PREDHYPO
Predicting hypoxia events in coastal waters
Benthic dynamic as the missing link

Application to A*Midex Interdisciplinarité-PR2I
Call 2014 - Dr Olivier RADAKOVITCH

I/ Acronym of the project: **PREDHYPO**

II/ Title of the project: **Predicting hypoxia events in coastal waters: benthic dynamic as the missing link**

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MIO-UMR7294, AMU

IMBE-UMR7263, AMU

IRPHE-UMR6594, AMU

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V/ Involved P2RI: **Environment**

VI/ Concerned disciplinary fields : **Geochemistry, Microbiology, Ecology, Physics, Modeling**

VI/ Requested funding for 2 years: **325 k€**

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1. SUMMARY

The inflows of Nitrogen and Phosphorus to the environment have increased as a result of rising intensive agriculture, industrial activities and population growth. The consecutive water enrichment with nutrients results in explosive proliferation of noxious algae and a drop of water oxygen (hypoxia) which destroy aquatic life in affected areas. A total of 415 areas worldwide are affected by hypoxia and the best known cases are the dead zones in the northern Gulf of Mexico and the Baltic sea.

If the consequences of hypoxia are known, its origin is often unclear, between locally controlled by physical and/or biological processes (altered hydrodynamics and eutrophication), remotely controlled (global change) or due to natural variability. In the coastal zone, sediment is a huge reservoir of organic matter (OM) and oxygen the primary oxidant used by microbial community for aerobic OM mineralization. As a result sediment is the most important sink for oxygen of the water column and a compartment largely responsible for hypoxia in the water column.

The objective of PREDHYPO is to **explore the processes and interactions controlling the oxygen and nutrient transfers within benthic coastal ecosystems submitted to episodes of hypoxia**, through 1) the characterization of the geochemical, microbiological and macrobenthic dynamics in the benthic compartment in response to changes in oxygenation conditions in the water column and 2) through the evaluation of the transfer of oxygen and nutrients to the sediment-water interface resulting from these dynamics by considering transport processes both in sediments and in the water column. The final aim is to adapt a diagenetic model able to predict the evolution of processes and fluxes under variable oxygen concentrations in the water column, and to construct a benthic-pelagic coupled biogeochemical model able to predict the dynamic of hypoxia in the water column.

The strategy will associate both experimental and modeling approaches. Field (in a coastal site impacted by hypoxia) and laboratory (mesocosms in oxygenation controlled conditions) experiments will provide quantitative data on the interactions between oxygen water column concentrations and the geochemical composition of sediments (Task 1), the structures and activities of microbial (Task 2) and macrobenthic (Task 3) communities, the hydrodynamics in the water column and the small scale turbulence at the sediment water interface (Task 4) and the resulting total chemical fluxes at the sediment-water interface (Task 5). The data obtained will be integrated into a diagenetic model in non-stationary conditions able to predict the fluxes of chemical species at the sediment-water interface in response to change in oxygen contents in the water column (Task 6). Finally, a coupled benthic-pelagic model will be developped (Task 7) by connecting the model from Task 6 to an existing circulation model based on hydroclimatic forcings in order to predict the initiation, expansion and duration of hypoxia events. The proposed study site is the Etang de Berre, a typical Mediterranean lagoon submitted to intermitant hypoxia despite the significant management efforts provided for remediation. PREDHYPO will face important socio-economic and ecological challenges and results will be exported to other Mediterranean threatened coastal sites.

2. CONTEXT, INTERDISCIPLINARY POSITION AND OBJECTIVES OF THE PROJECT

2.1. SCIENTIFIC CONTEXT : HYPOXIA EVENTS IN THE COASTAL ZONES

The health of aquatic ecosystems and the associated functions and services they provide for the humankind benefits directly depend on the oxygen concentrations. Dissolved oxygen concentrations in aquatic environments depend on a tight balance between its physical inputs (water mass transport and mixing, water-atmosphere exchanges), biological production (i.e., photosynthesis) and its removal processes (biological respiration and chemical reactions; Zhang et al., 2010). In coastal environments, the enhanced productivity coupled with water column stratification induce that the removal of oxygen often exceeds its inputs, and dissolved oxygen concentrations tend to be lower than the saturation concentrations. Aquatic organisms start to be affected when dissolved oxygen concentration drops below 63 µM (defined as hypoxia) but can go up to aquatic organisms mass mortality if oxygen almost completely disappears (i.e., anoxia) leading to "dead zones" formation, with large ecological and socioeconomic impacts (Rabalais et al., 2002).

Although hypoxia can naturally occur, this phenomenon is widely promoted and amplified with anthropogenic (increased in nutrients and organic matter inputs, i.e., eutrophication) and hydroclimatic (temperature increase, decrease of oxygen solubility, stratification of the water column) forcings (Naqvi et al., 2000; Middelburg and Levin, 2009; Pena et al., 2010; Rabalais et al., 2010; Friedrich et al., 2013). The number and surface of coastal areas affected by hypoxia increased at a global scale during the last decades (Diaz and Rosenberg, 2008) and will likely increase again in the next century (Keeling et al., 2010). Recently, more than 400 coastal zones affected by hypoxia have been identified, representing an area of ~250,000 km^2 (Diaz and Rosenberg, 2008). In addition, the large majority (~ 92%) of these coastal hypoxia are characterized by a strong temporal variability, from hours to seasons (Diaz and Rosenberg, 2008) in conjunction with local and/or regional variability (Naqvi et al., 2000; Kemp et al., 2005; Conley et al., 2007; Rabalais et al., 2010; Scholz et al., 2011; Friedrich et al., 2013). However, the driving processes leading to the apparition, intensity and disapareance of hypoxia are not well constrained and remain so far, unpredictible.

In coastal areas, where the water column height is relatively reduced, the water column and sediment are tightly coupled and biogeochemical processes taking place in one compartment strongly influence the other through chemical exchange at the sediment-water interface (Soetaert et al., 2000). As coastal sediment is a huge reservoir of organic matter (OM), and oxygen is the primary oxidant used by microbial community for aerobic OM mineralization and reduced species oxidation in surface sediment (Froelich et al., 1979), sediment is known as the most important sink for the oxygen of the water column in coastal zones (Glud, 2008). Consequently, biogeochemical processes occurring in surface sediment are often the main starting processes leading to the hypoxia event in the water column.

However, accounting for the role of sediment biogeochemical processes on the occurrence of hypoxia is particularly complex. Indeed, water column and sediment interactions during hypoxia have many synergistic consequences in coastal ecosystems. During hypoxic events, the release of nutrients (NH_4^+, PO_4) produced in the sediment to the water column is favored (Rigaud et al., 2013; Friedrich et al., 2013), and this can promote the surface water productivity and cause a positive feedback in maintaining eutrophication and hypoxia in the water column (Conley et al., 2007; Kemp et al., 2009). The accumulation of reduced species in the water column and porewaters, as well as the accumulation of labile OM in surface sediments may cause an "oxygen debt" of the benthic system resulting in a higher benthic oxygen demand in bottom water leading to the maintenance or the intensification of hypoxic conditions (Morse and Eldridge, 2007). The modification of oxygen concentrations in the water column also directly impact the macrobenthic communities (Diaz and Rosenberg, 1995; Gooday et al., 2009; Levin et al., 2009; Riedel et al., 2012) involved in bioturbation processes (sediment reworking and bioirrigation), and this could modify the rates of biogeochemical reactions in surface sediment and the nature and magnitude of chemical exchanges at the sediment-water interface (Middelburg and Levin, 2009). In addition, the release of toxic species (NH_4^+, H_2S and contaminants) under hypoxic conditions from the sediment to the water column (Rigaud et al., 2013) can also greatly impact the water quality and benthic communities, thereby limiting or preventing bioturbation processes.

Thus, sediment appears as a main compartment responsible for the hypoxia in the water column: the hypoxia in the water column will induce changes in biogeochemical processes in sediments, which will in turn intensify the hypoxia in the water column. Predicting the hypoxia in coastal areas imply thus to precisely characterise the dynamic interactions between the biogeochemical cycles in the benthic ecosystems and changes in oxygen concentrations in the water column. This highlight the benthic compartment as a key compartment, which constitute the missing link to understand and predict hypoxia events.

2.2. INTERDISCIPLINARY POSITION

Coastal hypoxia is thus a very complex phenomenon with several interconnected causes and consequences. A genuine quantitative prediction of the hypoxia occurrence will necessarily involve the use of predictive biogeochemical models at unsteady state coupling benthic and pelagic processes. Such model will have to incorporate the reactions of the microbiologically mediated geochemical reactions (OM mineralization, redox reactions), physical transport processes (advection and diffusion) and a module able to predict the evolution of biological transport (bioturbation) in response to changes in oxygenation in the water column. The parametrisation of such a model can be achieved only by coupling several disciplinary mechanistic approaches. Interdisciplinarity is thus the framework of the PREDHYPO project. It will create for the first time a synergy between geochemists, microbiologists, benthologues, physicists and modellers around coastal hypoxia with the final and primary objective to produce quantitative parameters necessary to construct such a predictive model.

2.3. OBJECTIVES

PREDHYPO is dedicated to define all the processes and interactions controlling the oxygen and nutrients transfer within benthic coastal ecosystems subject to episodes of hypoxia. The main objectives are:

1) to **characterize** the geochemical, microbiological and macrobenthic dynamics in the benthic compartment in response to changes in oxygenation conditions in the water column,

2) to **evaluate** the transfer of oxygen and nutrients to the sediment-water interface resulting from these dynamics by considering transport processes both in sediments and in the water column,

3) to **adapt** a diagenetic modeling able to predict the evolution of processes and fluxes under the influence of varying oxygen concentrations in the water column,

4) to **construct** a benthic-pelagic coupled biogeochemical model able to predict the dynamic of hypoxia in the water column.

3. SCIENTIFIC AND TECHNICAL PROGRAM, PROJECT ORGANIZATION

3.1. SCIENTIFIC PROGRAM AND PROJECT STRUCTURATION

The proposed strategy to reach these objectives associates both experimental and modeling approaches. PREDHYPO is structured with seven "disciplinary" tasks (Figure 1). The first five tasks constitute the experimental approach that will provide all quantitative data on the interactions between oxygen concentrations in the water column and the geochemical composition of sediments and water column (Task 1), the structures and activities of microbial (Task 2) and macrobenthic (Task 3) communities, the hydrodynamic processes at different scales (Task 4) and the resulting total chemical fluxes at the sediment-water interface (Task 5). These areas will be addressed in parallel during in-situ (in a coastal site impacted by hypoxia) and laboratory (mesocosms in oxygenation controlled conditions) experiments. The data obtained will be integrated into a diagenetic model in non-steady conditions able to predict the fluxes of chemical species at the sediment-water interface in response to change in oxygen contents in the water column (Task 6). This model will thus integrate the oxygen concentrations in the water column as an upper limit variable condition, the physical transport processes (molecular and turbulent diffusion, advection) and biological (sediment reworking, bioirrigation) as well as all biogeochemical reactions in the sediment. Finally, a coupled benthic-pelagic will be developped (Task 7) by connecting the previously contructed diagenetic model from Task 6 to an hydrological model based on hydroclimatic forcings already existing. The coupled model will be able to predict the apparition, intensity and duration of the hypoxia events. Each task is individualy described in the following section.

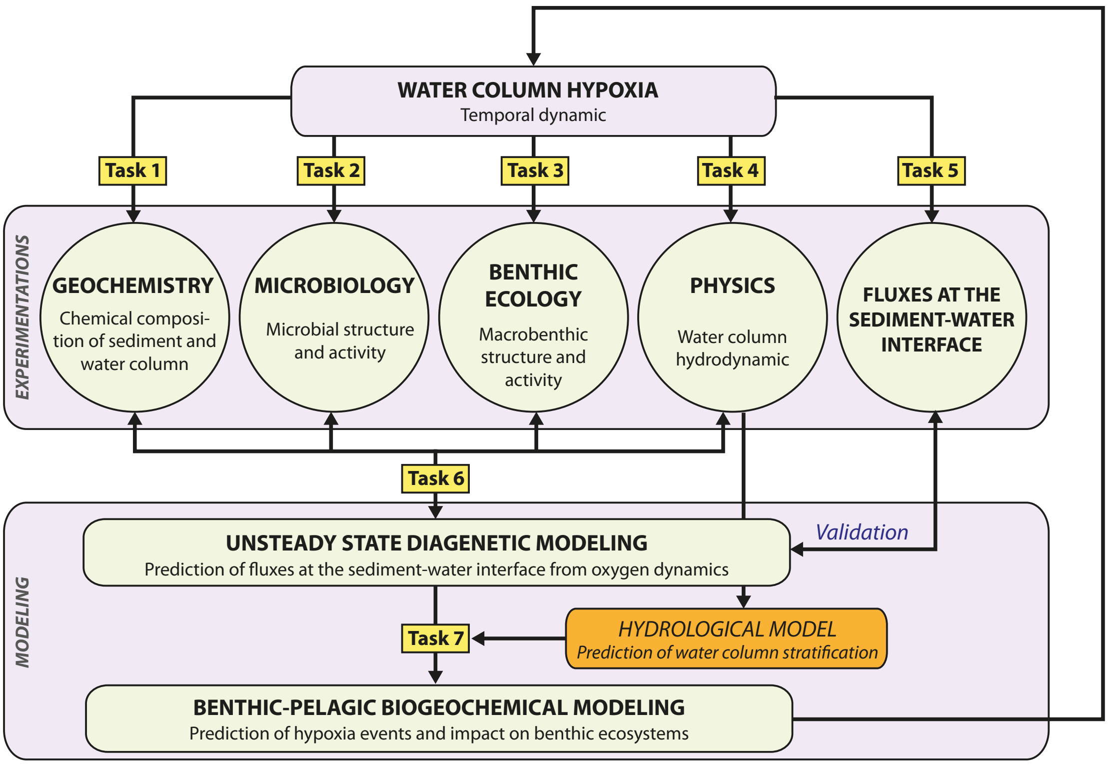

Figure 1: General structuration of the PREDHYPO research project

3.2. STUDY SITE: A DISTURBED MEDITERRANEAN LAGOON

The site chosen for the project is the Berre lagoon, a Mediterranean lagoon with national and international socio-economic and ecological issues. Like many other Mediterranean coastal areas (Sardigna, Spain, Italy, Tunisia), this lagoon has been strongly affected by eutrophication and is still impacted by hypoxia events. In this area, hypoxia events are especially favored by the stratification of the water column generated by discharges of fresh water from a hydroelectric power plant (Nerini et al., 2000). These events show different temporal dynamics depending on the area in the lagoon. The magnitude, duration and frequency of hypoxia are the highest during the summer months, when the oxygen solubility is low, the primary activity is maximum and the wind stress minimum. It is also more important in the deepest part of the lagoon. This temporal and spatial variability of the hypoxia generates a strong gradient in macrobenthic populations that are absent in the deepest areas, in relatively good condition close to the shore and degraded in the intermediate zones (Gipreb, 2009; Figure 2). It is therefore an ideal natural laboratory to study the processes leading to hypoxia occurrence and their impact on the lagoon ecosystem.

The data obtained from experimental approaches and subsequent modeling within the PREDHYPO project will provide a solid understanding of the processes responsible for the eutrophication and related hypoxia on the degradation of the benthic communities in the Berre lagoon, and will propose adjustments of possible management of this environment, which will therefore be directly extrapolated to other Mediterranean coastal sites.

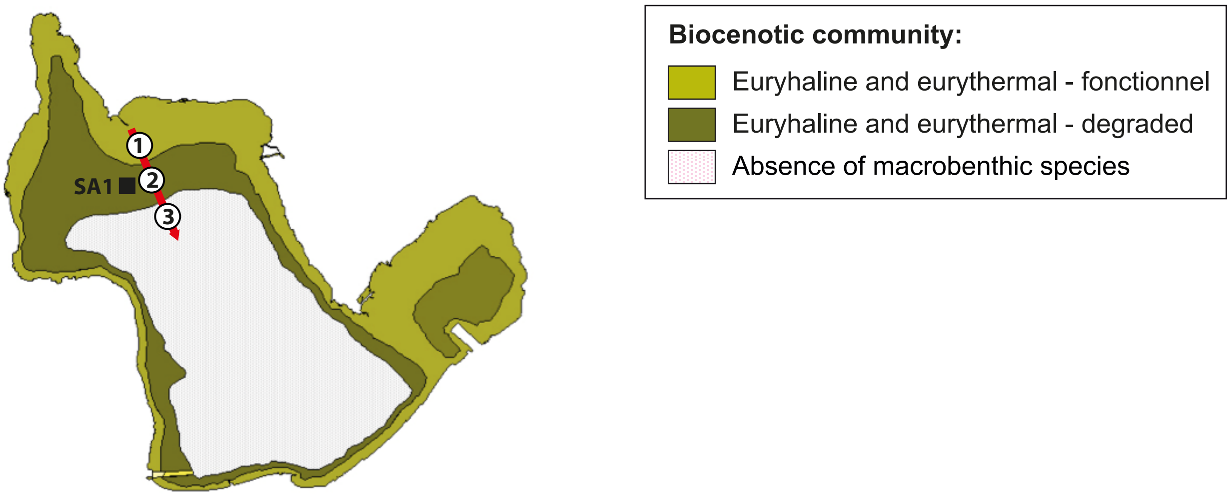

Figure 2: Distribution of benthic community in the Berre lagoon (GIPREB, 2009). Their status (functional, degraded or absent) is associated with frequency, intensity and duration of episodes of increasing hypoxia. The three sites proposed overlap these different levels of ecological communities and thus are experiencing an increasing gradient of hypoxia forcings (red arrow). The SA1 station (black square) is an automatic monitoring station already existing.

3.3. LABORATORY EXPERIMENTAL APPROACHES

To isolate the specific role of oxygen on the dynamics of sediment geochemistry, microbiology and benthology processes, and associated fluxes at the sediment-water interface, a mesocosm allowing the control of oxygenation conditions will be build and used during the first year of the project. Several sediment cores will be incubated under different oxygenation status of the water column and for different durations at in situ temperature. This mesocosm system will be an improved version of a previous one successfully used at CEREGE laboratory. The proposed experiments will allow continuous flow of fresh seawater (the experiment will be done at the MIO facility at Endoume) at in situ temperature in the overlying water with 100 %, 50 %, 15 % and 0 % oxygen saturation controlled by bubbling air-N_2 mixture before flowing through the cores (Figure 3). The flow of seawater in the overlying water of each core will prevent the accumulation of chemical species over time while the overflow will escape through a hole in the cap. For each condition, four cores will be considered:

- one core (ME) will be used to measure high vertical resolution of O_2 and H_2S concentrations profiles over time (Task 1),

- three cores (C) will be used to follow the temporal evolution of the fluxes at the sediment-water interface by regularly collecting and analysing the chemical composition in the overlying water before and after 2 hours of incubation (by stopping the flow of fresh seawater and hermetically closing the hole in the cap; Task 5). During the whole core incubation, O_2 concentration will be continuously monitored using microelectrodes and mixing will be assured using magnetic steerers. The cores will be taken successively (1 week, 2 weeks, 4 weeks), sliced and centrifugated in order to measure the vertical evolution of chemical species in the dissolved and solid phase of sediment over time (Task 1). Aliquot of these cores will be collected to determine the bacterial activities associated with nitrogen cycling taking into account aerobic process such as nitrification and anaerobic ones with denitrification, nitrate ammonification and anammox by using istopic approaches recently developped at MIO. The impact of oxidation levels on the production of N_20 (a greenhouse gas), on the balance between denitrification (net loss of nitrogen for the ecosystem) and nitrate ammonification (maintaining nitrogen available for the food chain) as well as on the coupling between nitrification and denitrification will be investigated (Task 2). Moreover, the actors responsible of these processes and their active part will be quantified and the composition of the microbial community described (Task 2).

In addition, five cores (D_{1-5}, not represented here) will be used to assess temporal changes in bioturbation processes (both particles and porewater transport) over three water column oxygenation (100, 50% and 0% saturation, 15 cores in total, Task 3). At the end of the experiments, three of these cores will be sliced to derive vertical profiles of particle tracers and estimate sediment reworking rates. The two other will be incubated for 48h after addition of a dissolved tracer in the overlying water to estimate bioirrigation rates.

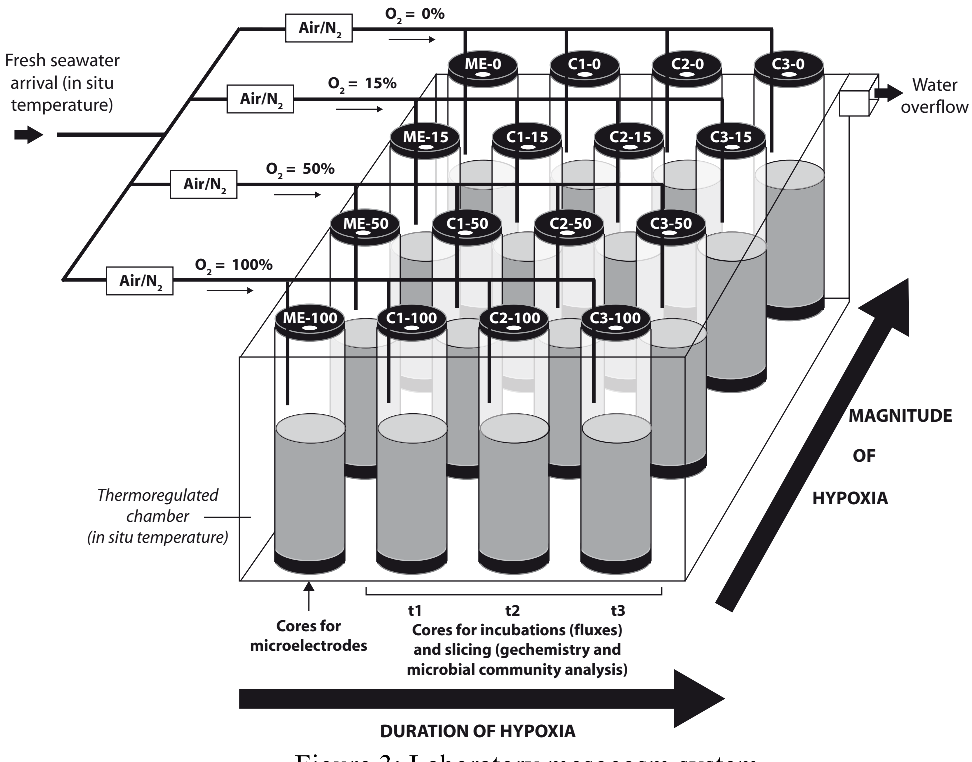

Figure 3: Laboratory mesocosm system

The sediment cores for this experiment will be collected in Site 1 (Figure 2) with initial well oxygenated water and functionnal benthic community. This experimental approach will allow to simultaneously follow the influence of the duration and magnitude of hypoxia on geochemical, micro- and macrobiological dynamics as well as the corresponding fluxes at the sediment-water interface.

In parallel to this large experiment, another set of cores will be used to characterize the role of turbulence on oxygen exchanges (see description in Task 4).

3.4. IN SITU EXPERIMENTAL APPROACHES

The in situ experiments will be conducted during the first and second year of the project. All in situ experiments will be done using RV Antedon and zodiac inflatable boats from the CEREGE and GIPREB and with the help of certified scuba divers from GIPREB. They will be achieved in the northern area of the lagoon, where the concentration of oxygen strongly fluctuated over time with the largest amplitude. Two complementary approaches will be carried out: 1) short surveys (one week) to look at the seasonal fluctuation of hypoxia a 2) a long-term survey (2 weeks) to look at the spatial influence of hypoxia gradient.

In situ survey over short-term and seasonnal temporal fluctuation of hypoxia

This approach, will be essentially carried out in the station 2, where the amplitude of the oxygen fluctuation is the highest. To evaluate the impact of short-term fluctuation of hypoxia on geochemistry (Task 1) and fluxes at the sediment-water interface (Task 5), microprofiler systems and currentmeters will be deployed for one week to follow total oxygen fluxes at the sediment water interface, the vertical and temporal dynamic of O_2 and H_2S in surface sediment and benthic turbulence (Task 4). Benthic chambers will be also deployed daily in order to obtained total chemical species fluxes above the sediment-water interface in relation to change in water column oxygen contents (Task 5). These one week survey **(OWS)** will be made four times during the project to get the seasonnal evolution of benthic chemical fluxes. They are essential for calibrating the diagenetic model (Task 6) on effective measured fluxes.

The continuous survey of O_2, temperature and salinity in the bottom water column over the complete field campaigns will be obtained from specific in situ autonomous probes deployed with emerged structures. The history of hypoxia and water column stratification over the weeks preceding the field campaings will be obtained from continuous measurements of O_2, temperature and salinity at three depth in a closeby permanent monitoring station (SA1 station, Figure 2).

In situ survey over a spatial gradient of hypoxia

The precise description and understanding of chemical fluxes exchanged between sediment and water column will be obtained through a more detailed campaign of two to three weeks **(TWS)** performed in the second year of the project. Three stations will be investigated according to a gradient from low, intermediate to high hypoxia conditions (Station 1, 2 and 3, respectively; Figure 2). This whole area is under the direct influence of the suspended material deposited from the hydroelectric channel and is constituted by geochemically homogeneous fine grained sediment (Rigaud et al., 2011). This will allow the direct comparison between the three sites for both geochemistry and benthic fauna, while the differences will be only associated to hypoxia related phenomenon.

Several experiments will be carried out conjointly on the three sites during the TWS, that will be done in summer, period where the hypoxia events are the most important:

1) O_2, pH and H_2S profiles at the sediment-water interface will be obtained using the microprofiler deployments (Task 1).

2) Sediment cores will be collected and a special device (SUSANE, see description in Task 1) will be deployed to get the vertical profiles above and below the sediment-water interface of the main dissolved and particulate species involved in the biogeochemical cycles.

3) Sediment cores will be collected for structure determination of microbial community and will be incubated to determinate their activity (Task 2).

4) Surface sediments will be collected using a grab sampler for macrobenthic density and specific diversity while associated bioturbation processes (i.e. bioirrigation and sediment reworking) will be assessed through both in situ and laboratory experiments. (Task 3).

5) The bottom water advection and turbulent diffusion rates will be assessed using ADCP while the vertical distribution of temperature, salinity and oxygen over the complete water column will be measured using probes (Task 4).

6) An Eddy covariance system and benthic chambers will be deployed to obtain the total oxygen and chemical species and fluxes effectively exchanged at the sediment-water interface (Task 5). This technic requires sufficient horizontal current near the bottom, and the existence of such currents will be tested during the OWS. These "real" fluxes derived will be used to calibrate those calculated from vertical profiles in the pore water (sediment cores) and bottom water column (SUSANE, Task 1) using the diagenetic modeling (Task 6) that will account for molecular diffusion, bioturbation transport in the sediment (Task 3) and turbulent diffusion measured in the water column (Task 4).

3.5 DETAILED DESCRIPTION OF THE WORK ORGANISED BY TASKS

3.5.1. TASK 1 – GEOCHEMISTRY

Principle project partners/ collaborators:

AMU: O Radakovitch, (CEREGE); C. Grenz, (MIO).

External: B. Deflandre, P. Anschutz (EPOC)

This task will establish the interactions between oxygenation conditions of the water column and geochemical composition of sediments and water column. This implies the measurement of vertical profiles of physicochemical conditions (temperature, salinity, pH) and the chemical composition of water (interstitial and bottom of the water column) and solid phase of sediments, with tools adapted to the spatial and temporal scales studied. This approach will allow us to evaluate the temporal evolution of main reactants involved in early diagenesis reactions under different magnitude and duration of hypoxia in the water column imposed during laboratory experiments or encountered during in situ campaigns.

First, profiles at submillimeter vertical resolution at the sediment-water interface (in-situ and lab. exp.) will be achieved by the use of potentiometric microelectrodes for pH and Eh and amperometric microelectrodes for O_2 and H_2S mounted on a autonomous in-situ microprofileur with a horizontal translator (EPOC). For in situ long-term deployment (>1 week), the profiling frequence will be programmed to take into account the changes in oxygenation conditions in the water column (higher the oxygen concentration change in the water column, higher the profiling frequence).

Samples of solid phase and porewaters at vertical centimeter scale resolution will be obtained from sliced and centrifuged sediment cores (in-situ and ex-situ experiments) under nitrogen atmosphere to avoid oxidation of reactive reduced species. Water samples from the bottom of the water column will be obtained at centimeter vertical resolution by the use of SUSANE (SUprabenthic Sampler for Nearshore Environments), a prototype system developed at Ifremer (Radford-Knoery et al., 2007). The chemical analysis (NO_3^-, NO_2^-, tCO_2, PO_4, NH_4^+, metals (Fe and Mn), $\sum CO_2$, SO_4^{2-} and H_2S) will be distributed between CEREGE, MIO and EPOC. Analysis of the particulate phase will include total organic and inorganic carbon (TOC and TIC), total organic nitrogen (TON) as well as total S, P, Fe, Mn after complete sediment acid digestion. The reactive Fe and Mn oxy-hydroxides particulate fraction and associated species (i.e., PO_4) will be obtained by selective extractions by ascorbate (Kostka and Luther, 1994).

In addition, physicochemical parameters (temperature, salinity, oxygen) vertical distribution over the complete water column and temporal evolution in the bottom of the water column will be continuously monitored using in situ autonomous probes in order to get information on the vertical distribution of the conditions in the water column.

The coupling between these sampling/measuring tools will allow to get a continuity in the vertical distribution of dissolved chemical species over and below the sediment-water interface and over time, in association with the observed dynamic of the oxygen concentration in the water column. The dissolved concentrations profiles obtained will be used to estimate the flux at the sediment-water interface (Task 5) by using transport-reaction vertical modeling, integrating both biological (Task 3) and physical (Task 4) transports rates in the porewater and the bottom of the water column. In the meantime, task 2 will provide informations on the associated microbial reactions occuring in the sediment in terms of temporal change and intensity.

3.5.2. TASK 2 - MICROBIOLOGY

Principle project partners/ collaborators:

AMU: P. Bonin and V. Michotey (MIO); P. Mirleau (IMBE).

The main objective of this task is to measure the effect of O_2 depletion on microbial diversity and activity in the surface sediment (10-15 cm top layer of the sediment column) with an particular interest to the aerobic/anaerobic interfaces and area submitted to oxygen fluctuation. It will be implemented by a consortium of microbiologists to simultaneously conduct comprehensive studies on the global bacterial activities and study in detail the structure of the functional microbial communities in terms of effective and phylogenetic diversity.

MIO is one of the leader laboratories on the study of the nitrogen cycle in the marine environment and in particular on the dissimilative processes and the coupling between aerobic and anaerobic processes (nitrification/denitrification). Bacterial activities associated with nitrogen cycling (one of the major oxidant in the sediment porewater under anoxic conditions) will be measured by the method of isotopic labeling recently developed in the laboratory. This technique is very promising to quantify all the processes (nitrification, denitrification, nitrate ammonification and anammox) on the same sample (Minjeaud et al., 2008) and to determine the origin of denitrified nitrate: from the coupling with nitrification or exogenous nitrate. Furthermore, we propose to quantify by using qPCR the different actors involved in the nitrogen cycle by targeting functional genes quantified in routine in our lab (nar, nosZ, nrfA, bacterial/ archaeal amoA and hzo for nitrate reducers, denitrifiers, nitrifiers and anommoxifiers, respectively) and their active part with RT-qPCR on RNA extracts.

Microbial diversity will be characterized (IMBE) by using barcode sequençing (Illumina) with various primer pairs, allowing to span large microbial taxonomic spectra that compose microphytobenthic biofilms (Mc Kew et al., 2013). Specifically, the V3-V4 hypervariable region of the procaryotic 16S rDNA will be used to assess bacterial diversity (Gottel et al., 2011 ; Vasileiadis et al., 2012) and primers targeting the 18S rDNA will be used to asses microeucaryote diversity (e.g. Pniewski et al., 2010). Real-time quantitative PCR methods will be also used to determine bacterial density and relative proportion of denitrifier (Henry et al 2006), sulphate reducer (Stubner, 2004) and metanotrophs (Kolb et al., 2003). Bioinformatic analysis will consist of (i) taxonomic affiliation and phylogenetic reconstruction based on available web-tools such as CLOTU (Kumar et al. 2011), (ii) microbial structure determination and (iii) multifactorial analysis of correlation with physiochemical factors. The microbiological proxies obtained will be directly implemented for the parameterization of the biogeochemical model.

All these analyses will be done during the ex-situ experiments for which the environment is totally controlled. The sediment cores corresponding to three oxygen conditions (100, 50 and 0%) will be sliced and five depths will be studied, with triplicate sampling. A specific sampling will be adapted for the in-situ experiment, but the strategy will be discussed in relation with the first results of the mesocosms.

3.5.3. TASK 3 – BENTHIC ECOLOGY

Principle project partners/ collaborators:

External: O. Maire (EPOC); N. Mayot (GIPREB)

The biological mixing of the sediment column resulting from benthic fauna activities (i.e., locomotion, feeding, burrowing and dwelling construction) is commonly referred to as bioturbation. This process includes both the transport of sediment particles (sediment reworking) and porewater solutes (bioirrigation). It is one of the major processes affecting the structure and functioning of the benthic compartment (Aller 2014). Through bioturbation, benthic infauna deeply controls the transfer and the mineralization of organic matter at the sediment-water interface and thus affects nutrient cycling, a factor of primary importance for the eutrophication of the water column.

This task will characterizes and quantifies bioturbation processes induced by benthic fauna communities at different O_2 concentrations in order to assess/predict the impact of O_2 depletion on biologically-mediated sedimentary processes. Overall, two main methodological approaches will be used to achieve the objective. An *in situ* approach will be conducted in year 2 to assess the spatial and temporal variability of bioturbation rates in relation with O_2 concentration in the water column. Two days before the beginning of the experiments, five PVC cores will be carefully pushed into field sediments where they will be let for several days depending on sediment reworking intensity. At the beginning of the experiment *per se*, a known amount of luminophores (i.e., natural sediment particles covered by a thin layer of paint fluorescing under u.v. light) will be gently spread by scuba divers at the sediment surface of each core using a Pasteur pipette. At the end of the experiments, sediment cores will be removed from the field, brought back to the laboratory, frozen (-20°C) and sliced (0.5 cm thick sections down to 5 cm depth and 1 cm thick sections down to 10 cm depth). Each slice will be photographed under u. v. light and analysed with a specifically designed image analysis software to derive vertical depth distributions of luminophores. Luminophore profiles will then be fitted with a biodiffusive mathematical model to estimate sediment reworking rates.

However, one of the main limitations of in-situ bioturbation study deals with the strong spatial heterogeneity of benthic fauna communities. Particularly, large organisms inducing high sediment reworking rates are very often patchy distributed and thus rarely captured with small (e.g. 10 cm diam.) sediment cores. Bioturbation rates may thus be strongly underestimated and variables between cores, even at small spatial scales, depending on which species have been randomly collected in each enclosure. To overcome this drawback, ex-situ experiments will also be carried out, allowing for the direct measurement of the effects of hypoxia on benthic fauna bioturbation activity. Fauna will be first collected with a grab over a large sediment surface and then *a posteriori* introduced, at field densities, in sediment cores filled with defaunated sediment. After a few days of acclimation and stabilisation of oxygen conditions (see 3.4), sediment reworking will be quantified using the same methodology with luminophores.

Simultaneously, bioirrigation rates will be quantified using fluorescein, an artificial dissolved conservative tracer (Meysman et al. 2007). A few ml will be injected in the overlying water at the beginning of the experiments. Once added in the overlying water, the dissolved tracer passively mixes to porewater by diffusion and actively through bioirrigation activity. Temporal changes of fluorescein concentration in the overlying water will be continuously monitored with fluorimetric probes (Cyclops-7, Turner Design). Bioirrigation rates will be then calculated by using a mathematical model to fit the decrease of fluorescein concentration over time.

3.5.4. TASK 4 - PHYSICS

Principle project partners/ collaborators:

AMU: L. Pietri (IRPHE) , M. Amielh (IRPHE), S. Meulé (CEREGE)

The main objective of this task is to characterize the hydrodynamics in the water column few centimeters above the sediment in order to asses its influence on the O_2 vertical distribution. The large scale hydrodynamics has obviously an influence on hypoxia by mixing the water column (through wind) which favors the recharge of oxygen through atmosphere-water column exchange. In contrast, low current near the bottom will favor the decrease of oxygen by biological reactions. However, the small scale currents just over the sediment interface appear to have an important role on the fluxes. First, the eddy (turbulent) diffusion over the bottom will have an infuence on the concentration gradients and thus on the intensity of exchanges between water and porewater. Second, the thickness of the diffusive boundary layer (the microlayer above the sediment through which molecular diffusion is the dominant mode) has also an influence on oxygen fluxes and aerobic mineralisation (Kelly-Gereyn et al., 2005). Up to now, no work has been done on the possible influence of these small-scale currents above the sediment and thus on the vertical fluxes of dissolved species at the sediment-water interface. The characterization of the hydrodynamics at such a scale is a technical challenge for in-situ measurements that will provide new information on these interfacial processes. In situ measurements and incubation experiments will be conducted for that. In situ data will help to validate numerical modeling (task 7) and to compare tentatively field measurements with physical experimentations.

In situ surveys:

The measurements are dedicated to characterize the currents and turbulence above the bottom during the surveys. Weather observations from Marignane airport and other local stations will give the local meteorological forcings, and statistical analysis of the meteorological conditions (wind, waves, regional circulation in the Berre Lagoon) will be done on these data to prepare the best protocol for the survey. Autonomous instrumented benthic frames will be deployed to get time series of physical forcing, including: a) circulation patterns in the study area; b) analysis of wave generation by winds; c) measurements of the directional wave spectrum and wave characteristics, including instantaneous water level; d) measurements of velocity profiles in the entire water column, with focus on the benthic boundary layer; e) analysis of the non-linear wave-current interaction; f) analysis of low frequency modes.

In parallel of direct measurements of currents, the sediment interface and the influence of sediment rugosity on the benthic boundary layer will be taken into account through grain-size analyses of grab samples and turbidity profiles. Shear stress due to wave, current, and wave/ current interaction will be estimated, including the bed roughness. The near bottom turbulence will be also approached through the turbidity, higher turbidity being related to resuspension processes.

All these analyses will be done thanks to the equipment available from the platform GLADYS (CEREGE), including ADCP and 2 Aquadopp profilers (normal and high resolution). One OBS will be acquired by the project. These measures will be performed during the OWS and TWS surveys.

Turbulence experiments

The role of turbulence on oxygen exchanges at the interface will be studied during the laboratory approaches. Turbulence in the overlying water column will be characterized in separate experimental devices with optical measurements related to particle image velocimetry (PIV). The principle of PIV is based on the measurement of the displacement of small tracer particles carried by the fluid during a short time interval, providing two-component velocity fields. A light sheet illuminates a portion of the flow and a set of two successive frames are recorded by a CCD camera and processed by cross-correlation analysis. Statistics from the double-frame set are then calculated: means, variances, intensity, turbulent stress, etc. PIV will be combined with planar laser induced fluorescence (PLIF) in order to measure turbulent fluxes above a sedimentary layer. PLIF indeed measures concentration fluctuations owing to a flow tracer emitting fluorescence when excited by means of a laser with a specific wave length. The combination PIV/PLIF is available at IRPHE. Sediment oxygen consumption (SOC) experiments will be performed during the OWS and TWS surveys by incubating 4 replicate sediment cores in which a range of different turbulent stresses will be produced by an oscillating grid (Redondo et al, 2001). Turbulent conditions will match the in situ ranges measured during the field surveys (high, low and mean regime). These data will be used to calibrate the numerical model (task 7).

3.5.5. TASK 5 – FLUXES AT THE SEDIMENT-WATER INTERFACE

Principle project partners/ collaborators:

AMU: Dr C. Grenz, (MIO), Dr O Radakovitch, (CEREGE).

External: B. Deflandre, O. Maire, P. Anschutz (EPOC)

The objective of this task is to measure the effective transfer of chemical species at the sediment-water interface over different conditions of oxygen concentrations in the water column, encountered during both in situ and laboratory experiments.

Two complementary in situ approaches will be carried out. Firstly, an aquatic Eddy Covariance system will be used for the accurate determination of the total oxygen fluxes at the sediment-water interface. This approach will be carried out with EPOC, the only French laboratory disposing of such a system. This innovative, purely non invasive, technique allow an instantaneous oxygen flux determination calculated from the covariation between the O_2 concentrations measured with an oxygen microelectrode and the vertical flow velocity measured with an ADV at a given point above the sediment-water interface (Berg et al., 2003). This method will allow a good estimate of the evolution of oxygen fluxes integrated over several m^2 and over few minutes periods. However, such method is applicable only if bottom water velocity is ca 10 cm/s, and such conditions will be checked by the Task 4. If applicable, this approach will be particularly relevant to study the dynamic response of oxygen fluxes at the sediment-water interface under fluctuating oxygen concentration in the water column. Secondly, benthic chambers from the MIO will be adapted and deployed to assess the total fluxes of different chemical species (O_2, NO_3^-, NO_2^-, $\sum CO_2$, PO_4, NH_4^+, Fe, Mn, SO_4^{2-} and H_2S). The total oxygen fluxes during benthic chambers deployment will be estimated from the evolution of its concentrations over time continuously measured using optodes located in the chambers. Fluxes of other chemical species will be calculated from the concentrations differences between the beginning and end of the deployment from samples collected by divers. Both clear and dark benthic chambers will be simultaneously deployed in order to obtain the chemical species fluxes in association with autotrophic (clear) and only respiration (black) activities.

During the laboratory experiments, the total fluxes at the sediment water interface will be obtained from cores incubations. The fluxes rates will be calculated from changes in concentrations over time.

3.5.6. TASK 6 – DIAGENETIC MODELING

Principle project partners/ collaborators: C Grenz (MIO)

External: R.-M. Couture (NIVA), E. Yakushev (NIVA)

This task aims to construct a non steady state reactive-transport model able to simulate early diagenesis in the sediments and to predict how the chemical fluxes at the sediment-water interface respond to dynamic changes in the oxygen concentrations of the water column. The model will be built on existing formulations for physical (e.g., advection, biodiffusion, molecular diffusion and pore water irrigation), geochemical (e.g., equilibrium and kinetic reactions) and microbial (enzyme kinetics, assimilatory and dissimilatory redox reactions) processes. The rate of these process will be provided by the experimental and analytical works conducted whithin the 5 previous tasks.

Unlike most mecanistic geochmical models design to predict flows or concentrations as a function of time, diagenetic models are often used to predict the temporal evolution of benthic fluxes (see Boudreau 1997). Because fluxes are rarely measured, diagenetic models calibrated against concentrations profiles bear significant uncertainty, which underminimise their predictive power. Here, building on the unique time series that will be acquired in Task 5, and on the proposed synergy between experimentalist and modellers, the reactive-transport model will be calibrated and valided against measured fluxes. To our knowledge, this has not been attempted before due to the lack of available measurements.

The model will build on an unsteady state model recently developped by Couture et al. (2010) in the MATLAB/Octave programming environment. This choice of programming environment allows taking advantage of the flexible solving routines embedded in Matlab, thus simplyfing the modellers's task and allowing the users to focus on implementing the diagenetic processes. This model will be applied to the study site where the experiments will be conducted, and be used to predict the evolution of the system under different scenarios of changes in oxygenation conditions. In particular, the impact, on benthic fluxes and macrofaune, of the increase in both the duration and the intensity of hypoxic episodes will be accessed in the coastal areas.

3.5.7. TASK 7 – BENTHIC-PELAGIC BIOGEOCHEMICAL MODELING

Principle project partners/ collaborators: O Radakovitch , S Meule (CEREGE), G. Bernard (GIPREB)

External: R.-M. Couture (NIVA), E. Yakushev (NIVA)

This last task constitute the final step of the PREDHYPO project. The benthic-pelagic biogeochemical modelling must be able to predict the severity and duration of the hypoxia event as a function of hydroclimatic data. As modeling of benthic-pelagic coupling requires the incorporation of sediment diagenesis processes, this task will build directly on the outcome of Task 6, coupled with an existing hydrological model for the site. A hydrological model is already develop in the framework of GIPREB. The model (developed on TELEMAC code) will be calibrated in March 2014 and will be able to reproduce the hydrodynamics of the entire system, including stratification processes (GIPREB, Com pers.). The oxygen concentrations will be included in the model and will constitute the forcing inputs for the diagenetic modeling. The coupling of the sediment and hydrological model to model benthic-pelagic will be performed as outlined in Smit and van Beek (2013), by coupling horizontally integrated water-column layers, benthic boundary layers and sediment layers with biogeochemical processes simulating oscillating redox conditoins. Codes already avialable at NIVA for sediment (Couture et al., 2010), benthic-bounrady layer and water-column dynamic (Yakushev e al. 2013) will be adapted. The initial composition of the water column will be provided by routine monitoring data, and will also be used for the calibration of the model. Water-column processes especially difficult to measure, such as particle sinking rates, will be parametrized. Inflows and outflows of water will be derived from water balances based on inflows, seepage and precipitation. Climate forcings of the coupled model will be provided by publicly-available weather data.

Because most of the works must be dedicated to field and analyses, to get all data necessary for the calibration from all the disciplines involved, it is not expected that a fully fonctionnal software will be produced by the end of that project, instead the coupled model will be delivered as a series of script. We do believe, however, that the tool has a potential to acquire a user-base of scientists and basin-managers, and aim to secure additionnal funding to provide a model with extended funcitonnality, such as calibration and post-processing tools. This final model will be initiated here and will be the subject of future applications to other program (ANR especially).

3.6. MANAGEMENT

The management of the PREDHYPO project will be conducted by O. Radakovitch (CEREGE) and C. Grenz (MIO) but a steering committee will be organized in order to gather each involved partners and task leaders. The Geochemistry (Task 1) and measurment of fluxes at the sediment-water interface (Task 5) will be coordinated by CEREGE and MIO in close collaboration with EPOC, for chemical analysis and instrument deployments. The measures of diversity and microbial diversity (Task 2) will be coordinated by MIO and IMBE. The EPOC will coordinate the measures of diversity and activity of the macrofauna (Task 3) while the hydrodynamic of the water column (Task 4) will be conducted by the IRPHE and CEREGE laboratories. The modeling (Tasks 6 and 7) will be coordinated by NIVA laboratory.

In situ and laboratory experiments as well as the technical resources (boat, marine station, multi-corers, divers) will be managed by CEREGE and MIO laboratories in collaboration with the site manager, GIPREB. All the resources necessary for the implementation of the instrumentation, equipment and analysis will be managed by CEREGE laboratory. The PREDHYPO project implies that the steering commity will meet twice a year to optimize the organization of the work and account for the constraints of the field and laboratory experimentations. The project manager will warant the scientific coordination and animation during the project duration and will organize its valorization strategy. A postdoc researcher will be recruted over the two years of the project in order to coordinate the scientific and technical progress of field and laboratory experiments in addition to the model development and application.

3.7. DELIVERABLE AND MILESTONES

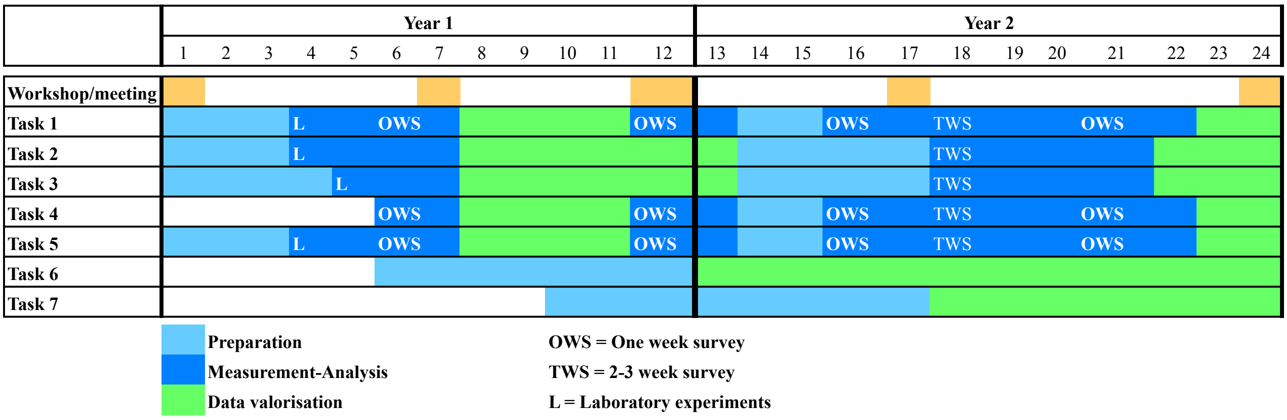

Table 2: Tasks schedule

Milestones: **M1**: Kick off meeting ; **M4**: Start of the laboratory experiments ; **M6**: In situ test experiments ; **M7**: End of the laboratory experiment and intermediate meeting; **M10**: First seasonal benthic chamber deployment, start of biogeochemical modelling ; **M12**: Annual meeting: feed back from lab experiments and valorization, preparation of in situ experiments; **M13**: Second seasonal benthic chamber deployment ; **M16**: Start of the in situ experiments over the spatial gradients of hypoxia, including the third seasonal benthic chamber deployment ; **M17**: Intermediate meeting ; **M19**: In situ experiment on short-term temporal variation of hypoxia, including the fourth seasonal benthic chamber deployment ; **M20**: End of in situ experiments; **M24**: Final meeting and future projects definition.

Deliverables: M7: report on the field experiments testing (tasks 1, 4, 5) ; **M12**: report on the results from laboratory experiments (tasks 1-6) ; **M20**: reports on the results from the in situ experiments (tasks 1-6) ; **M24**: report on the biogeochemical modeling (task 7).

4. DESCRIPTION OF THE TEAMS INVOLVED

4.1. CEREGE

O. Radakovitch (Assistant Professor, inorganic pollution in aquatic systems, CV in annex) and S. Meulé (Assistant Professor, hydrodynamics, 10 publications). CEREGE has developed an long time expertise on the analyses of metal species in water and sediment, environmental pollution and hydrodynamics processes in the coastal area. All the equipment required for the project is already in the lab (sampling devices, ICP-MS, currentmeters…) including zodiac and scuba equipment. Both scientists are also specialist of the Berre lagoon environment.

4.2. MIO

C Grenz (DR CNRS, Biogeochemistry, 45 publications) and P. Bonin (DR CNRS, Microbiology, 60 publications). MIO became recently the largest Oceanographic Centre in South France, specialized in all fields of Oceanography including hydrodynamic and biogeochemical process studies. The consortium of PREDHYPO is composed of experts internationally recognized in the field of biogeochemistry, ecology and biology of micro-organisms involved in the oxygen and nitrogen cycles. They are involved for more than 20 years in marine environmental studies and specialized in measuring rates and processes of O_2, N_2, N_2O production, as in molecular microbial ecology (abundance and diversity of N cycling organisms). MIO is among the few labs able to measure all the processes of the nitrogen and oxygen cycle at the sediment-water interface. Lab space and equipments are available for experiments under controlled variable hypoxic conditions.

4.3. IMBE

P. Mirleau (Assistant professor, microbiology, 11 publications). IMBE aims to develop an integrative and interdisciplinary profile in global ecology - with a primary interest in the human-environment relationship in the coastal zone. Their specific objectives are to study the impacts of human activity, pollution and climate change on ecosystem function, especially of coastal ecosystems. The team « interactions, diversity, evolution and adaptation » is more particularly interested by processes concerning major questions of evolutionary biology (phenotypes emergence, adaptation, speciation) and ecology (migration, persistence/extinction, community assemblages). Addressed issues combine phylogeny and phylogeographic tools with eukaryote and prokaryote population genetics tools, as well as functional genetics. It seeks to establish statistical relationships between environmental conditions and genetic structures from populations and communities according: molecular or phenotypic polymorphism, phylogeographic pattern or microbial diversity. Experimental approaches are used to test hypothesis on adaptation or phenotypic plasticity (greenhouses, aquariums, rearing or experimental cultures).

4.4. IRPHE

L. Pietri (Assistant prof., fluid mechanics, 7 publications) and M. Amielh (CR CNRS). IRPHE is a pluri-disciplinary research institute interested in the modelling of complex macroscopic systems through their experimental, analytical and numerical aspects. Turbulence team is more particularly interested in fluid turbulence associated with environmental problems. Turbulence team is specialized in velocity measurements in turbulent flows. A PIV/PLIF technique is now developed to simultaneously measure velocity and concentration in variable density turbulent jets.

4.5. EPOC

B. Deflandre (assistant Prof., biogeochemistry, 28 publications), P. Anschutz (Prof, geochemistry, 76 publications); O. Maire (Assistant prof., bioturbation, 10 publications). The EPOC group has a long-time international expertise on the biogeochemistry of marine sediments. This group is interested in early diagenetic processes in coastal sediments involving transient phenomena at different time and spatial scales, and/or associated to the activity/diversity of benthic macrofauna (bioturbation). All the in situ and lab instruments required for the project are available (sampling/analysis devices, microprofiler, EC, benthic chamber, autonomeous sensors), and the group has already worked in the Berre lagoon in the scope of the french programs BERTOX (INSU, PI O. Radakovitch) and IZOFLUX (ANR blanche, PI P. Anschutz).

4.6 NIVA

Raoul-Marie Couture (Researcher), Evgeny Yakushev (Researcher)

The Norwegian Institute for Water Research (NIVA) team will lead the modelling efforts by adaptin existing reative-transport models for sediment diagenesis and benthic-pelatic coupling. NIVA is a research institute with significant experience and skills in research focusing on biogeochemical and hydrological modelling in marine and freshwater ecosystems. NIVA manages several widely-used environmental models such as GEMMS, MAGIC, INCA, and MyLake and has strong skills in data management and data-model interactions. The team composed of E. Yakushev and R.-M- Couture is specialised in the design and application of diagenetic and benthic-pelagic models in marine (Yakusehv) and freshwater (Couture)

4.7. SYNDICAT MIXTE DU GIPREB

N. Mayot, G. Bernard, R. Grisel. The GIPREB team is in charge of the environmental observation of the Berre lagoon system since more than 10 years. Besides his long term experience on the system (benthic ecology, water colum status) and its databank, it has the equipment and abilities necessary for sampling and surveys (boat, scuba divers).

5. POTENTIAL IMPACT OF THE PROJECT FOR THE SITE

The main impact of PREDHYPO for the Aix-Marseille site will be associated to the societal and economical aspects of the rehabilitation of the Berre lagoon. The political interest for this work is clearly precised in the support letter from the GIPREB (see annex). Human sciences are presently not associated to this project, but they surely will be interested by the results in the near future. Indeed, the main present problem of the lagoon is the occurence of hypoxia events associated to the stratification of the water colum, induced by the inputs of freshsurface water through the canal used for hydroelectric production. These inputs have altered the salinity of the lagoon for a long time, causing a drastic decrease of the ecosystem, but they are now regulated since few years, and the mean salinity increased to 25‰, which must allows the rehabilitation of the lagoon for brackish ecosystems. However, the system is far from what could be expected, and hypoxia events are the next problem that must be faced. A better scientific knowledge of this process is now necessary to go further, and this is expected from PREDHYPO. As soon as scientists will be able to precise the causes of the hypoxia, the role of the sediment, and their effect on benthic and microbial ecosystem, management of the system will have to be discussed and maybe replanified.

It has to be noted that a study conducted by the GIPREB underlined the real economic impact for the area that will have a restored ecosytem. Such impact could be between 3 to 10 billions euros for the local economy within the next fifty years. The first objective of the GIPREB is the restoration of the lagoon ecosystem, a restoration that could not be achieved until hypoxia events will be solved.

6. SCIENTIFIC JUSTIFICATIONS OF REQUIRED MEANS

	Year 1 (€)	Year 2 (€)	*Total*
Operating costs : travel expenses, boat renting, conference, internal meetings	8700	19200	*27900*
Operating costs: analyses, laboratory expenses	46000	57000	*103000*
Operating costs: subcontracting	23000	115000	*345000*
Small equipment	12600	2000	*14600*
Salary (including Master grants)	87000	58000	*145000*
Total	**177300**	**147700**	***325000***

The total amount requested for the budget is : 325 k€

Costs for salary are dedicated to: 1) a two year post-doctoral position that will be involved in all the tasks, but more especially in tasks 1, 2, 5 and 6 (CEREGE+MIO); 2) one year of technical assistance for microbial analyses (IMBE+MIO); 7 Master grants.

7. LETTERS OF SUPPORT FROM PR2I

The letter will be sent later on by the P2RI environment directly to AMIDEX.

A support letter from the President of the GIPREB is given in annex of this project.

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ANNEXES

CV of Proposant : Dr Olivier Radakovitch (47 yrs)

Education: Ph.D. in oceanography 1995.07 University of Perpignan (advisor: A. Monaco)

Professional Positions:

Assistant Professor (Hors classe), CEREGE Aix-Marseille University (1997.09 – Present)

Postdoctoral Researcher, National Center for Research, Bologna, Italy (1996.09 – 1997. 09) –

Additional Service:

Associate to the Editorial Board of *Ocean Science Journal* since 2012

Participation to 7 scientific or editorial boards for International meeting and Book edition.

Ongoing Projects (participation to more than 40 national and international projects up to now):

2014-2018: Co-director of the Rhone River Sediment Observatory. *Funding: FEDER, Water agency, CNR, EDF, CR paca, CR Rhone-alpes, CR Languedoc-Roussillon.*

2009-2019: MERMEX: Marine Ecosystems Respons in the Mediterranean Experiment. Co-PI of the WP3: Land-Ocean interactions including extreme events. *Funding : Chantier Mistrals.*

2014-2015: PI of the COMECOM project: Metal contamination in Mediterranean coastal areas. *Funding: CNRS + Foreign affair.*

2014-2017: Human-Environment Observatory on the Rhone Valley. *Funding: CNRS.*

2014-2018: Zone Atelier "Rhone watershed". *Funding: CNRS.*

Experience in interdisciplinary projects:

Participant of the Zone Atelier "Observatory of Rhone Mediterranee Environment" and member of the directory committee of the Zone Atelier "Rhone watershed"

Co-PI of the first "Human-environment Observatory" (CNRS-INEE): Bassin minier de Provence

CAMPLAN: integrated management of an hydrosystem (programme MEDD "Eaux et territoires")

Supervision of Students and Postdoc:

Supervisor of 15 MS, 8 Postdocs or CDD and 9 PhD (presently three).

Referred Publication (publications from the last 3 years: 2011-2014, on a total of 48 publications in peer-reviewed international journals; H-index 17):

Angelidis M., **Radakovitch** O., Veron A., Aloupi M., Heussner S., Price B. (2011). Pollutant metal invasion and sapropel imprints in deep Mediterranean basin. *Marine Pollution Bulletin*. 62, 5, 1041-1052.

Ollivier P., **Radakovitch** O., Hamelin B. (2011) Major and trace partition and fluxes in the Rhone river. *Chemical Geology.285, 1-4; 15-31*.

Durrieu de Madron and MERMEX group. (2011) Marine Ecosystems Responses to climatic and anthropogenic forcings in the Mediterranean. *Progress in oceanography*. 91, 97-166.

Roussiez V., Ludwig W., **Radakovitch** O., Monaco A., Probst J.L., Charrière B., Buscail R. (2011). Fate of heavy metals in coastal sediments of a flood-dominated system: an approach based on total and labile fractions. *Estuarine, Coastal and shelf studies*. 92, 486-495.

Gattacecca J., Mayer A., Cucco A., Claude C., **Radakovitch O.**, Vallet-Coulomb C., Hamelin B. (2011) Submarine groundwater discharge in a subisding coastal lowland: a 226Ra and 222Rn investigation in the southern Venice lagoon. *Applied geochemistry*. 26, 907-920.

Rigaud S., **Radakovitch** O., Nerini D., Picon P., Garnier J.M. (2011) Reconstructing historical trends of Berre lagoon contamination from surface sediment datasets : influences of industrial regulations and anthropogenic silt inputs. *Journal of Environmental Management*. 92, 2201-2210.

Ferrand E., Eyrolle F., **Radakovitch** O., Provansal M., Dufour S., Vella C., Raccasi G., Gurriaran R. (2012) Historical levels of heavy metals and artificials radionuclides reconstructed from overbank sediment records in lower Rhône river (South-east France). *Geochimica Cosmochimica Acta.82, 163-182*.

Rigaud S., Di Giorgio C., **Radakovitch** O., Garnier J.M. De Méo M. (2012) Genotoxicity of sediment extract of the Berre lagoon (France). *Chemosphere*. 88, 937-944.

Roussiez V., Heussner S., Ludwig W., **Radakovitch** O., Guieu C., Probst J.L., Monaco A., Delsaut N. *(*2012*)* Impact of oceanic floods on particulate metal inputs to coastal and deep-sea environments: a case study in the NW Mediterranean Sea. *Continental Shelf Research*. 45, 15-26.

Church T., Rigaud S., Baskaran M., Kumar A., Friedrich J., Masque P., Puigcorbe V., Kim G., **Radakovitch** O., Hong G. Choi H., Stewart G. (2012) Intercalibration studies of 210Po and 210Pb in dissolved and particulate seawater samples. *Limnology and Oceanography: Methods*. 10, 776-789.

Eyrolle F., **Radakovitch** O., Raimbault P., Antonelli C., Ferrand E., Raccasi G., Aubert D., Gurriaran R., Jacquet S. (2012) Long term survey of suspended particles and associated natural and artificial radionuclides transport in the Rhone river. *Journal of Soil and Sediments*. 12, 9, 1479-1495.

Damnati B., Ibrahimi S., **Radakovitch O.** (2012) Quantifying erosion using 137Cs and 210Pb in cultivated soils in three Mediterranean watershed: synthesis study from El Hachef, Raouz and Nakhla (North West Morocco). *Journal of African Earth Sciences*. 79, 50-57.

Rigaud S., **Radakovitch O.**, Couture R.M., Deflandre B., Cossa D., Garnier C., Garnier J.M. (2013) Mobility and fluxes of trace elements and nutrients at the sediment-water interface of a lagoon under contrasting water-column oxygenation conditions. *Applied Geochemistry*. 31, 35-51.

ETANG DE BERRE
GIPREB
SYNDICAT MIXTE

Berre l'Etang, le 11 février 2014

Objet : Lettre de soutien au projet de prédiction et anticipation de l'hypoxie côtière PREDHYPO

Mesdames, Messieurs les membres du comité de sélection des projets AMIDEX,

L'étang de Berre constitue l'une des plus grandes lagunes de méditerranée. Sa situation, ses caractéristiques et son histoire en font aujourd'hui un site qui malgré son état écologique dégradé, est au cœur des réflexions sur le devenir du territoire.

Depuis plus de vingt ans la masse d'eau et ses différentes composantes font l'objet d'un suivi régulier et d'investigations scientifiques pour en améliorer la connaissance. La structure en charge de la réhabilitation de l'étang de Berre aujourd'hui devenu Gipreb Syndicat Mixte est plus que tout attachée à la rigueur scientifique et aux projets de recherche permettant de mieux appréhender la complexité de cet écosystème. C'est pour cela que, depuis sa création, le Gipreb s'est doté d'un Conseil scientifique particulièrement actif, régulièrement renouvelé et fortement impliqué dans la vie de la structure.

L'étang de Berre, par les améliorations portées à la gestion de l'eau sur son bassin versant, a vu les pressions sur la qualité de ses eaux diminuer fortement au cours des dernières décennies : réduction drastique des apports industriels, mise aux normes de tous les ouvrages de traitements des eaux usées des collectivités riveraines, réduction des apports d'eau douce de la chaîne Durance/Verdon.

Pour autant les désordres écologiques persistent avec des conséquences graves pour l'activité économique, les loisirs et la biodiversité. L'eutrophisation et la stratification des eaux ont pour conséquences des épisodes d'anoxie fréquents dans les zones les plus profondes (-9,5 m), et parfois même sur la bordure côtière en période estivale. Si les apports d'eau douce, dont les effets sur la dégradation du milieu ne sont plus à prouver, font aujourd'hui l'objet d'une gestion optimisée permettant de « contrôler » la salinité via un modèle hydrodynamique exploité par EDF ; les phénomènes d'anoxie restent eux largement imprévisibles du fait de la diversité des paramètres en jeux.

.../...

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Ces épisodes répétés de manques d'oxygène représentent une contrainte majeure pour le retour de la vie et donc d'un fonctionnement équilibré de l'écosystème. Même si des pistes d'amélioration ont été identifiées dans le Contrat pour l'Etang de Berre signé en 2013 et pour les six années à venir, le manque de compréhension des paramètres à l'origine de ces crises limite les acteurs locaux dans la prise de décision sur les mesures à mettre en œuvre pour limiter l'occurrence des périodes d'anoxie.

Le Gipreb est donc particulièrement attaché à voir se mettre en œuvre, sur l'étang de Berre, un programme scientifique d'envergure dont l'approche interdisciplinaire permettra une démarche de recherche commune et innovante sur les phénomènes d'hypoxie des eaux côtières.

Comme il a pu le faire dans le cadre de différentes participations à des programmes de thèses et programmes de recherche européens, le Gipreb soutient le projet PREDHYPO et pourra mettre à disposition ses connaissances du site, ses moyens humains et matériels afin de favoriser l'acquisition de données de terrain.

En vous remerciant vivement de l'attention que vous voudrez bien porter à ce projet, je vous prie d'agréer, Mesdames, Messieurs, mes salutations distinguées.

Président du GIPREB Syndicat Mixte

S. ANDREONI