring and systematic analyses (implemented throughout the coastline in France and around the world) and of course to identify toxins in seawater.

We have identified more than 500 toxins (including those produced by marine cyanobacteria) globally, although the chemical structure is not yet known for

all of these molecules. However, the number of toxins observed is increasing. Indeed, the intensification of maritime transport increases the flow of "exotic" species via ballast water. Climate change and the warming of coastal waters also favour their proliferation in subtropical and temperate zones.

You are developing a new approach to toxin analysis. How is this method innovative?

The bioassay method, prior to 2011, was not very specific, mice were used as tests (to know 24 hours later if the shells were consumable). Since then, the official method of analysis is based on mass spectrometry. This quantitative method is "targeted" on molecules known for their toxicity but only on 12 molecules for lipophilic toxins.

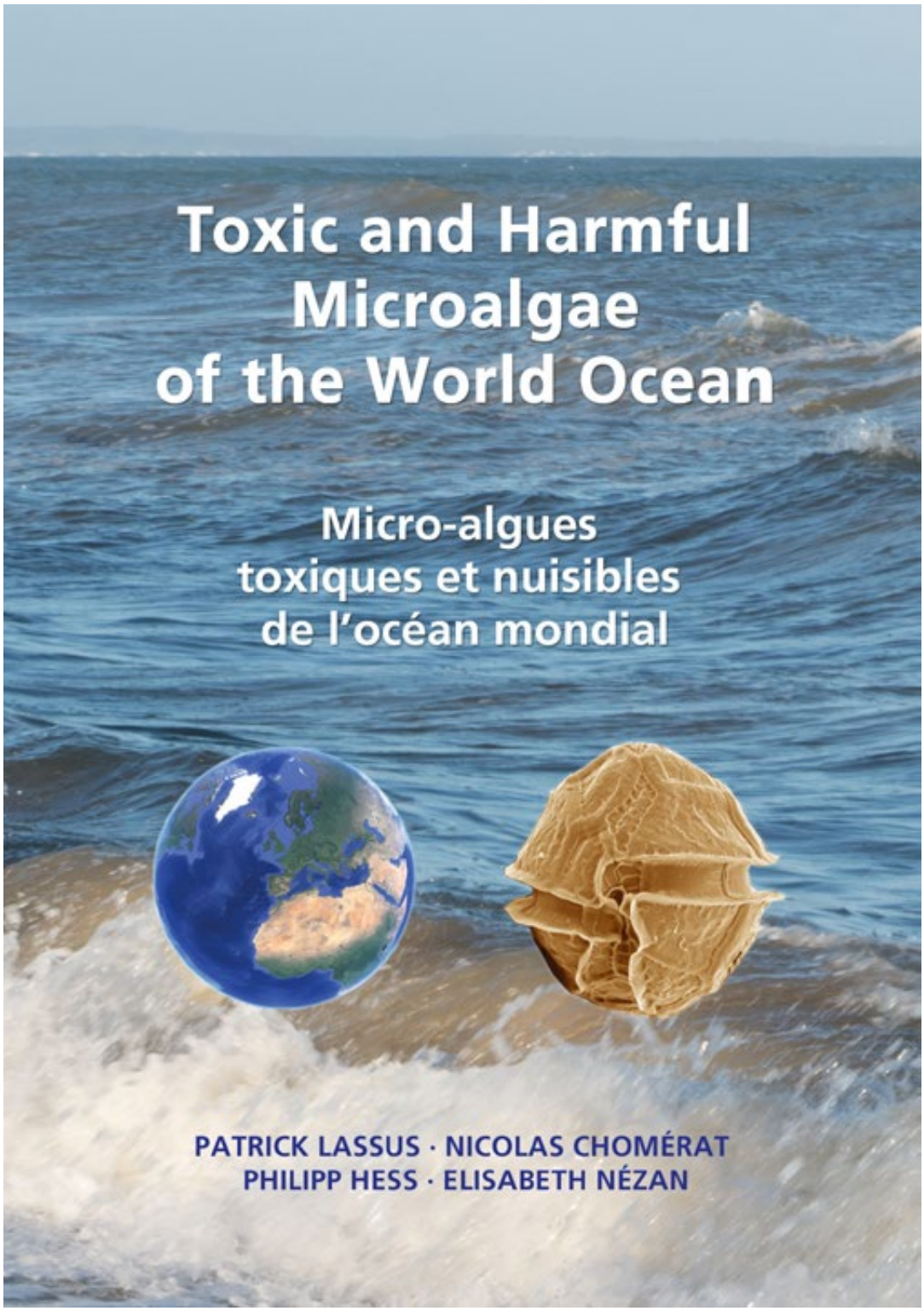
In the framework of the COSELMAR regional project, we have shown the feasibility of a new method[1] which complements the techniques of regular sea water sampling as well as this targeted analysis. We have worked on a combined approach of two techniques: passive sampling (1) and high resolution mass spectrometry (2). The first technique makes it possible to accumulate all the lipophilic compounds dissolved in seawater, a kind of "chemical imprint" left by microorganisms (including microalgae), while the second measure simultaneously a massive number of chemicals, without having to target a molecule (non-targeted analysis). We thus detect a large number of dissolved compounds and, in particular, algal toxins. Once the data was acquired, our database was screened to see if any of the 500 toxins, listed globally, would be present. We are only at the beginning of our research in this field because few metabolites produced by microalgae are known. Many other organic compounds and emerging toxins, derived from phytoplankton or cyanobacteria, remain to be discovered in marine and brackish environments.

TOXIC AND HARMFUL MICROALGAE OF THE WORLD OCEAN

With the support of the Pays de la Loire Region (via the COSELMAR project), Ifremer researchers have published a comprehensive book on toxic microalgae.

This book updates available international databases on toxic and harmful species of phytoplankton and micro-phytobenthos. It lists regional occurrences at world-wide scale: localities, cell densities, toxicity levels in contaminated animals, human and animal poisoning, isolation of identified active molecules and toxins, documentary sources. Finally, this book addresses the geographic distributions of phycotoxin-producers from recent data. The objective is to analyze the evolution of toxic and harmful episodes over the past 30 years to identify trends, and to introduce a discussion on the reality of a time-dependent increase in the number of known species and toxins.

1. Zendong Z. et al. 2016. Environ. Sci. Technol.



Toxic and Harmful Microalgae of the World Ocean / Micro-algues toxiques et nuisibles de l'océan mondial, by Patrick Lassus, Nicolas Chomérat, Philipp Hess andt Élisabeth Nézan Denmark, International Society for the Study of Harmful Algae / Intergovernmental Oceanographic Commission of UNESCO. IOC Manuals and Guides, 68 pages (Bilingual English/French) October 2016. http://www.issha.org/Welcome-to-ISSHA/Web-shop/Toxic-and-Harmful-Microalgae-of-the-World-Ocean

OCEANEXT

The multidisciplinary conference OCEANEXT, held in Nantes on 8, 9 and 10 June 2016, was a great success!

SOME STATISTICS

More than 220 registered, scientists representing laboratories in 18 different countries (South Africa, Germany, Belgium, Canada, Chile, Finland, France, Great Britain, Ghana, Ireland, Morocco, New Caledonia, The Netherlands, Norway, New Zealand, Portugal, USA), 4 plenary sessions, 14 keynote talks, 65 oral presentations, 19 flash presentations, 20 posters, 4 roundtables and 9 pairs for "3 minutes for COSELMAR!"

EXCITING PLENARY SESSIONS

Dorothy DANKEL and Transdisciplinarity, Chris BOWLER and the TARA expedition, Thierry CHOPIN and IMTA, Luc Van HOOF and foresight planning... All made us think, laugh, and dream, with their ability to address biologists, geographers, economists, sociologists and engineers.

GREAT KEYNOTE SPEAKERS

Antonio Alvarez ALONSO (CSIC, Spain), Elisa BERDALET (CSIC, Spain), Allan CEMBELLA (Alfred Wegener Institute for Polar and Marine Research, Germany) Gilbert DAVID (IRD, France), Michael DEPLEDGE (Exeter University, ECEHH, UK), Marcel JASPARS (Aberdeen University, UK), Stephen JAY (Liverpool University, UK), Darren LUMBROSO (HR Wallingford, UK), Katie LYNCH (Cork University, Ireland), Alan O'CONNOR (Trinity College Dublin, Ireland), Erik OLSEN (IMR Bergen, Norway), Koen SABBE (Ghent University, Belgium), Jean-François SASSI (CEA Cadarache, France), and Benoit SCHOEFS (University of Maine, France)... all attended and presented their work at the opening of each session.

ROUND TABLES... SMOOTHLY CONDUCTED!

Frédéric DENHEZ led the dialogue between each speaker and the public, on topics as diverse as "Infinite food supplies from the oceans?", "What is the future for offshore aquaculture?", "Challenges for Marine Renewable Energy?", and "Sharing our coasts and oceans".

A FUN AND INSTRUCTIVE POPULARIZATION EXERCISE

The nine teams of "3 minutes for COSELMAR" clearly succeeded in their objective of popularization by making us laugh and enabling each viewer to understand subjects as difficult as kleptoplastidy or metabolomics.

SOCIAL EVENTS ENJOYED

From the Ice Breaker on June 8 to the Gala Dinner on June 9, everyone enjoyed the gourmet food, the climate and the musical delights of our beautiful region of Nantes. Many contacts were made, which will no doubt lead to future regional, national and international collaborations!


Transdisciplinary Insights into
Integrated Ecosystem Assessments
What they are, what they can be, what they should be
Dorothy J. Dankel, Ph.D.
University of Bergen, Norway
Nordic Marine Think Tank
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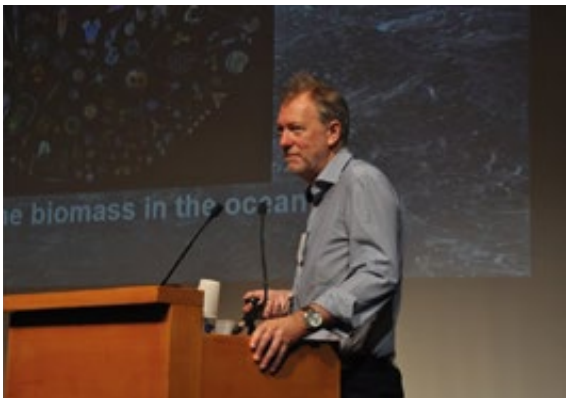
#oceanext



La websérie interactive dont des chercheurs sont les héros

LES ÉCLAIREURS
MER & LITTORAL
EMBARQUEZ DANS LE DÉFI CITOYEN

À PARTIR DU 27 AVRIL

EN TOURNÉE PRÈS DE CHEZ VOUS **GRATUIT**

27 AVRIL - Nantes
4 MAI - Les Sables d'Olonne
11 MAI - Le Croisic
18 MAI - Notre-Dame-de-Monts
1er JUIN - Nantes

EN LIGNE

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Avec le concours du journal le marin et de les Sables d'Olonne... AGGLOMÉRATION · Les Jardins de la Mer · Biotopia

Les Éclaireurs

Scientists heroes of a web-series

For once, they are not behind their microscope but behind a camera. A dozen scientists from Nantes have come together to create their own humorous web-series in the hope of making their work easier to understand.

A SHOWCASE FOR THEIR RESEARCH

Like their ironic teaser, "Les Éclaireurs" is not taken at all seriously, as explained by Sophie Pardo, scientific coordinator for the University of Nantes: "In 2013, we created a multidisciplinary project (COSELMAR) with the participation of 169 researchers and we wanted to disseminate our studies quickly and above all to popularize them. Research about the sea is carried out in collaboration with Ifremer and 17 laboratories in Nantes and Anjou."

The goal was to find "an innovative medium that caters to the greatest number. We immediately thought about the Internet and, after a few exercises, the idea of a web-series emerged," says Justine Dumay, who is part of the team that worked on the project with the help of the Nantes company, Cyanéa, specialists in audiovisual production.

FOUR INTERACTIVE EPISODES OF A FEW MINUTES

Two years of work with hours of interaction between the director, the actors and the researchers. "It was quite complex to build the dialogues but they gave us a free hand," according to Jérôme Fihey of Cyanéa. In order to make their research better understood, the scientists chose to tackle mainstream subjects.

Sophie Pardo recalls that "Important issues are highlighted in the different episodes. On the other hand, they are always connected to problems of everyday life. For example, the web-series addresses the subject of oysters and their relationship with microalgae through the issue of consumption."

MEETINGS WITH THE PUBLIC

The web-series is also interactive, that is "you can make choices during an episode to change its ending", according to Justine Dumay. Beyond the four episodes that will be available on the Internet, scientists have organized what they call "The Scouters Tour". After Nantes this Thursday evening, they will be at Les Sables d'Olonne, Croisic, Notre-Dame-de-Monts and finally again in Nantes at the beginning of June to meet the public.

In any case, they have found it "very enriching" and are already making another.

From an article in the online newspaper *20 minutes* (http://www.20minutes.fr/nantes/2058155-20170427-video-nantes-chercheurs-heros-web-serie).

COSELMAR

www.coselmar.fr

leseclaireurs.coselmar.fr

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