les dossiers
d'**AGROPOLIS**
INTERNATIONAL

Expertise of the scientific community
in the Occitanie area (France)

Marine and coastal sciences in Occitanie

Number 24
July 2019

AGROPOLIS INTERNATIONAL

agriculture • food • biodiversity • environment

With its headquarters in Occitanie region, Agropolis International brings together an outstanding group of organizations and institutions involved in agricultural and environmental sciences.
Agropolis International—an association founded by research and higher education institutes with the support of the French government and local authorities—continues to provide an open space for collective expertise and collaboration.

Agropolis International fosters links between different stakeholders involved in agriculture, food, environment and biodiversity sectors:
• Institutions of the regional scientific community
• Foreign and international research organizations
• Local authorities
• Technology transfer, innovation and economic development stakeholders
• Civil society structures

By marshalling such a broad range of institutions and backed by an outstanding scientific community, **Agropolis International has become France's leading agroenvironmental research hub addressing issues affecting Mediterranean countries and the Global South.**

Agropolis International—a forum for exchange and dialogue, training and capitalization of knowledge, a think tank, a support structure for collective projects and international outreach, and a place to host structures and events—applies and tailors its expertise acquired over the past 30 years to the major missions entrusted by its members.

Agropolis International is structured around a broad range of research themes corresponding to the overall scientific, technological and economic issues of development.

Research and training themes of the Agropolis International community:
• Agronomy, cultivated plants and cropping systems
• Animal production and health
• Biodiversity and aquatic ecosystems
• Biodiversity and land ecosystems
• Economics, societies and sustainable development
• Environmental technologies
• Food: nutritional and health concerns
• Genetic resources and integrative plant biology
• Grapevines and wine: regional specific supply chain
• Host-vector-parasite interactions and infectious diseases
• Modelling, spatial information, biostatistics
• Water: resources and management

A few figures regarding the East Occitanie scientific community:
• 27 higher education and research institutions
• 35 interinstitutional and interdisciplinary open research infrastructures
• 150 training courses
• 2,700 researchers and teachers in 74 research units
• 300 expatriate researchers in 50 countries
• 5,000 French and international students
• 1,000 international researchers hosted

Preface

Occitanie Region's coast is a tremendous asset for the attractiveness and development of the territory. With 215 kilometres of coastlines, 40,000 hectares of lagoons, 1.3 million permanent inhabitants, 8 million tourists a year, 20 coastal resorts, 35 marinas, 3 commercial ports, 4,700 km² of protected marine areas, including a 4,000 km² marine park, Occitanie's Mediterranean coastline provides a horizon for the Blue Economy.

The *Parlement de la Mer* and the Coastal Plan 21 (*Plan Littoral 21*), signed with the State and the *Caisse des Dépôts* in 2017, are the tools set up by the Region to reconcile economic, coastal and maritime dynamism, employment and innovation, and environment protection. Hence, blue biotechnology, aquaculture and marine renewable energy, are all assets that the Region intends to develop in the coming years while preserving both traditional activities—such as fishing and shellfish farming—and biodiversity. Indeed, coastal and maritime resources' valorisation must not undermine the attractiveness of the coast, its identity and the quality of life of its inhabitants.

Today, this territory faces many challenges, the first of which is global warming. Understanding phenomena and anticipating ecological, biological and physical changes as well as natural risks, is essential for future development.

Therefore, in order to meet these challenges and help this territory to adapt and transform itself for and with its inhabitants and sea users, as well as to succeed in this ecological and economic transition, the Region can rely on a rich and dynamic pool of scientific and technological skills (universities, research organisations, competitiveness clusters, engineering schools, development agency); this is perfectly exemplified in this Agropolis International *Dossier*.

Carole Delga,
President of the
Occitanie / Pyrénées-Méditerranée Region (France)

Editorial

More than 150 teams of scientists and experts from the Occitanie Region participated in the 24th issue of the *Dossiers d'Agropolis International* series, dedicated to marine and coastal sciences in the Mediterranean. These teams come from 15 universities and engineering schools, 13 national research institutions, as well as—and this is a first for this series—private businesses—namely start-ups, consultancy firms, national and even international companies having a presence in Occitanie—and civil society organisations.

Thus, without being exhaustive, this *Dossier* reflects the diversity, dynamism, originality and multidisciplinary nature of the scientific, applied technological and citizen research pertaining to marine and coastal sciences, both in Occitanie and at national and international levels.

The Occitanie Region—with its significant sea basin, marshes and lagoons, commercial ports and marinas, and the millions of tourists who visit every year—faces a convergence of both diverse and major economic, social and environmental challenges, related to climate change, biodiversity, living resource management and energy transition. Therefore, the ambition of this *Dossier* is to present the regional stakeholders who, through their activities, are striving to provide keys to understanding and potential responses to the questions that the managers of this vast coastal and maritime area daily face. These elements have been organized into six main thematic areas: Impacts of natural and anthropogenic forcing on Mediterranean marine dynamics; Biodiversity and dynamics of marine biological communities; Scientific evidence of ocean vulnerability; The basics of sustainable development of the 'sea system'; Power of long-term observation and synergy of digital integration; Innovative scientific mediation and citizen science.

Many training courses pertaining to the 'Sea and the Coast' thematic, awarding degree (ranging from two-year Higher Education diplomas to PhDs) or not, are offered in Occitanie. A list of these training opportunities may be found on the websites of Agropolis International (www.agropolis.org/training) and Toulouse Midi-Pyrénées Federal University (https://en.univ-toulouse.fr/courses-all).

Agropolis International is pleased to have, once again, contributed to presenting the wealth and originality of skills available throughout the Occitanie Region, in relation to an issue as sensitive as the marine world and its interfaces with coastal human settlements.

Jean-Luc Khalfaoui
Former President of Agropolis International

Marine and sciences in

coastal Occitanie

summary

Foreword

"Nowhere in the histories of humanity has sufficient attention been given to the sea's decisive role in the development of religions and cultures, techniques and enterprises, nations and empires. The story of humankind as seen from the sea has never been told. And yet, it is here that the most fundamental issues can be grasped." (*In* Stories of the Sea *(Histoires de la mer),* Jacques Attali, 2017)

SDG 14. This is the fourteenth of the seventeen **S**ustainable **D**evelopment **G**oals encompassed in the United Nations 2030 Agenda, which was adopted in New York on 25 September 2015. SDG14 is not the least of SDGs, and plays a key role in laying down a framework for planning and development policies, as well as policies addressing the realignment of human activity and of its impact upon maritime and coastal areas as a whole. The challenge here is to "*conserve and sustainably use the oceans, seas and marine resources for sustainable development*".

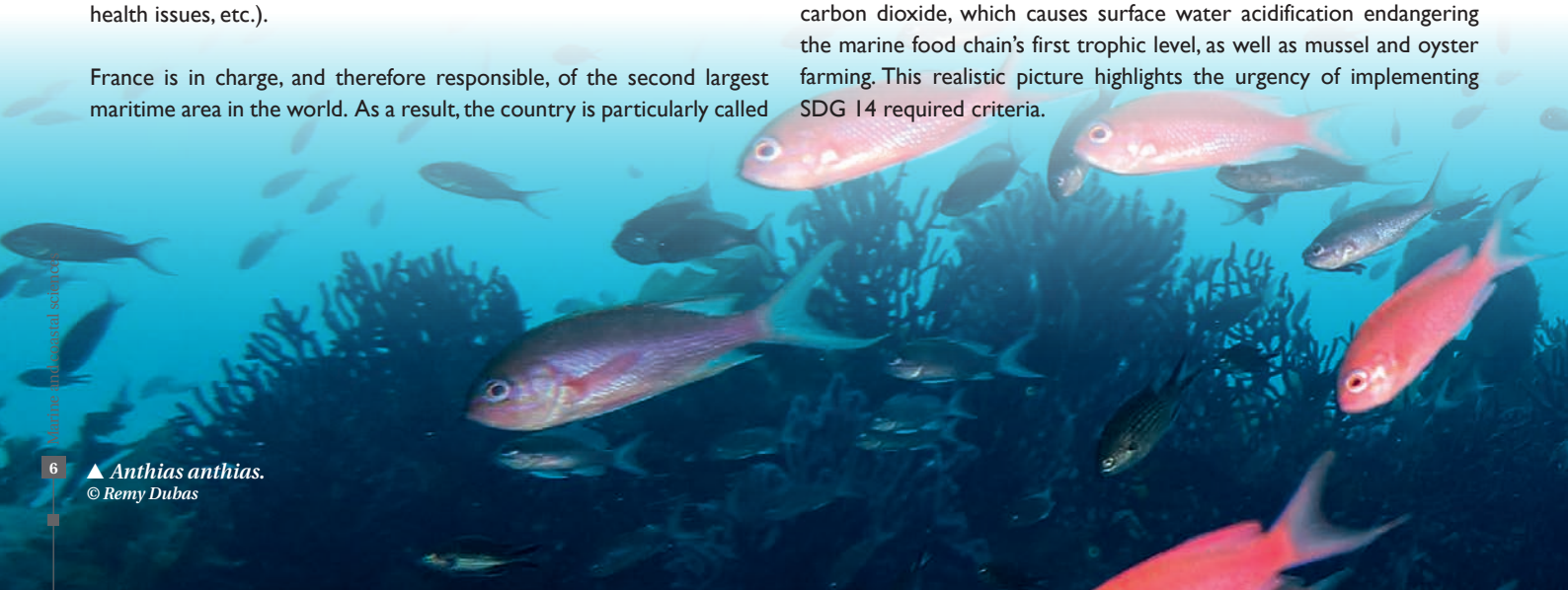
A political challenge, the inclusion of the oceans and related activities into the international agenda, following the discussions launched in Rio on the occasion of the 3rd Earth Summit in 2012, must now lead to the emergence of a new world: today's understanding of the processes involved in climate change confirms that life on Earth is to a large extent supported by the interdependencies between terrestrial and marine environments.

A complex challenge, integrated and interdisciplinary, even cross-disciplinary approaches are now required, drawing upon powerful synergies between technical, natural and social science experts, but also resource managers, businessmen, maritime professionals, civil society partners, citizens and decision-makers.

A multifaceted challenge, in order to design the right strategies and find a viable middle-ground between ocean conservation and ocean health and the welfare of economic systems, the scientific community must be able to structure and set up observation and analysis systems, both experimental and operational, as well as develop scenarios using the most robust models possible. These scenarios focus mainly on (1) the environmental impacts of both resource-extracting activities (e.g. fisheries, dredging, etc.) and others (e.g. mass tourism, transports, etc.), (2) the detection of multiscale changes and stress in ocean system (climate variation, sea level rise, acidification, deoxygenation, biodiversity damage, pollution, etc.) and (3) the societies responses to these constraints (e.g. resilience, migration, nutrition changes, new health issues, etc.).

France is in charge, and therefore responsible, of the second largest maritime area in the world. As a result, the country is particularly called upon and expected to take actions in relation to SDG 14. We are aware of the major assets that Occitanie Region stakeholders possess and can mobilize in order to contribute to meeting this challenge. Therefore, in order to provide evidence of the foregoing, we have compiled a selection of examples of cutting-edge research and innovative activities. These examples—"*Brief Answers to Big Questions*"—are divided into six chapters that attempt to researches carried out by the Occitanie Region's scientific community. The emphasis is deliberately placed upon the priority issues of the Mediterranean region, as both a biodiversity and climate change vulnerability hotspot. However, the teams showcased here are also involved, directly or through partnerships in Southern countries and all the French maritime regions.

The first chapter, **Impacts of natural and anthropogenic forcing on Mediterranean marine dynamics,** illustrates, through non-exhaustive examples, a number of mechanisms and challenges that are specific to marine physics and chemistry. Teams at the forefront of climate and meteorological research describe the role played by the ocean-atmosphere duo in relation to the Earth's climate. And, more specifically, describe the significant influence on humidity, droughts and the occasionally-snowy winter events affecting the Mediterranean Basin exerted by mechanisms originating in the Atlantic Ocean. On a finer scale, keys are provided to elucidate the occurrence of cyclones and tornadoes, and the triggers behind the local storm phenomena (*épisodes cévenols)*, with their direct and indirect consequences in human and economic terms. This work requires the deployment of measurement equipment during observation campaigns, such as the HYMEX campaign, coordinated at the highest level by Toulouse teams. Oceanographers are actively engaged in studying the constraints that impact the functioning of the Mediterranean, both in the past (such as when the Mediterranean almost dried up) through the use of parameters recorded in archives, or in the present, in order to precisely understand ocean circulation, which also draws upon field observations and models. Human activities impact both the physics of water, through the rise of sea levels, the intensification of storms, and storm surge phenomena, and the chemistry of water, through penetration of excess carbon dioxide, which causes surface water acidification endangering the marine food chain's first trophic level, as well as mussel and oyster farming. This realistic picture highlights the urgency of implementing SDG 14 required criteria.



▲ *Anthias anthias.*
© Remy Dubas

The second chapter, **Biodiversity and dynamics of marine biological communities**, drawing upon a handful of examples, describes the extraordinary diversity of species found along the Occitanie coast. While coralligenous reefs and posidonia beds are among the richest biotopes in terms of biodiversity, they are also subject to high environmental pressures. A number of exploited species, such as sardines, anchovies and gilthead seabreams, are particularly threatened, and are being extensively investigated by teams that are now equipped with high-performance investigation and monitoring tools. Some of these tools were even devised by laboratories from Occitanie.

A great number of researchers are studying the frontiers within ecosystems, the connectivity between habitats, and the vulnerability of species to infrastructure development or human activities. This research is key in order to develop predictive scenarios and provide managers with solutions. Some species are studied in-depth in order to better understand the mechanisms of their response to environmental change, as well as their evolution over time. This work focuses on both macroscopic and microscopic species, as well as on their interactions, and uses the latest genomic tools. The regional scientific community is recognized for its very active involvement in the field of marine biology, and is equipped with remarkable experimental platforms thanks to the European Marine Biological Resources Centre (EMBRC) in Banyuls and the MEDIMEER platform (MEDIterranean platform for Marine Ecosystem Experimental Research) in Sète.

The third chapter, **Scientific evidence of ocean vulnerability,** discusses how climate change, and more broadly, anthropogenic pressures, are likely to impact not only the shoreline but also ecosystems and living resources. A number of teams from the Occitanie Region (Montpellier, Toulouse and Perpignan) are working together to study marine storm surge evolution and sediment dynamics in relation to hydrological events and river inputs. This work is essential in order to predict coastal evolution and establish key territorial management and land use planning scenarios.

As a result of demographic change, the coast is subject to multiple anthropogenic pressures. A great number of research projects are addressing sand exploitation, wastewater treatment effluent discharge, plastic waste, chemicals and other pollutants directly discharged into the sea, with the twofold objective of improving our understanding of the associated impacts on ecosystems and living organisms, and developing monitoring tools. Several laboratories, specializing in different disciplines, are working together in order to develop sensors enabling continuous measurement of these types of pollution, while other laboratories are inquiring into the role played by certain species as environmental quality indicators. Many of these studies are directly aimed at understanding possible threats to economic activities such as shellfish farming.

The fourth chapter, **The basics of sustainable development of the 'sea system',** goes further into the question of the knowledge and technologies required in order to design sustainable activity systems. In addition to implementing cross-cutting approaches, the objective of research into the implementation of sustainable development is to thoroughly explore, for each sector—fisheries, aquaculture, tourism, maritime transport, etc.—the interactions between uses and activities in relation to nature and ecosystems. Corollary knowledge serves to guide and support economic stakeholders, citizens and public decision-makers in evolving their practices into processes and uses that are more respectful of the environment. To this end, multiple collaborations between disciplines and laboratories, public decision-makers, and private businesses are required.

Initially focused upon coasts and coastal areas, the issue of sustainable development is gradually extending further offshore, thereby resulting in a shift in research and activities towards allegedly sound and sustainable exploitation of all marine areas and resources, without leaving behind the challenges of climate change, which require that the study and management of environmental and societal vulnerabilities be integrated. Several types of issues are central to the research being undertaken. These include the impacts of acidification and increased seawater temperature on the equilibrium of ecosystems and marine species, be they exploited or pathogenic, as well as the risks of invasive species proliferation. Responding to rising sea level and marine flooding phenomena requires innovative forms of adaptation at the territorial level. Research is supporting changes in production practices, by transposing agroecology principles to aquaculture, while also fostering the improvement of governance processes, in particular those of marine protected areas, ecological restoration and engineering processes.

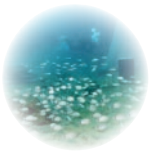
▸▸▸▸

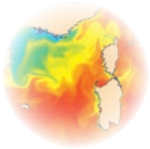
The fifth chapter, **The power of long-term observation and synergy of digital integration**, is a mosaic showcasing internationally renowned teams: France, in particular Toulouse, is maintaining its historical world leadership in the field of space oceanography. This has been made possible both by the development of new high-performance space systems, and by the upkeep of adapted mechanisms for *in situ* collection, archiving and processing of databases that are essential for the validation of all measurements and algorithms. These mechanisms are being applied both for physical oceanography databases and for the territory's biology and human science related databases. Just as for the major sectors of the space industry, these mechanisms draw upon a whole range of competencies pertaining to the development and exploitation of new sensors and new technologies. The algorithms, be they deterministic or statistical, simple or sophisticated (i.e. calling upon the latest deep learning techniques), are generating novel applications, innovations, and even new professions, some of which are presented in this chapter, through concrete examples. These algorithms are being applied in a variety of fields, including: satellite surveillance of marine and coastal environment (offshore and coastal currents, sea state and wind, surface temperatures, climate change detection, pelagic resource monitoring, oil pollution, maritime traffic, shoreline, etc.), underwater monitoring (benthic biodiversity, marine ecosystem health, etc.) through diverse techniques (gliders, robots, 'overboats', environmental DNA collection, etc.), as well as through predictive modelling (coastal evolution, extreme events, etc.). This long and fascinating list is by no means a tedious catalogue. On the contrary, it is an expression of all these research teams' dynamism and creativity.

The sixth chapter provides a range of examples of **Innovative scientific mediation and citizen science** initiatives conducted in the Occitanie Region. Science is increasingly perceived by the public as ambiguous, being both a vector of progress for the future yet likely to generate new technological risks. This, despite the fact that two-thirds of the French population is interested in scientific news, and 78% believes that science provides solutions to today's challenges (Ipsos, 2016)! However, any evolution in perception will require that knowledge be intelligible and accessible to all—citizens, professionals, natural environment managers, etc. Bringing science within everybody's reach: this is made possible thanks to scientific mediation, and the many forms it takes.

Scientific research is often perceived as a world of its own, exclusively reserved for professional researchers. This explains the appeal of participatory science, which provides all citizens—experts, amateurs, maritime professionals, naturalists, etc.—with opportunities to help extend the frontiers of knowledge and share knowledge with scientists. Anyone who is ready to invest him/herself personally has the opportunity to better understand scientific advances from a more global perspective, and impact research debates and challenges. Another benefit—and by no means an insignificant one!—of this participatory process is that it provides a means to collect, thanks to a very wide audience, a plethora of data over vast territories and extended time scales, thereby making it possible to conduct studies that would otherwise be very difficult, or downright impossible, to conduct…

We invite you to dive into this *Dossier*. It is by no means exhaustive. However, you will discover first-hand an abundance of regional stakeholders and myriad endeavours being conducted both at sea and along the coast, in particular in the Mediterranean. We also invite interested readers to visit the websites of the stakeholders who contributed to this *Dossier*, and to contact them directly (see p. 124).

Dedication

Pierre Soler †, internationally renowned geophysicist and director of the Observatory Midi-Pyrénées (OMP), played a major part in the creation of this Dossier, notably by joining its editorial board, with an overflowing enthusiasm that he was renowned for. Pierre tirelessly devoted himself to the dissemination of knowledge and the improved understanding of both scientific and technological issues among decision-makers and citizens alike. With his passing, we have lost his wise advice and friendship. We would like to pay tribute to Pierre and dedicate this issue of the *Dossiers d'Agropolis International* to him.

© OMP

Prado Reefs, Marseille. *2014 Grand Prize for Ecological Engineering (see p.111).*
© Sandrine Ruitton

© Hubert Bataille / IRD

Impacts of natural and anthropogenic forcing on Mediterranean marine dynamics

The Mediterranean Sea—a source of water, employment, livelihoods and leisure—is a key maritime region in the European and North African landscape. Viewed from the shoreline, the sea may appear calm or rough, a peaceful blue or a looming ominous grey, but it has always been a constant and eternal feature from a human perspective—it was there when we came into this world and will be there when we vanish. Yet, as with all elements that make up the Earth, the dynamics of the Mediterranean Sea are the result of climate forcing at all spatiotemporal scales. This chapter offers a non-exhaustive review of some of these climate drivers and their impacts on the geography, circulation patterns and behaviour of the Mediterranean Sea against the backdrop of global change.

On a geological scale, the presence or absence of seas is dictated by plate tectonics. The African tectonic plate, for instance, is moving very slowly northward, thus compressing the Eurasian plate. Its progression is marked by violent earthquakes affecting Italy, Greece, Turkey and the Pyrenees. The Mediterranean Sea is expected to gradually disappear some 10 million years from now under the effect of this movement. After all, as A. Maillard-Lenoir explains, this same sea was a 'lake' 5 or 6 million years ago (Messinian Salinity Crisis). The sea's history can actually be traced by analysing the natural signs emanating from the climate archives, like the mollusc shells studied by G. Dera.

On a much shorter time scale, i.e. from decades to years, L. Batté highlights how the Mediterranean Sea impacts the neighbouring Atlantic Ocean. This influence is part of a more global ocean-atmosphere exchange process which determines the Earth's climate, as described by S. Planton. Surface water from the Atlantic Ocean enters this closed basin via a single channel—the Strait of Gibraltar. For roughly 85 years, it then circulates between the 'western' and 'eastern' basins, separated by the Strait of Sicily, before re-exiting via the Strait of Gibraltar, but this time at a deeper level after increasing in density along its pathway. This water changes after entering the Mediterranean Basin. First, it evaporates and increases in salinity under the effect of high air temperatures and relatively low river flow. Secondly, mixing occurs as a result of the cold northerly winds and marine circulation. These key physical mechanisms determine the extent of water oxygenation and the development of life in the Mediterranean Sea enhanced by the upwelling of nutrients from the seabed. M. Herrmann and I. Taupier-Letage highlight the extent to which regular, calibrated and long-term monitoring helps gain insight into circulation patterns while also challenging long-standing paradigms, as R. Waldman clearly illustrates. Submarine cascading dynamics in the Gulf of Lion and the impacts of these deep-water formations on surface plankton blooms are showcased in the review of C. Estournel's and P. Conan's research.

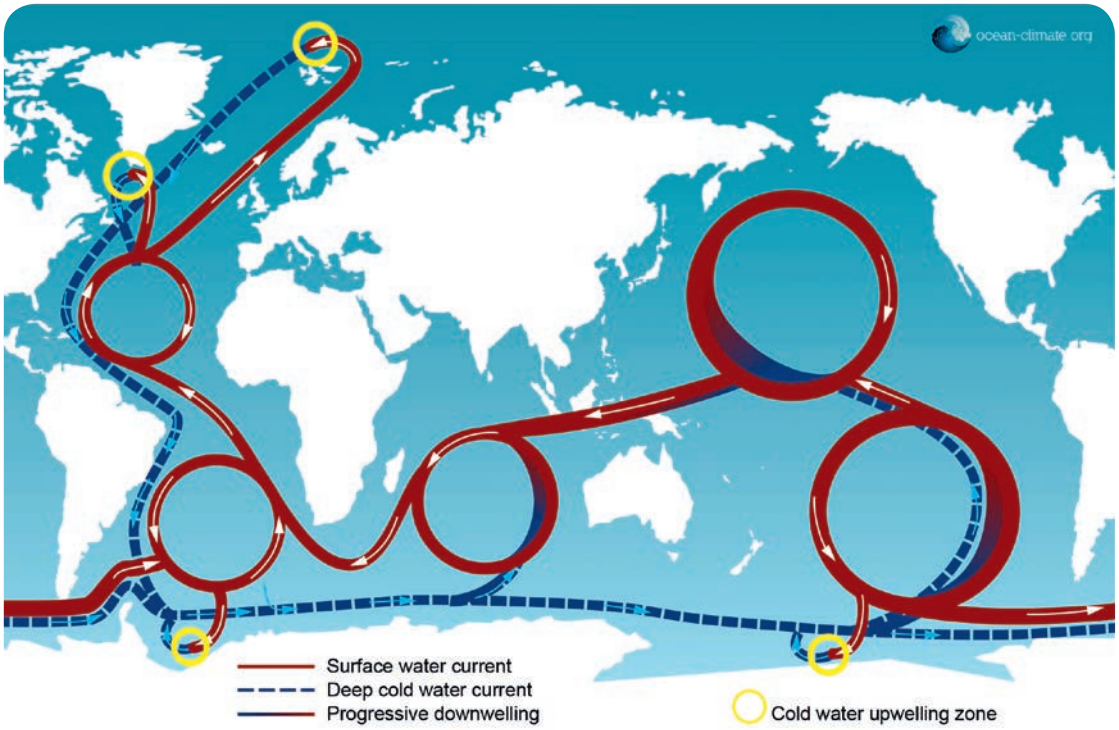
On a seasonal scale, the findings of the HYMEX research project reviewed by V. Ducrocq underline the extent to which the Mediterranean Sea can in turn have major impacts on coastal regions —*Cévenol* heavy rainfall events occur following hot-weather periods when the air is laden with water vapour due to evaporation and the colder nearby mountains trigger condensation. This resembles another mechanism which—on a much larger scale in the Atlantic, Indian and tropical Pacific oceans, and even recently in the eastern Mediterranean Sea—sometimes generates violent cyclones (P. Marchesiello). These events often have a major economic impact since the torrential rains may inundate and wash away everything in their pathway. Eight major *Cévenol* events have occurred over the last 20 years (1999, 2002, 2003, 2005, 2010, 2011, 2014 and 2015). The December 2003 event affected a vast area from Aude region to the southern French Alps: burst dikes, sharp water level rises and overflows in the Rhône, Vidourle and Hérault rivers, as well as smaller streams (Lez, Mosson, Orb, etc.), and flooded towns and villages (16 million m^3 ravaged in Arles, Sommières, etc.). This flooding is often accompanied by storms, and the combination of low barometric pressure (thus lowering the water pressure and prompting a water level rise), enormous waves and high river water levels induce major flooding in coastal areas (C. Estournel, Y. Leredde). The human, industrial and public costs generated by these events emphasize the societal issues underlying this research.

On a current and future scale, unfortunately the Mediterranean Sea is and will continue to be impacted by anthropogenic pressure, i.e. forcing induced by human activities. Some dynamic properties of the Mediterranean Sea such as vertical mixing of the water column will alas intensify water acidification—a hardly perceptible yet highly threatening effect of excess CO_2 generated by human activity. This acidification is the result of a chemical reaction, i.e. when CO_2 dissolves in sea water it reacts with the water and boosts its acidity via carbonic acid formation. Seawater is actually not acidic, but its acidity level is 30% higher than a century ago, and this level will triple by the end of this century if we continue burning fossil fuels. Many organisms that thrive in the surface waters of the Mediterranean Sea have calcium carbonate shells, which will dissolve in acidic conditions. Biologists and coral specialists are thus rightfully concerned about this increased acidification, and the negative impacts have already been observed on marine biodiversity and on the development of species of major economic importance, such as oysters and mussels. F. Touratier and his team explain how —via intense downwelling in the coastal region—the Gulf of Lion has become a hotspot for CO_2 uptake in the deep Mediterranean waters.

The rising sea level is another major threat for the Occitanie coastal region (Meyssignac *et al.*). This rise is estimated to have been 17 cm during the 20th century as a result of ocean expansion due to heat and the melting of continental glaciers and polar ice caps, which in turn releases trapped water in solid form that flows into the sea. This phenomenon is currently picking up speed, and a start-up was thus launched to help communities monitor beaches and coastlines (Y. Soufflet). Forecasts for the late 21st century all predict a minimum sea level rise of 40 cm, with a potential maximum of 2 m, depending on how the Antarctic coastline reacts to the onrush of a warmer sea waters.

Catherine Jeandel (CNRS, UMR LEGOS)

The ocean – a multiscale climate forcing agent



▲ *Simplified image of ocean currents related to water density variations and thus temperature/salinity variations (thermohaline circulation). Surface currents (red) and deep currents (blue) redistribute the captured surface heat.*
© Ocean & Climate platform - http://ocean-climate.org

Role of the ocean as a climate driver

The ocean, like the atmosphere, has a major role in regulating the world climate by redistributing part of the solar energy received by intertropical regions to polar and temperate latitudes. This huge reservoir of water and energy covers about 71% of the Earth's surface. Due to its total calorific capacity—about 1,200 times that of the atmosphere—it stores a very large share of the heat received by the planet. The ocean has thus stored about 93% of the Earth's accumulated energy that has been boosted in recent decades by increased greenhouse gas concentrations. The absorbed thermal energy is transported with time constants that can range from months for surface currents to up to 1,000 years for deep currents. **This high storage capacity and inertia provides a buffer for sudden atmospheric variations that could result from violent volcanic eruptions, sharp changes in the solar constant or very severe disruptions associated with human activities.**

Ocean-atmosphere interactions are ceaseless. The ocean is the main source of water vapour and provides the atmosphere with much of the energy needed for wind and cloud formation. Through friction, these winds move ocean surface layers, giving rise to surface currents such as the Gulf Stream or the well-known El Niño phenomenon, which causes severe climate disturbances worldwide. But the ocean has yet to reveal all its secrets. This includes the not fully understood role played by the North Atlantic Ocean surface temperature at time scales of several decades on the atmospheric pressure variability in Europe which, for instance, accounts for the mild winters in Montpellier (France).

Contact (CNRM*): S. Planton, serge.planton@free.fr

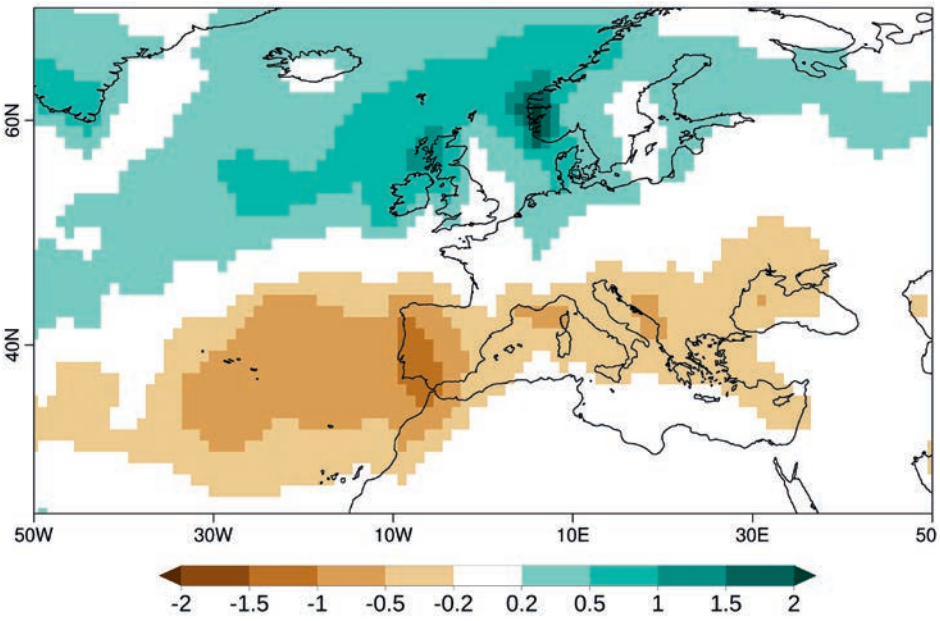
* The full names of the research structures to which the authors belong are listed on p. 124.

Ocean-atmosphere exchanges shape the Earth's climate.

Climate forcing in the Euro-Mediterranean region

Climate variability patterns at monthly to seasonal scales throughout the Euro-Mediterranean region partly mirror the intensity of the most prevalent weather phenomena, such as the North Atlantic Oscillation (NAO). This oscillation, measured by the surface pressure difference between Reykjavík and Lisbon, represents relative fluctuations in the intensity of the Azores High and Icelandic Low. In winter, a positive NAO phase corresponds to an increase in the north-south atmospheric pressure gradient and to a shift in storm tracks towards northern Europe, and thus to a precipitation deficit over Spain and the northern Mediterranean Basin. Conversely, a negative NAO favours low pressure systems over the Mediterranean region which—in contact with cold air from the northeast—can generate snowfall in lowland areas, as occurred in Hérault department (France) in the winter of 2018.

On a seasonal scale, several studies based on atmospheric data combining general circulation models and *in situ* observations have revealed a link between *El Niño* (in the Pacific) and the winter NAO. These mechanisms function via the upper troposphere or stratosphere. At mid-latitudes, the ocean is a key factor in Mediterranean climate variability. Recent research has suggested that **the multi-decadal variability that prevails in the North Atlantic can modulate precipitation extremes in Europe**. However, the robustness of these statistical relationships is hampered by the scant number of years during which they have been assessed, and by the high non-linearity of the observed impacts. The different mechanisms involved may therefore be studied through idealized experiments with climate models. The study of climate forcings* on the Mediterranean Sea and their implications for climate forecasting is a prime focus of the ERA4CS* MEDSCOPE project involving *Météo-France* and the French National Institute for Agricultural Research (INRA) at Avignon. The main aim of the project is to enhance the integration of seasonal to decadal forecasts into hydrology, energy and agriculture impact models in order to generate relevant sectoral indicators.



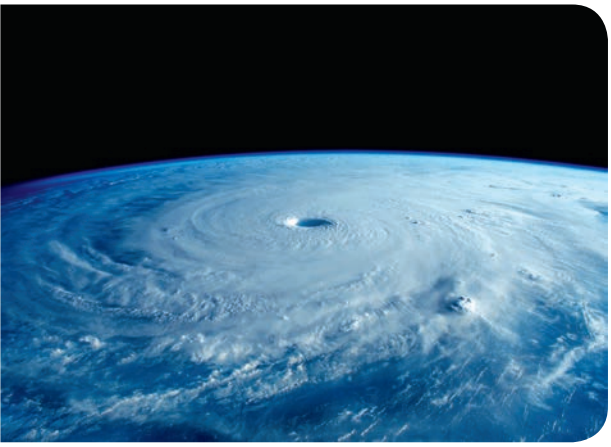
▲ *Covariance between the seasonal average rainfall (mm/day) and the NAO index in the Euro-Mediterranean region for the winter season (December-February) over the 1993-2015 period. The precipitation data are from the Global Precipitation Climatology Project (GPCP) reanalysis and the NAO index is derived from 500 hPa geopotential data from the ERA-Interim reanalysis.*
© L. Batté

Contact (CNRM):
L. Batté, lauriane.batte@meteo.fr

For further information on the Mediterranean Services Chain Based on Climate Prediction (MEDSCOPE) project: www.medscope-project.eu

* n.b. Climate forcings are disruptions in the Earth's energy balance that cause temperature changes (therefore generating winds).
** ERA4CS: European Research Area for Climate Services, cofunded by the European Commission.

Tropical cyclones – ocean monsters



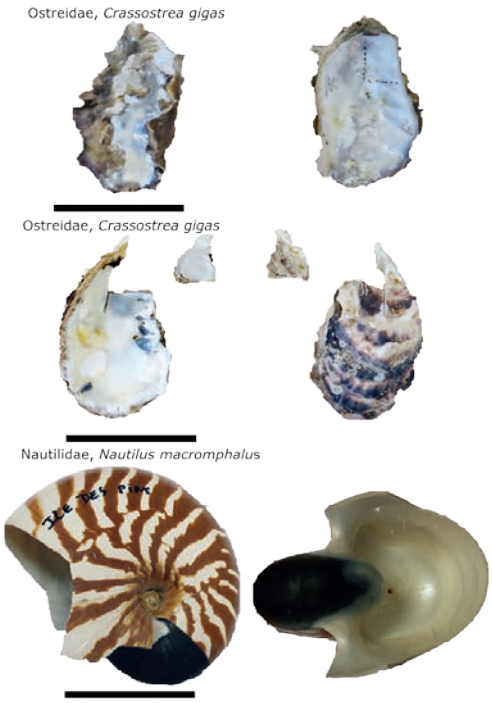
▲ *Typhoon Maysak approaching the Philippines as viewed from the International Space Station at 21:18:54 UTC on 31 March 2015.*
© Terry Virts/NASA/ISS [Public domain] via Wikimedia Commons.

Tropical cyclones—also known as hurricanes or typhoons—are among the most severe weather events on Earth, posing a major threat to coastal populations. These colossal natural engines are typical marine phenomena because they feed on the considerable thermal energy of the tropical ocean through evaporation. About 80 cyclones a year are formed around the world, mainly in summer, with two-thirds of them occurring in the Northern Hemisphere. Our understanding of cyclone distribution patterns, as well as the temporal variability in their activity, has greatly improved since the advent of meteorological satellites in the 1970s and the assimilation of their data into models. Climate is known to have a modulating effect on the environment that determines cyclonic formation—ocean temperatures, air humidity and upper-level winds. *El Niño*-Southern Oscillation (ENSO) has by far the greatest influence on the interannual variability in the cyclone frequency. The ENSO index thus serves as a predictive measure of seasonal cyclone activity, at least in the Pacific. High-resolution models have nevertheless shown that a significant portion of the variability in cyclone activity is unpredictable from one year to the next because it is subject to the vagaries of chaos, associated with the strong non-linearity of triggering processes. With regard to long-term trends, the relatively short period for which our data are reliable makes it difficult to discern climate change from natural variability occurring on decadal to multi-decadal scales. Climate projections based on current models are still unreliable, but the most widely shared assumption is that **global warming—involving effects in the ocean and atmosphere that may cancel each other—ultimately has little impact on the cyclone frequency and intensity**.

Contact (LEGOS): P. Marchesiello, patrick.marchesiello@ird.fr

Mediterranean coastal molluscs – the climate archives

Strontium is a chemical element that occurs naturally in seawater, and the relative abundance of some of its isotopes (e.g. 86Sr and 87Sr) reflects alterations in continental rocks and the seafloor, respectively. Despite the spatial heterogeneity of these two sources, the 87Sr/86Sr ratio in the world's oceans is surprisingly homogeneous because the mean residence time of strontium in seawater is higher than the overall ocean mixing time. Any deviation from this isotopic benchmark is therefore an indicator of the degree of mixing between normal seawater and fresh or brackish water from rivers or underwater resurgences with different isotopic signatures. This seawater geochemical ratio can therefore vary markedly in coastal areas, particularly since climate change is amplifying runoff on mainlands. Knowledge is lacking, however, on the factors that cause these fluctuations (nature of nearby rocks, freshwater supply, coastal configuration and climate conditions). Why do such geochemical anomalies occur in some coastal waters? How do the organisms that live in that environment perceive them?



▶ *Fig. 1. Example of analysed mollusc shells from Brittany and New Caledonia.* © S. El Meknassi

The GET joint research unit (UMR) used a TIMS* spectrometer (funded by Occitanie region) to study the strontium isotopic composition in water, sediment and mollusc shells from several coastal areas worldwide (see Fig. 1 opposite)**. The Salses-Leucate lagoon (Aude region) is a benchmark for the Mediterranean domain (see Fig. 2). Initial findings indicate that 80% of the world's coastal mollusc shells clearly reflect the isotopic composition of the oceans, while the remaining 20% show strong deviations due to the restrictive effects of water bodies and resurgences from coastal aquifers, such as the lagoons of Salses-Leucate and Oualidia (Morocco). These results highlight that **groundwater inputs can significantly change the geochemical composition of waters in some very confined coastal areas even when there is no significant river contribution**.

Contact (GET): G. Dera, guillaume.dera@get.omp.eu

* TIMS: thermal ionisation mass spectrometer.
** Malaco project of the LEFE-CYBER (*Les Enveloppes Fluides et l'Environnement – Cycles biogéochimiques, environnement et ressources*) programme of the National Institute for Earth Sciences and Astronomy (INSU).

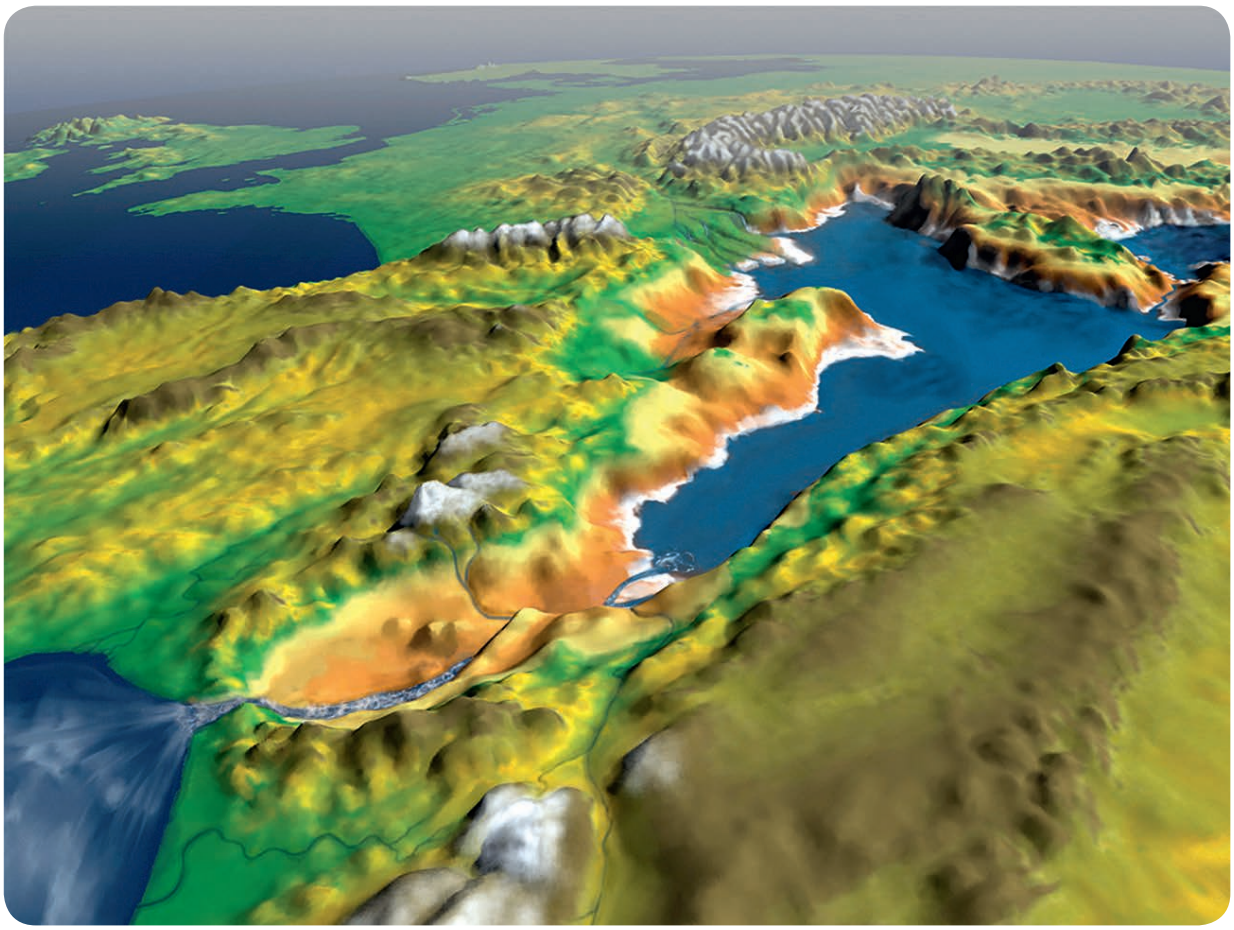
▲ *Fig. 2. Water, sediment and gastropod sampling at the Font Dame resurgence point on the western side of the Salses-Leucate lagoon.* © G. Dera

Messinian Salinity Crisis – when the Mediterranean Sea emptied

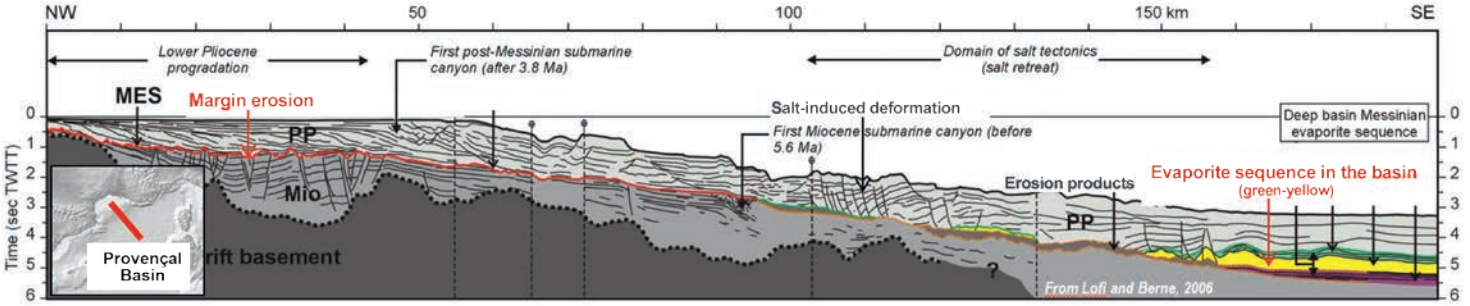
The Messinian Salinity Crisis (MSC) was an unprecedented event that dramatically altered the Mediterranean environment between 6 and 5 million years ago and still impacts the geology of the region today. The gradual closure of passages connecting the Mediterranean Sea and the Atlantic Ocean during the Messinian led to desiccation of the Mediterranean over a very short period on a geological time scale (300,000 to 600,000 years), but with far-reaching consequences. The sea level then dropped by as much as 1,500 m due to evaporation, leaving most of the basin dry, as is still evident today from the erosion surface which deeply scars all of the basin margins and from the overdeepening of upstream parts of the rivers (erosion extending northward past Lyon for the Rhône river, and beyond Assouan for the Nile!). The overall destabilisation of the basin caused mass transfer of erosion products to the basin floor, where a layer of evaporites more than 1 km thick precipitated. This massive salt layer has caused major tectonic deformations on post-MSC sediments while also impacting the hydrocarbon potential.

Since the discovery of this 'salt giant' in the 1970s via marine seismic techniques, the international scientific community has focused research on this crisis as it **provides a unique opportunity to analyse the factors controlling a sea-level decline of such magnitude**, including the combined effects of geodynamics and the climate on palaeoenvironments. Increasingly precise MSC scenarios are being formulated, while many questions remain, particularly about the causes, the chronology of events and their regional isostatic consequences. GET researchers are contributing to this quest through land and sea missions that are revealing spatiotemporal links between the different markers and through regular participation in specialized workshops.

Contact (GET): A. Maillard-Lenoir, agnes.maillard-lenoir@get.omp.eu



◀ *Western Mediterranean region during the Messinian.* *Source: Garcia-Castellanos D., 2009. Artistic illustration by R. Pibernat.*



▲ *Section of the margin to the deep basin illustrating the sub-shelf erosion area, saline deposits in the abyssal plain and subsequent overlying sediment deformations.*

Formation and acidification of deep Mediterranean waters – the role of the Gulf of Lion

Observing and modelling deep convection in the Mediterranean Sea to gain insight into its functioning, variability and evolution

Deep ocean convection occurs when atmospheric conditions make surface waters colder and/or saltier, and therefore denser, than the underlying waters. This causes vertical mixing of the water column, sometimes to the depth of the seabed. Dense waters formed in this way flow to the bottom of the oceans where they spread, resulting in the deep branch of ocean circulation. The convection intensity varies greatly from year to year, particularly according to weather conditions. Deep convection is common in the northwestern Mediterranean Sea during very cold winter gales such as the *Mistral* or *Tramontane*. This is responsible for the formation of deep water masses in the Mediterranean circulation, but also for the high spring production of biological organisms in the region. This process affects ocean dynamics as well as climate, biodiversity, fisheries resources and the carbon cycle. It is hence essential to gain insight into its functioning, monitor its variability and predict its evolution in response to global change.

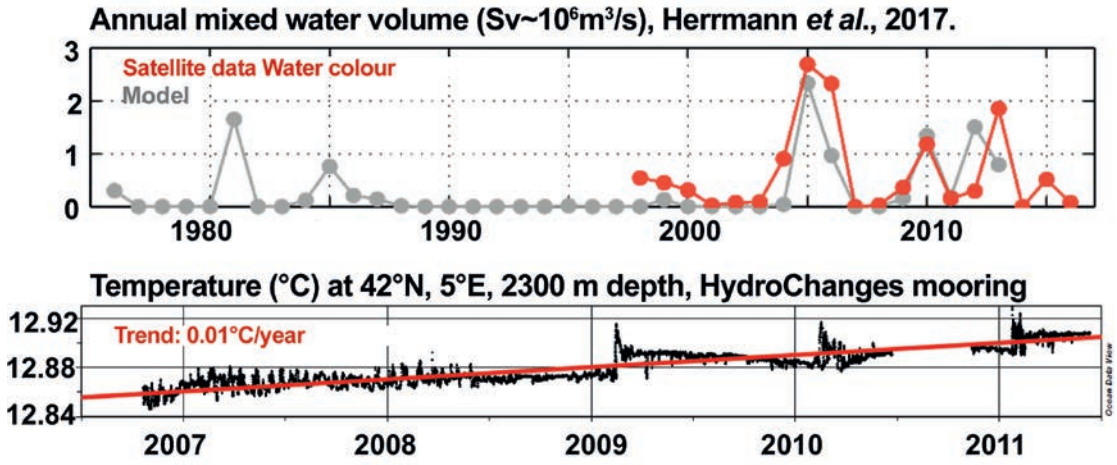
The effective combination of field observations, satellite data and numerical modelling tools in recent years has facilitated this research task. The fact that the Mediterranean Sea is relatively easy to access compared to other convection zones located at the poles has facilitated the development of intensive long-term observation programmes, which are invaluable for boosting knowledge on this phenomenon. The HyMeX (see p. 20) and HydroChanges* programmes have provided a remarkable opportunity to pool monitoring and modelling specialists from laboratories in different countries and regions around the Mediterranean Basin. Through this joint effort, interannual variability can for the first time be estimated over several decades, thus **enhancing insight into the convection phenomenon, something that model simulations suggest could decline sharply by the end of the century.**

Contacts: M. Herrmann (LEGOS), herrmann@legos.obs-mip.fr and I. Taupier-Letage (Mediterranean Institute of Oceanography, MIO), isabelle.taupier-letage@univ-amu.fr

For further information:

www.ciesm.org
www.hymex.org
www.mistrals-home.org
https://youtu.be/NTMORRHqcpE (video of the rescue of a HydroChanges mooring line equipped with oceanographic instruments to monitor climate change in the Mediterranean Sea).

* The HydroChanges programme is an initiative of the International Commission for the Scientific Exploration of the Mediterranean Sea, with a French contribution supported by the Hydrological cycle in Mediterranean eXperiment (HyMeX) programme and the Mediterranean Ocean Observing System for the Environment (MOOSE).



◀ *Top: Annual variations in the volume of dense water formed in the northwestern Mediterranean Sea based on the SYMPHONIE model (grey) since 1975 and satellite observations of the seawater colour (red) since 1998. Sverdrup (Sv) is a water volume transport measurement unit used to measure ocean current flows. Source: Herrmann* et al., *2017. J. Geophys. Res. Oceans. 122(2): 1457-1475. DOI:10.1002/2016JC011833*

◀ *Bottom: Temperature variations in the core convection zone (~42°N-5°E, ~2,300 m, time series recorded at 2,300 m depth from 2006 to 2011 (HydroChanges programme). The observations show an increase of 0.01°C/year over this period—comparisons between modelling data and satellite observations should reveal whether this is a long-term trend.*

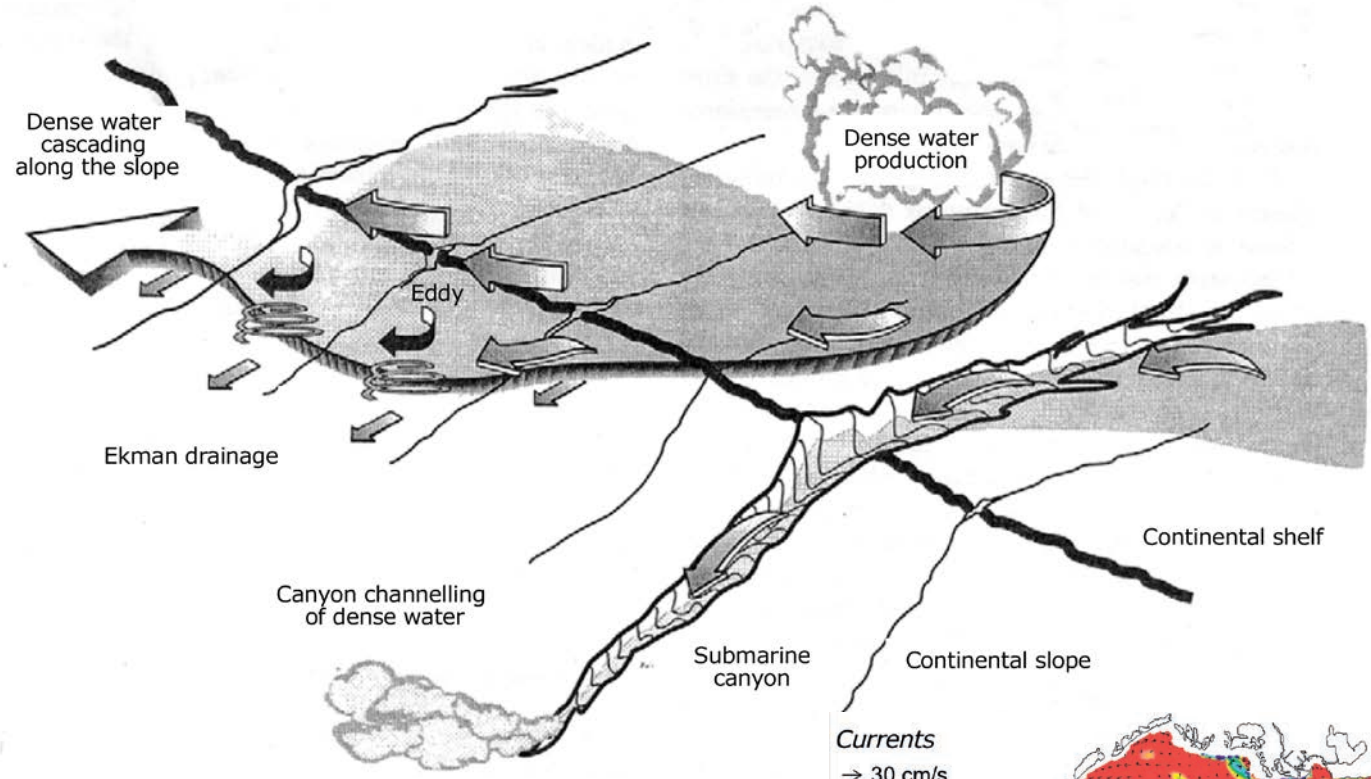
Ocean circulation has a vital climate buffering role that could be disrupted by a decline in circulation velocity.

Cascading – open-ocean convection and shelf-slope exchange dynamics

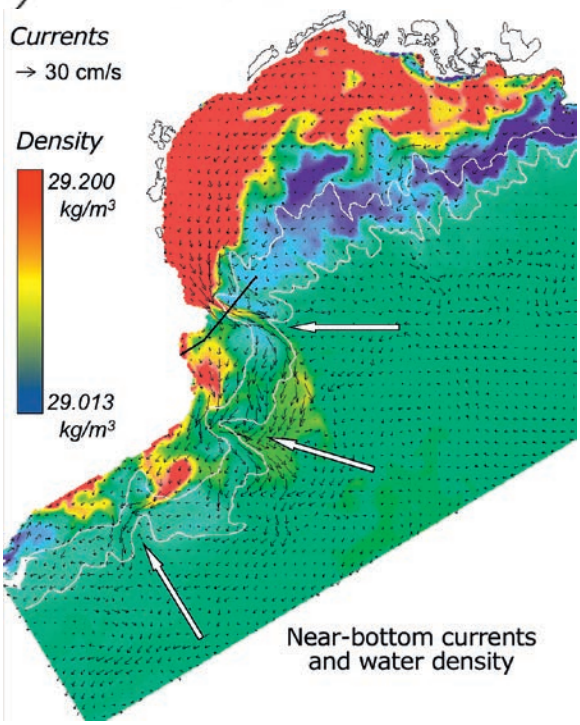
The Gulf of Lion consists of a continental shelf (120 m maximum depth), a continental slope, interspersed with submarine canyons that sharply drop to 2,000 m depth, and an abyssal plain. A permanent current (the so-called northern current), which flows along the slope, forms a barrier between coastal waters, influenced by river inflows, and offshore waters. The current is unstable and forms meanders, which result in mixing the coastal and offshore waters along their winding pathway. The predominant northerly (*Mistral*) and northwesterly (*Tramontane*) winds, as well as the occasional easterly and southeasterly (*Marin*) winds, modulate currents over the shelf and contribute to water and material exchanges between the coast and the open sea.

The Gulf also features major cooling of the sea surface in autumn and winter due to the gusting *Mistral* and *Tramontane* winds. In line with the deep water mass formation that occurs in the Mediterranean Basin, these meteorological conditions induce cold dense water mass formation along the Languedoc and Roussillon coasts. These dense coastal waters—conveyed by wind-driven currents—spill over the shelf and cascade by gravity along the slope. This downslope flow intensifies in the canyons that channel dense water to depths of 200-1,000 m during normal winters and deeper than 2,000 m in more severe winters. **This process, although local, induces a rapid and massive export of water laden with substances (sediment, organic matter, nutrients, pollutants and waste) from mainland and coastal sources to the deep ocean, while also directly impacting benthic ecosystems.** The most intense cascading events interact with deep water mass formation in the abyssal plain and have repercussions on the hydrology and dispersion of these materials throughout the western Mediterranean Sea. This process—like dense offshore water mass formation—is influenced by climate change, and **the formation and export of dense coastal water masses to the deep ocean would decrease with surface water warming. For 25 years,** CEFREM has been monitoring long-term water and particulate flows in several canyons and in the abyssal plain in the Gulf of Lion.

Contact (CEFREM): X. Durrieu de Madron, demadron@univ-perp.fr



▲ *Schematic view of the production of coastal dense water mass, formation of dense plumes, their movements on the shelf and subsequent downslope flow or via an underwater canyon.* *Source: Baines and Condie, 1998.* Antarctic Research Series. *75: 29-49. DOI: 10.1029/AR075p0029*



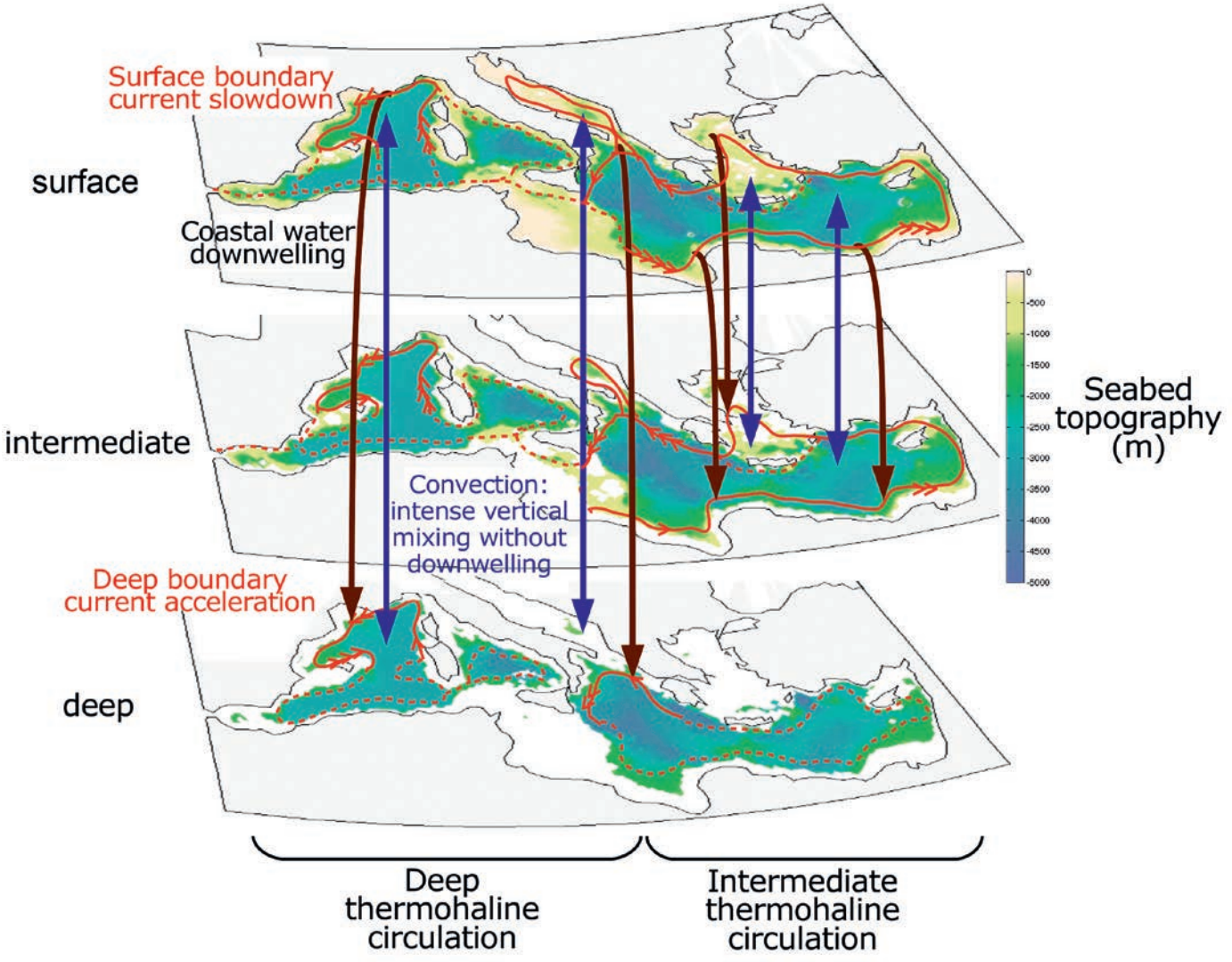
▶ *Potential density anomalies and simulated current speeds at 10 m above bottom for an extreme downwelling event on 13 March 2005 in the Gulf of Lion and along the Catalan margin.* *White arrows indicate dense water plumes channelled to the base of the continental slope via submarine canyons. Source: Ulses* et al., *2008.* Geophysical Research Letters. *35. L07610. DOI:10.1029/2008GL033257.*

Where does the Mediterranean thermohaline circulation sink?

For over half a century, scientific studies have highlighted the presence of so-called 'thermohaline' circulation in the Mediterranean Sea, similar to that of the global ocean—it can to some extent be considered as a regional version of it. This circulation—described as an oceanic 'conveyor belt'—is triggered by differences in seawater density, i.e. temperature (thermo) and salinity (haline). It has a key global climatic role as it transports warm surface waters, which sink as they cool, to the poles. If its speed were to decrease, its buffering capacity, and therefore its global warming mitigation role, would be reduced accordingly. The warming trend in the Mediterranean Sea that has been under way since the 1950s has recently accelerated to a greater extent than in the rest of the global ocean, combined with increased deep water salinisation. Therefore it is essential to analyse its warming trend and understand its circulation, and particularly the location of the rare and reduced areas of ocean convection, i.e. sinking according to the common belief.

Our team compared the results of a numerical model of the Mediterranean Sea and *in situ* observations off the French coast to determine where and how this sinking takes place. The findings indicate that it occurs in the vicinity of the coast and far from the open sea convection zones. In particular, we identified **sinking areas along the coasts of France, Libya (the most poorly monitored area in the basin), Egypt and the Aegean Sea**, some of which are far from convection sites. The physical analysis clearly highlighted the key role of the Earth's rotation, which hampers any downwelling far from the coast. This constraint—which has prevailed since the emergence of our planet—implies that **open-sea convection zones will never be sinking sites, contrary to the current belief**. Our results thus contradict the common view of a 'conveyor belt' sinking in convection zones and instead suggest the existence of 'coastal sinking rings' (see below).

Contacts (CNRM): R. Waldman, robin.waldman@meteo.fr, S. Somot, samuel.somot@meteo.fr and F. Sevault, florence.sevault@meteo.fr



▲ *Revised schematic diagram of the Mediterranean thermohaline circulation. At the Strait of Gibraltar—the sole interface between the Mediterranean Sea and the global ocean—the Mediterranean thermohaline circulation is characterized by a surface water inflow and a deep water outflow. Convection zones—historically viewed as the sinking areas of this circulation—actually just experience intense vertical mixing between surface and deep waters. Co nversely, boundary currents, which prevail throughout most of the basin, interact with coastal waters and are the main sinking area. Hence, as they sink, boundary currents weaken at the surface and intensify at depth. Only the three main thermohaline circulations (two deep and one intermediate) are represented here, while the remainder of the circulation (dashes) is overlooked.*
Source: Waldman et al., *2018.* Geophysical Research Letters. *https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2018GL078502*

Modelling deep water formation in the northwestern Mediterranean Sea and impacts on planktonic ecosystems

The water mixing mechanism driven by strong winds (as detailed above) intensifies during winter. This may—under harsh autumn and winter weather conditions—lead to homogenisation of the entire water column (~2,500 m depth) over an area of up to 50,000 km^2. The water properties (temperature, salinity, dissolved element concentration) from the surface to the seabed are then almost identical. This is a key process for deep systems that thus benefit from massive amounts of atmospheric oxygen and organic matter derived from the surface layers, as well as for surface systems that are substantially enriched with nutrients such as nitrates, phosphates and silicates. When vertical mixing stops in spring, phytoplankton remain at the surface exposed to light, therefore creating ideal phytoplankton 'spring bloom' conditions, i.e. the basis of food webs, whose scale is unparalleled in the rest of the Mediterranean Sea.

▲ *The DeWEX initiative during the winter of 2012-2013 (upper band) combined autonomous platform approaches with drifting buoys, underwater gliders (right and left photos in the lower band) and sampling surveys aboard oceanographic vessels (central photo of the lower band, launch of a rosette sampler with 12 Niskin bottles).*
© Conan Pascal

The question of the impact of climate change on these dense water formations and the resulting chemical and biological processes is crucial for the future of western Mediterranean marine ecosystems. Current environmental problems of acidification, oligotrophication of surface waters (increased stratification and biological depletion) and deoxygenation of deep waters (anoxia and creation of dead zones) are in part directly related to these hydrodynamic processes. The DeWEX* consortium carried out an intensive monitoring initiative in 2012-2013 to gain insight into atmosphere-ocean interactions and the impact of dense water formations on Mediterranean ecosystems. A multiplatform approach combining aircraft, balloons, ships, moorings, floats and underwater gliders has enhanced the overall understanding of wind-driven changes in water masses and the role of physical phenomena such as eddies and fronts that develop on a kilometric scale, and secondly of the nutrient distribution variability and associated pelagic ecosystem dynamics. This approach has significantly improved digital model parametering and verification.

Contacts: C. Estournel (LA), claude.estournel@aero.obs-mip.fr and P. Conan (LOMIC), conan@obs-banyuls.fr

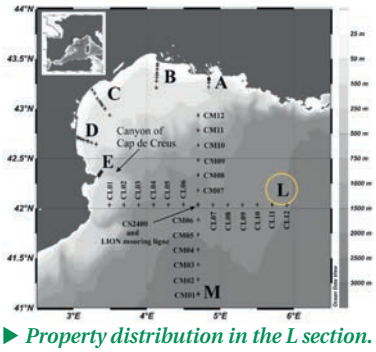
* DeWEX: Impacts of deep water formation on Mediterranean pelagic ecosystems.

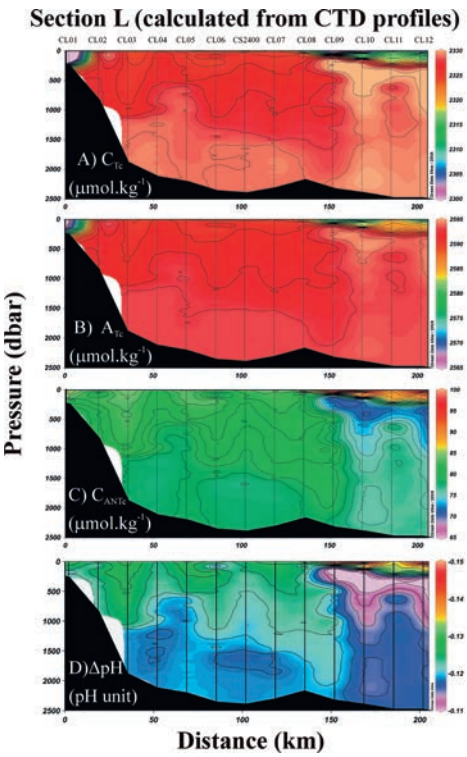
Anthropogenic CO_2 sequestration in a northwestern Mediterranean deep convection zone

One aim of the European MEDSEA project was to study the impact of the most active deep convection zone in the Mediterranean Sea (Gulf of Lion) on the anthropogenic carbon cycle. Measurements taken aboard an oceanographic vessel (CASCADE cruise) during the winter of 2011 enabled us to compare vertical profiles for different properties sampled under stratified conditions or during/after a convection event (see map below). The results revealed that a large amount of anthropogenic CO_2 (C_{ANTc}) is rapidly transferred to the deepest water layer during deep convection events (see opposite graph). The anthropogenic CO_2 concentration in the water column increases with the water density and oxygen content. **Deep convection in the Gulf of Lion, in conjunction with cascading along the continental slope, could thus explain the very high anthropogenic CO_2 levels observed—and thus acidification—in deep western Mediterranean water layers.**

Contacts: F. Touratier (ESPACE-DEV), touratier@univ-perp.fr, C. Goyet (ESPACE-DEV), cgoyet@univ-perp.fr and X. Durrieu de Madron (CEFREM), demadron@univ-perp.fr

For further information:
Mediterranean Sea Acidification in a Changing Climate (MEDSEA) project: http://medsea-project.eu
Cascading, Surge, Convection, Advection and Downwelling Events (CASCADE) cruise: http://campagnes.flotteoceanographique.fr/campagnes/11010020





▶ *Property distribution in the L section.*
A) Total dissolved inorganic carbon concentration (C_{Tc}, µmol.kg^{-1})
B) Total alkalinity concentration (A_{Tc}, µmol.kg^{-1})
C) Anthropogenic CO_2 concentration (C_{ANTc}, µmol.kg^{-1})
D) Acidification since the preindustrial age (DpH)
Source: Touratier et al., *2016.* Deep-Sea Research. *113: 33-48. DOI:10.1016/j.dsr.2016.04.0003*

Combined impacts of meteorological/oceanographic factors – the case of Cévennes floods

HyMeX – a research programme on intense rainfall and flash flood events in the Mediterranean Basin

The main objective of the international Hydrological Cycle in the Mediterranean Experiment (HyMeX) research programme is to gain further insight into the water cycle in the Mediterranean Sea and hydrometeorological events with high associated impacts, both in terms of predictability, evolution under climate change, and the socioeconomic vulnerability of territories and populations to these extreme events, as well as their adaptation capacity. Intense rainfall and flash flood events which regularly affect the Mediterranean region are a key focus of HyMeX. Hence, HyMeX researchers study these phenomena by monitoring and modelling the 'atmosphere/sea/continental surface' system at time scales ranging from a few hours to several years. A major 2-month international measurement survey—with *in situ* offshore, terrestrial and aerial monitoring—was organized in France, Spain and Italy in the autumn of 2012. For flash flood monitoring, hydrological measurements were repeated over several autumn seasons in the *Cévennes* basins, and sociological and hydrological measurements and surveys are carried out in the field after major events. These observations enhance our overall knowledge on the processes involved in the development of these events, as well as their modelling and forecasting. This programme, coordinated by *Météo-France* and CNRS, was launched in 2010 for a 10-year period as part of the multi-institutional** MISTRALS project. The scientific community involved in HyMeX includes more than 350 scientists from about 20 countries specialized in the fields of the ocean, atmosphere, continental surfaces, human and social sciences. **The programme has already generated extensive results, with more than 400 articles published in international scientific journals to date.**

▲ *Installation of new sensors in the framework of the HyMeX programme on the* Météo-France *fixed buoy in the Gulf of Lion.* © CNRM

Contact (CNRM):
V. Ducrocq, veronique.ducrocq@meteo.fr

For further information:
HyMeX programme: www.hymex.org
Mediterranean Integrated Studies at Regional and Local Scales (MISTRALS) programme: www.mistrals-home.org

** Collaborators: the main research laboratories and institutions in Occitanie region are the joint research units (UMRs) CNRM, IMFT (Toulouse Fluid Mechanics Institute), LA, LEGOS, HSM and CEFREM, IMT *Mines Alès* and the Universities of Toulouse and Montpellier.

Flooding and submersion in coastal areas

In autumn and winter, the northwestern Mediterranean Sea experiences storms with easterly winds and heavy rainfall, which often generate major so-called 'flash floods'. These events often also feature 'storm surges', involving a rapid rise in sea level that may be very serious in lowland coastal regions where communities, infrastructures and beaches are at risk of coastal submergence. Several mechanisms are often combined in major storm surges: atmospheric pressure drop, tide, wind and waves. A 1 hPa (1 mb) drop in atmospheric pressure will result in a sea level rise of about 1 cm, while pressure drops of more than 30 mb are common. The sea level varies by 20 cm throughout the Gulf of Lion during a tidal cycle. When the wind blows against the coast—as often occurs during storms along the Languedoc and Roussillon coasts—water accumulates, which causes a further rise in sea level of about 10 cm. Finally, the least documented mechanism is related to breaking waves. These waves are formed several hundreds of kilometres offshore from the Gulf of Lion and they increase in height as they progress, sometimes reaching heights of 6-10 m in the Gulf. As the depth decreases near the coast, the waves begin breaking since they can no longer propagate freely, thus further boosting the mean sea level, in some cases by several dozens of centimetres. **Rising sea levels can cause coastal flooding, while also sometimes stalling the flow of inland rivers, in turn inducing overflows. Forecasting these events is still very complicated because all of these mechanisms must be accurately taken into account.** The Aerology Laboratory is developing the tools necessary for this modelling, which have already been tested as part of the CRUE-SIM* project around the mouth of the Têt River in the Pyrénées-Orientales region (see below).

Contact (LA): C. Estournel, claude.estournel@aero.obs-mip.fr

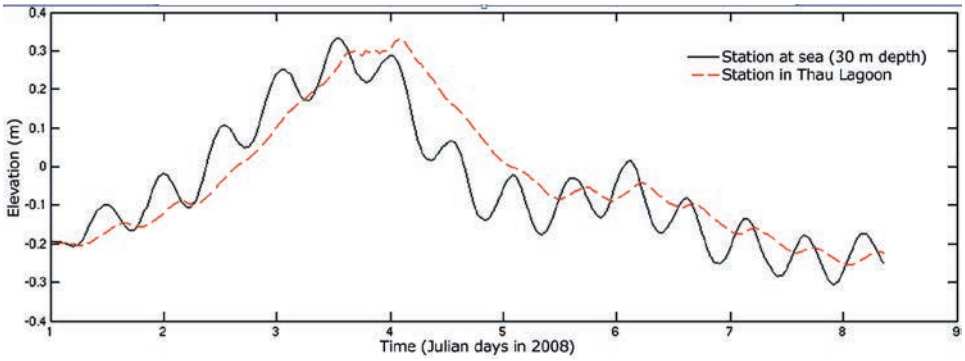
* *Transport de l'eau et de matière depuis les bassins versants jusqu'à la mer dans les systèmes Méditerranéens caractérisés par des crues éclair* (CRUE-SIM) project supported by the *Réseaux thématiques de recherches avancées Sciences et Technologies pour l'aéronautique et l'espace* (RTRA STAE networks).

▲ *Modelling flooding due to Têt River overflow (Pyrénées-Orientales region) and marine submersion. The colours highlight water-covered areas. Here the flooded areas correspond mainly to the former Têt riverbed and no-build zones between the former and current riverbeds.*
© P. Marsaleix/Aerology Laboratory

Exchanges between the Thau lagoon and Mediterranean Sea – the role of tide and storms

The astronomical tide is generally considered to be a minor process in the Mediterranean Sea, but it does control regular exchanges between coastal lagoons, such as Thau, and the open sea. These exchanges are studied through high-frequency monitoring using acoustic current meters based on the Doppler effect and multi-parameter sensors positioned at sea, in the lagoon and in the Sète canals. A numerical model coupling a hydrodynamic model (Symphony) and a biogeochemical model (Eco3m-s) is also being developed within the framework of PhD thesis research focused on the impact of extreme events. **In addition to the tide, differences in level between the sea and the lagoon during storm events can induce major inflow towards the lagoon and then sudden outflow towards the Sea, thus highlighting its marine character.** Accurate high resolution water level modelling is necessary to properly simulate these exchanges (see below). It is essential to take all of the effects into account, including the astronomical tide, the inverse barometer and the impact of winds, currents and waves.

Contacts (GM): Y. Leredde, yann.leredde@umontpellier.fr and R. Caillibotte, remi.caillibotte@gm.univ-montp2.fr



▲ *Elevation of the free water surface (m) simulated over a time course at two stations in the Mediterranean Sea and Thau Lagoon between 01/01/08 at 12 am and 08/01/08 at 12 pm.*
Source: Leredde Y., 2011. Apports de l'océanographie physique côtière à la caractérisation des risques littoraux. *PhD thesis, UM2, France. 122 p. www.gm.univ-montp2.fr/IMG/pdf/HDR-leredde-2011.pdf*

Understanding the causes of sea level rises and predicting future coastal impacts

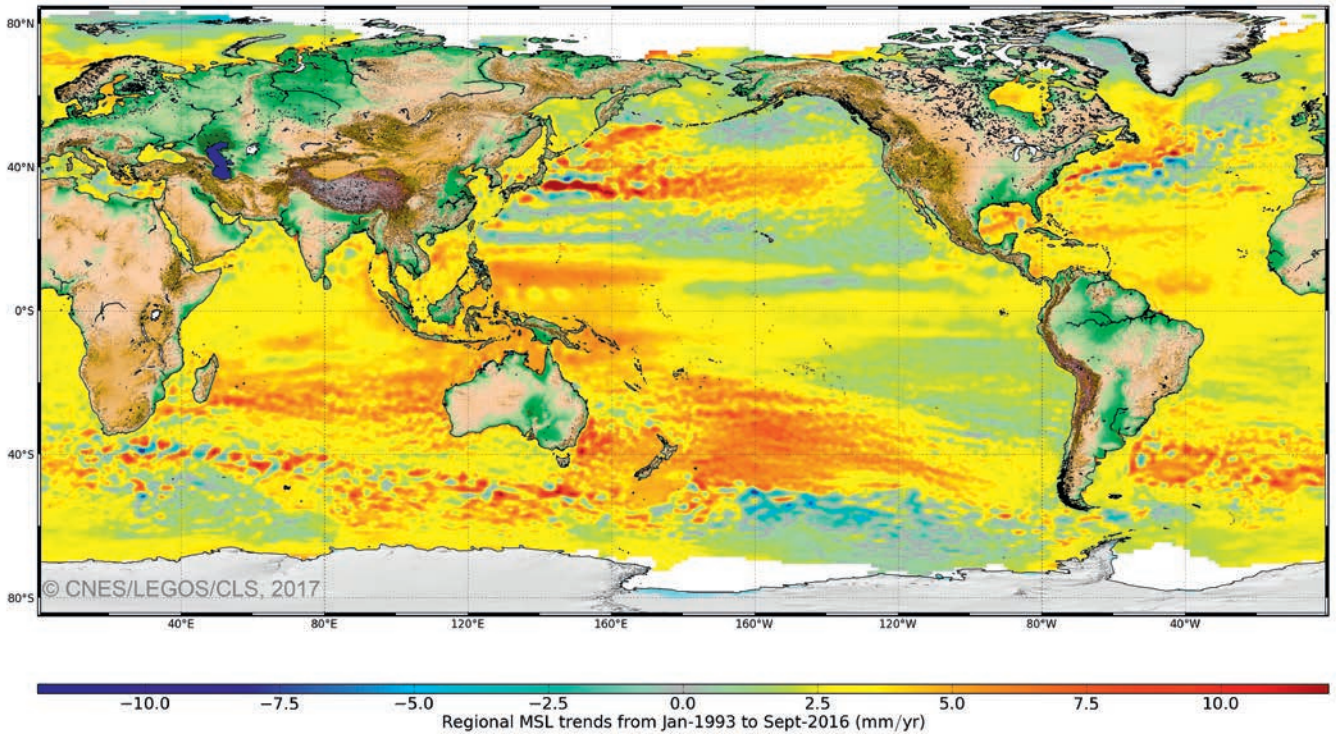
Tide gauges indicate that the sea level rose at an average rate of 1.5 ± 0.4 mm/year during the 20th century. Meanwhile, since the early 1990s, there has been an overall average rise of 3.2 ± 0.4 mm/year, with marked regional variability, as revealed by satellite altimetry data, which has become an essential complement to tide gauges since 1992 (see Fig. 1). The sea level rise is mainly due to ocean warming and continental ice melting (mountain glaciers and polar ice caps) as a result of anthropogenic greenhouse gas emissions. **Ocean warming is mainly responsible for regional variability in the sea level rise.**

Climate models indicate that the sea level will continue to rise in the future. **For the 2081-2100 period, models predict an average rise of 26-81 cm** (relative to the 1986-2000 period) under future warming scenarios, with an uncertainty range of ± 15 cm due to the imperfection of present models. Substantial regional variability (± 30% of the overall average) will overlap the overall average rise (see Fig. 2).

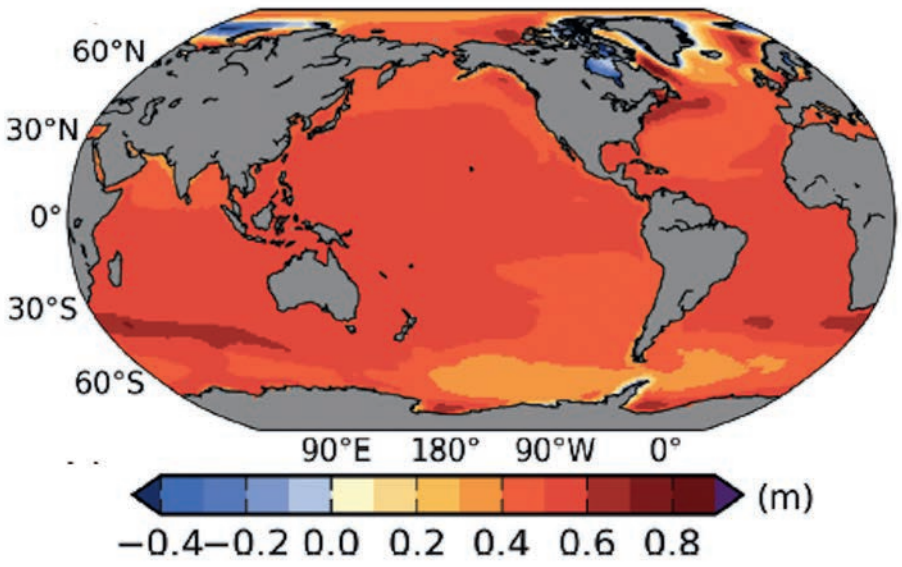
Many doubts remain about the processes involved in sea level variations. LEGOS is actively working with CNES and CLS satellite data to gain greater insight into these processes. Their simulation has been improved in ocean forecasting models in collaboration with *Mercator Océan* and in climate models with *Météo-France* and CERFACS. The aim is to fine-tune future sea level projections so as to foresee their impacts and prepare coastal adaptation strategies. LEGOS is conducting research jointly with CLS and BRGM—and with the participation of coastal communities—on the impacts and adaptations to rising sea levels.

For further information:
www.aviso.altimetry.fr
www.cerfacs.fr/avbp7x/index.php

Contacts: B. Meyssignac (LEGOS), benoit.meyssignac@legos.obs-mip.fr, G. Larnicol (CLS) glarnicol@cls.fr, D. Salas y Mélia (CNRM), david.salas@meteo.fr, A. Melet (Mercator Océan International), angelique.melet@mercator-ocean.fr, N. Picot (CNES), nicolas.picot@cnes.fr, G. Le Cozannet (BRGM), g.lecozannet@brgm.fr and L. Terray (CERFACS), laurent.terray@cerfacs.fr



▲ *Fig. 1. Rate of sea level rise based on satellite observations since 1993.*



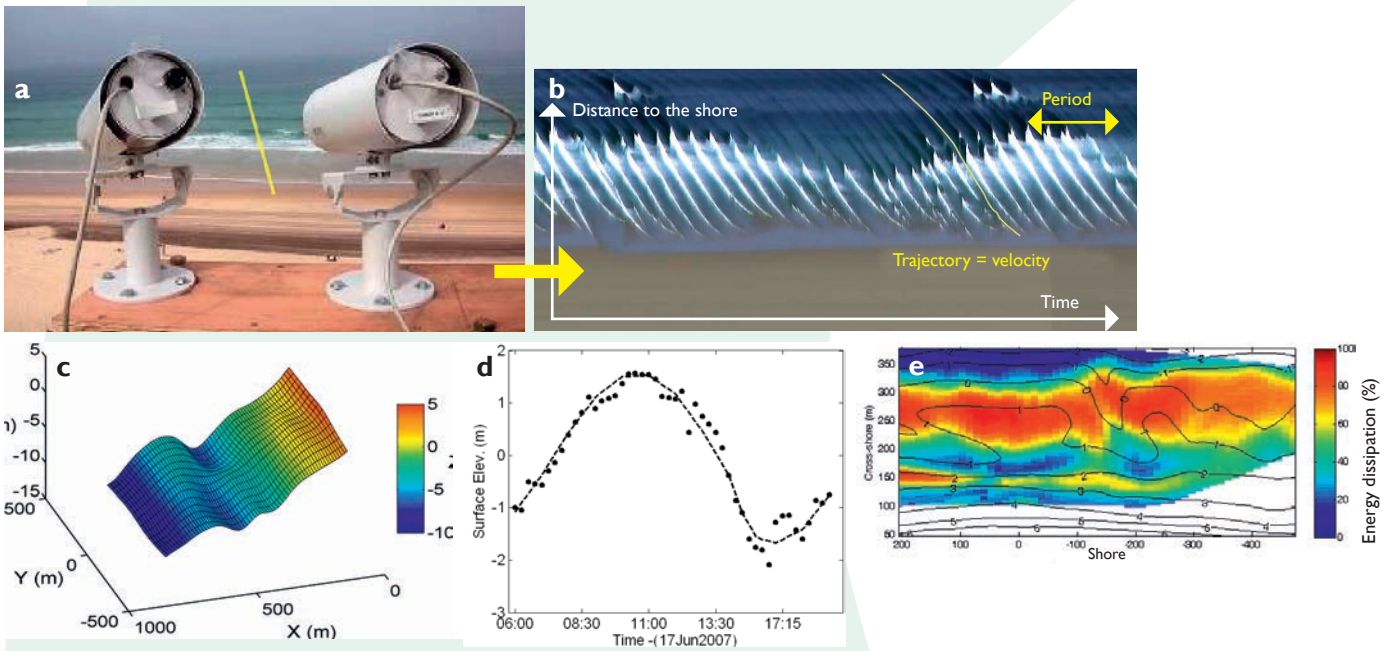
▶ *Fig.2. Sea level projection for the 2086-2100 period compared to 1986-2100 under an average greenhouse gas emission scenario. Source: Church* et al., *2013. Sea level change.* In: *Stocker* et al. *(eds.) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge, UK and New York, NY, USA).*

PREDICTING STORM SURGE AND FLOOD RISKS BY VIDEO DATA ASSIMILATION

Ocean storm surges are complex phenomena that depend on the atmospheric (wind, atmospheric pressure) and swell (wave setup) conditions. While all of these components are now fairly well managed by forecasters for the nearshore area, the effects of these extreme water levels and their impacts on the shoreline are still complex to model. One of the main difficulties concerns the lack of bathymetry data, which is an essential input to which the digital model is highly sensitive. This parameter also has to be assessed in ultra-dynamic environments like the nearshore area. Video technology enables seamless measurement of beach changes and characterisation of different beach profile elements (bar, surf and run-up area, intertidal beach). The entire profile can then be described by combining all of this information. However, information elements extracted from the video are only 'proxies' linking, for instance, the wave dynamics to the bathymetry by inversion methods. Since the physical aspects of waves in shallow waters are typically nonlinear, inversion of these proxies requires information that is only available via the model. To address this issue, data assimilation enables heterogeneous and uncertain model information to be matched with *in situ* observations so as to obtain a more reliable estimate of the underlying bathymetry. The OPTIBAT* project aims to dynamically integrate these assimilation techniques into a hydrodynamic model in order to correct the bathymetry and certain hydrodynamic parameters when *in situ* observations are available. This has generated an operational and dynamic assimilation system while greatly enhancing the forecasting of marine submersion phenomena.

Contacts: Y. Soufflet (Waves'n See), yves.soufflet@wavesnsee.com, R. Benshila (LEGOS), rachid.benshila@legos.obs-mip.fr, R. Almar (LEGOS), rafael.almar@legos.obs-mip.fr and E. Simon (IRIT), ehouarn.simon@enseeiht.fr

* OPTIBAT project: *Recherche optimale pour la bathymétrie littorale.*



▲ *Collection of data from video observations.* © *R. Almar/UMR LEGOS/IRD*
a. Timetack extraction: composite image formed by a line of pixels extracted from each video image
b. Wave period and velocity measured via peak detection
c. & d. Bathymetry and water level estimation
e. Wave energy dissipation

Depending on the region, a 26-81 cm rise in sea level is expected by the late 21st century due to global warming.

*Common two-banded seabream shoal (*Diplodus vulgaris*) in Cerbère-Banyuls Marine Reserve.*
© Pascal Romans / Sorbonne University

Biodiversity and dynamics of marine biological communities

Seas and oceans cover 70% of the Earth's surface and are essential reservoirs of biodiversity, hosting extremely varied biologically rich habitats located in shallow coastal waters to deep sea trenches. The United Nations declared 2010 the International Year of Biodiversity to raise public awareness on the state and implications of the global decline in biodiversity. Insight into marine biodiversity is still very sketchy—especially in deep-sea zones—due to the sheer complexity of monitoring marine flora and fauna (scant sunlight and other radiation penetration in seawater) and the very high cost of offshore surveys (especially since the depth of this 3D environment can exceed 1,000 m). Biodiversity damage therefore often goes unnoticed in this secret and mysterious world. The lack of barriers in the marine environment also facilitates the dispersal of marine organisms. New marine species are thus gradually being discovered as ocean exploration continues.

Over half of the world's population now lives within 60 km of the 1.6 million km of sea coast, and this figure could reach 75% by 2020. Anthropogenic pressure on oceans is an ever-increasing phenomenon, particularly in coastal areas, thus seriously undermining marine biodiversity. Around 275,000 marine species have been identified to date, representing 15% of global biodiversity. This natural heritage is the result of thousands of years of evolution and is a vital resource upon which humankind depends. Many of these species are essential for human wellbeing, either directly as a key food resource (via fisheries and aquaculture) or indirectly to uphold the proper functioning of marine ecosystems and the services they render to the biosphere, including humankind.

Biodiversity refers to variability among living organisms of the same species (genetic, physiological and biological diversity), the number and proportion of species within a community, as well as ecosystems in a given area (coastal, continental shelf, deep sea ecosystems). Under natural and anthropogenic pressure, the loss of genetic diversity weakens species' adaptive capacity, while species loss lowers the resistance of biological communities and ecosystems to anthropogenic impacts and environmental change, thus undermining the adaptation capacity of the entire biosphere.

Biodiversity therefore plays an essential role in marine ecosystem functioning and contributes to numerous ecosystem services. Local species richness can improve ecosystem productivity and stability (i.e. capacity to withstand recurrent disturbances). Biodiversity loss could have serious global economic impacts, while also altering and reducing commercial seafood resources and essential services provided by oceans, including contributions to the water cycle, to global regulation (e.g. carbon sequestration) and to human culture (e.g. tourism).

The north-western Mediterranean, particularly the Gulf of Lion, is a habitat-rich (lagoons, continental shelves, canyons) and highly productive (e.g. in the Rhone estuary) biodiversity hotspot. However, the coastal of the French Occitanie Region (220 km long) is also at high risk of suffering the consequences of climate change—droughts, floods, shoreline erosion, submersion due to the sea level rise—along with other anthropogenic impacts such as marine pollution (plastics, heavy metals, persistent chemical compounds) and overfishing, etc. Meanwhile, the Occitanie coastal area is still attracting many people to the region, thus generating significant demographic momentum. Indeed, over half of the human population growth under way in Occitanie is concentrated in the coastal area, making it one of the most dynamic regions in France. By 2030, the population of the region will likely increase by roughly 800,000, with an influx of over 50,000 new inhabitants a year. Around 8 million tourists also visit the region every summer, thus putting further pressure on the marine environment.

Many Occitanie-based research teams have long been focusing studies on the region's exceptional biodiversity in both land and marine environments. In relation to the marine environment, several teams are conducting research on the functioning of French Mediterranean marine ecosystems and their responses to environmental variations. This research spans the entire spectrum of living organisms, ranging from microbial communities to megafauna, including target (or model) species, among which the most iconic species harvested in this area. These teams are developing novel assessment and monitoring tools, as well as novel research platforms.

Jean-Marc Fromentin (IFREMER, UMR MARBEC),
Catherine Aliaume (UM, UMR MARBEC) and
Philippe Lebaron (Sorbonne University, CNRS, USR LBBM)

Structure, dynamics and functioning of marine communities

Mediterranean coralligenous habitats and *Posidonia oceanica* meadows

Posidonia oceanica meadows and coralligenous reefs are the most biodiverse coastal marine habitats in the Mediterranean Sea. The French Mediterranean coastal area (1,700 km) hosts 72,641 ha of *P. oceanica* meadows and 2,661 ha of coralligenous reefs*. Since 2010, 96 *Posidonia* and 83 coralligenous sites have been monitored every 3 years by the TEMPO and RECOR monitoring networks, respectively (both overseen by *Andromède Océanologie*, with the support of the Rhône-Mediterranean-Corsica Water Agency). An analysis of RECOR photoquadrats ('coralligenous' observation task conducted by the Earth Science and Astronomy Observatory [OSU] OREME) showed that the functional and phylogenetic diversity of coralligenous reefs increased gradually as the reefs approached the surface. However, the deeper the sites, the greater the diversity of the species assemblages, particularly a 50-70 m depth, where the differences are greatest.

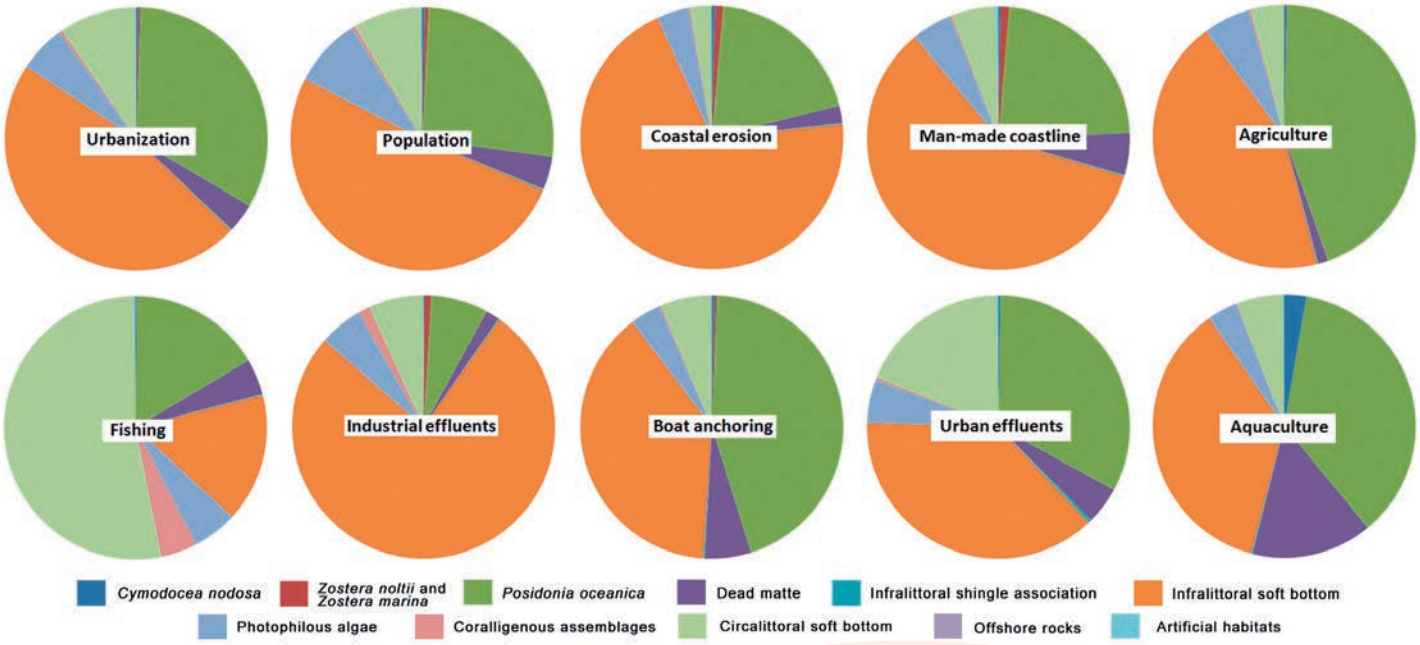
Over 68% of coralligenous habitats are subject to medium-to-high cumulated pressures (10 pressures considered, see below). Using automatic identification system (AIS) data for vessel identification and tracking, it has been demonstrated that close to **30% of the coastal seabed is impacted by the anchors of large ships, with *P. oceanica* meadows being the most durably affected**. Marine *P. oceanica* meadows are habitats most subject to cumulated pressures in coastal areas. In the French Provence-Alpes-Côte d'Azur Region (200 km of coastline), a comparison of 1920s aerial photographs (prior to any coastal artificialisation) with current images shows that **73% of *P. oceanica* communities (0-15 m depth) have declined, representing a 13% loss in *P. oceanica* cover.** Landscape indices are now being sought in order to establish correlations between *P. oceanica* community configuration and dynamics**.

Contacts: J. Deter (Andromède Océanologie/ISEM/LabCom InToSea), julie.deter@andromede-ocean.com, F. Holon (Andromède Océanologie), florian.holon@andromede-ocean.com and F. Houngnandan (ISEM), fabrice.houngnandan@umontpellier.fr

For further information on the Medtrix mapping platform managed by the *L'œil d'Andromède* non-profit organisation: www.medtrix.fr

* Mapping conducted as part of F. Holon's PhD thesis research with Andromède Océanologie: https://tel.archives-ouvertes.fr/tel-01279487v1
** Occitanie Region/Water Agency thesis under way.

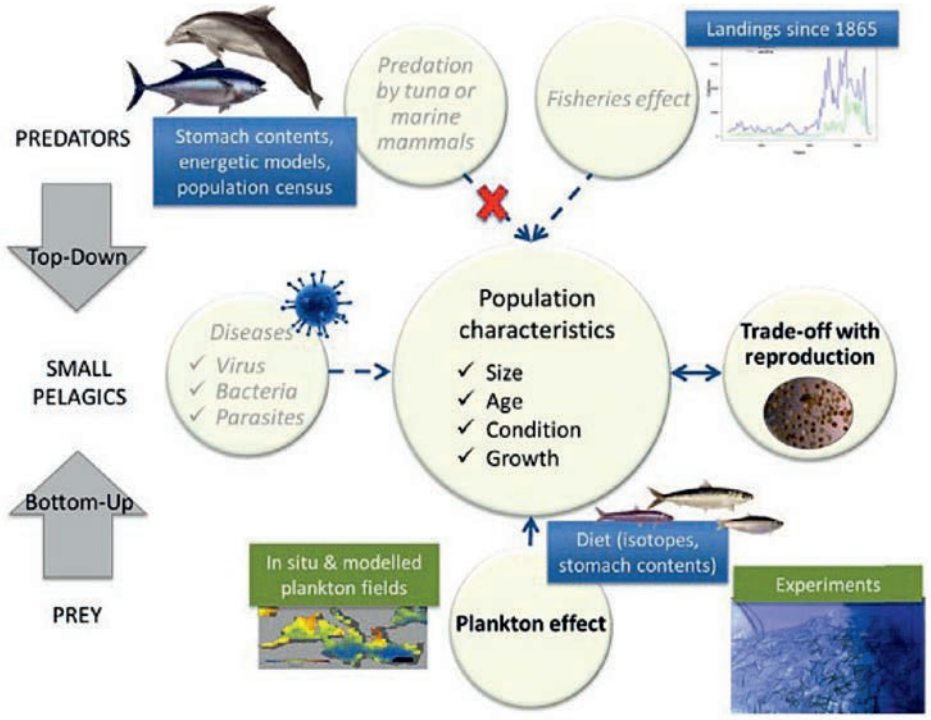
▼ *Distribution of the total cumulated value of pressures as a function of coastal marine habitat.*
Each graph shows the distribution (percentage) of the total cumulative value (sum of all 20 x 20 m cell values concerning a pressure) for each individual pressure (name indicated in white rectangles) as a function of the habitats. From Holon et al., *2015.* Plos One.



Disruptions of marine ecosystems impact the adaptive capacity of organisms, ecosystem habitats, population distributions and dynamics, as well as community structure and functioning.

Why are Gulf of Lion anchovies and sardines disappearing from your stalls?

In recent years, sardine and anchovy catches have declined sharply in the Gulf of Lion, even though these two species have historically been by far the most important species for fishermen. However, the fish have not disappeared. On the contrary, their numbers have increased. Why then are the two species disappearing from your stalls? The culprit is fish size. Indeed, sardines and anchovies are much smaller and leaner than they used to be, and their purchase price is no longer sufficient to enable fishermen to cover their costs. As a result, fishermen have stopped fishing these two species, and are turning to other ones. But, how do we explain these changes in fish size and condition? Although the fish are growing more slowly, our studies have also demonstrated that they are dying younger, resulting in a population made up solely of young individuals (0 to 2 years), despite the fact that they can normally live up to 6 or 7 years. **Such an increase in mortality is not due to fishing, nor to predation pressure from tunas or dolphins, which remains limited, nor even to pathogens. Rather, it appears that we are dealing with a change in diet.** Sardines and anchovies are now feeding on smaller prey (plankton) than before, which might explain their slow growth and low energy reserves. Nevertheless, they are continuing to invest a lot of energy into reproduction, which may be the source of the increase in adult mortality. In order to gain a better understanding of why this change in diet has occurred, we are currently tracing climate, oceanographic and plankton related data back 25 years. At the same time, we are conducting tank experiments to understand the ecophysiological consequences of diet change on these fish. This work is part of the MONALISA project (EMFF*, Measure 28), funded by the European Union, France and *France Filière Pêche*.



▲ *Summary diagram outlining the main potential causes of the poor condition of Mediterranean sardines.*
© Claire Saraux/MARBEC

Contact (MARBEC):
C. Saraux, claire.saraux@ifremer.fr

* European Maritime and Fisheries Fund.

Gilthead seabream life cycle and key habitats

The gilthead seabream is hermaphrodite (first male then female). Its exploitation in Occitanie dates back over 2,500 years, with significant socio-economic implications, as most of the wild seabream consumed in France comes from Occitanie fish auctions. Yet, to date, no local management strategy is being applied to the harvesting of this emblematic fish, mainly because of a lack of knowledge about its life cycle and key habitats in the Gulf of Lion. In order to fill this knowledge gap, approximately 400 seabreams (larvae, juveniles and adult males and females) have been collected since 2008 for study purposes, both at sea and at the inlet of four diverse lagoons spread along the Languedoc coast. The objective of this research is to finally be able to correlate local seabream population genetic structure and habitats with the probability of its individuals reaching the adult stage and contributing to the next generation of seabream, first as males and then as females. This correlation is made possible by optimising the use of the physiological (growth rate) and environmental (water bodies inhabited) information stored throughout the fishes' lifespans in their 'ear stones' (otoliths). Our analyses have already confirmed the existence of two distinct spawning areas for the local seabream population, and clarified fish growth determinism (genetic and/or environmental) and its consequences upon survival and reproduction. This has demonstrated **the central role of lagoons in the renewal, productivity and genetic diversity of the stock caught at sea: over 80% of the adult seabream spent their first year in lagoon areas, where growth rates are often higher, with consequences on fish sex change and age at sexual maturity**.


© Sébastien Villeger

This knowledge will enable more sustainable fish stock management, based on reliable biological data and knowledge of the coastal habitats that must be protected in order to keep this emblematic species in the region.

Contact (MARBEC):
A. Darnaude, audrey.darnaude@cnrs.fr

For further information on the Boucledor project (Researcher for the future project, European Regional Development Fund - Languedoc-Roussillon Region):
www.boucledor-project.com

ELECTRONIC TRACKING OF MARINE MEGAFAUNA IN THE NORTH-WESTERN MEDITERRANEAN

Acquiring biological knowledge relating to the way in which exploited species and/or species indirectly impacted by fishing activities tend to use space throughout their life cycle is essential in order to optimize the efficiency of future management measures. Yet, understanding the life cycle of marine fish poses a serious scientific challenge, as continuous observation at sea is challenging and costly. The advent of electronic tagging is shaking up this context, making it possible to follow the individual movement of fish, turtles, marine mammals and seabirds, and to study how these animals respond to environmental changes of natural origin (such as the *El Niño* phenomenon) and anthropogenic origin (fishing, marine pollution, climate change). This information is even more critical today in the Mediterranean, a body of water caught between two continents and subject to extreme human pressure. Thanks to the important technological progress that has been made over the past 20 years, a wide range of electronic tagging has been developed. Thus, researchers have equipped a wide spectrum of both significant-sized marine animals, such as blue sharks, common stingrays, bluefin tuna and loggerhead sea turtles, and smaller-sized marine fish, such as gilthead seabream, European bass and eels. Results on bluefin tuna have shown that while each trajectory is unique and different from one individual to the next, collective seasonal migrations occur at specific times of the year, demonstrating that these fish are able to memorize seasonally rich prey areas and return to these areas at a specific time of the year. Knowing these species' movements and what motivates them may seem trivial, but it remains essential for addressing key scientific issues, such as the identification of feeding and breeding areas, migration routes, and even habitat attractiveness and geographical coverage.

Contacts (MARBEC): J. Bourjea, jerome.bourjea@ifremer.fr and J.-M. Fromentin, jean.marc.fromentin@ifremer.fr

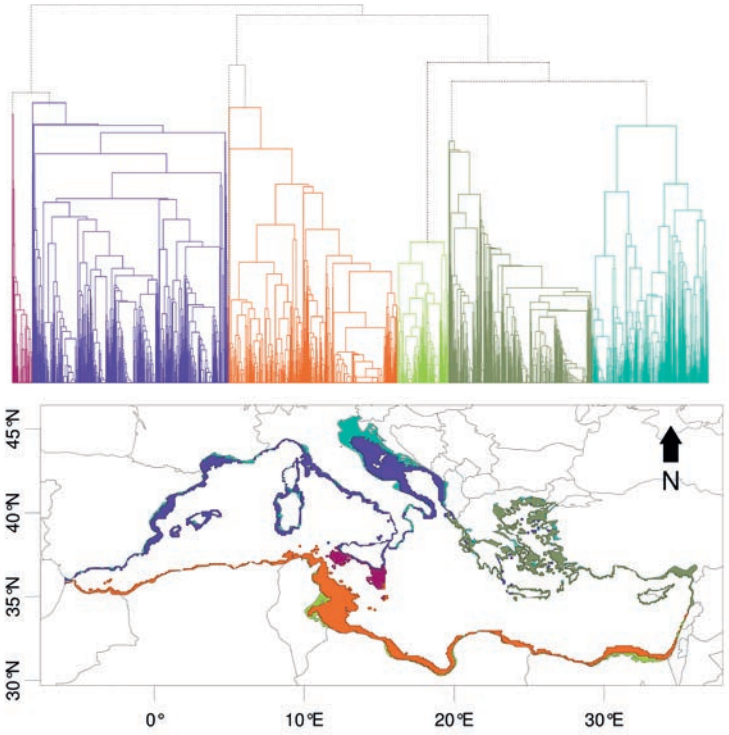
▲ *Loggerhead sea turtle equipped with an electronic tag.* © *J. Bourjea/IFREMER*

Biogeography of fish communities in the Mediterranean

The precise definition of ecosystem biological boundaries is often considered a key step in resource management and conservation policy implementation. Identifying these biological boundaries effectively means delimiting biogeographical regions characterized by specific species communities separated by distinctive environmental conditions and/or geographical history. Research work has been undertaken in the Mediterranean Sea in order to delineate the continental shelf's biogeographical regions, drawing upon the spatial distribution and evolutionary relationships (phylogeny) of 203 coastal saltwater fish. This research has identified **six biogeographical regions across the Mediterranean continental shelf**. These regions display a clear division between the northern and southern regions, as well as a disjunction between coastal and offshore areas. Observed biogeographical gradients are mainly linked to the temperature/depth gradient. In addition, results indicate that, with the exception of a few fish families, such as the Gobid family, evolutionary processes play only a minor role in structuring contemporary fish biodiversity patterns. Indeed, results show that **no major species differentiation events have been caused by the geographical isolation of populations, a sign of such events being a contrasted distribution of taxa**. Thus, the recolonisation with native Atlantic species that followed the Messinian Salinity Crisis (see p. 15) may be behind the biodiversity of today's native Mediterranean species. **It appears that climate is the main determinant of fish diversity distribution in the Mediterranean.**

Contacts (MARBEC): T. Hattab, tarek.hattab@ifremer.fr and F. Leprieur, fabien.leprieur@umontpellier.fr

For further information:
https://doi.org/10.1111/jbi.12505



▶ *Map of biogeographical regions of Mediterranean coastal fish. Dendrogram (tree diagram) showing the hierarchical relationships between identified biogeographical regions.*
© Tarek Hattab/MARBEC

Do cetaceans have a sense of smell?

In the course of their singular evolutionary history, cetaceans' sensory systems have adapted to the aquatic environment, as evidenced in particular by the evolution of their exceptional acoustic capacities. On the contrary, according to a few anatomical and genetic studies, the chemical senses of these marine mammals may have greatly regressed or even disappeared. Have cetaceans really lost the use of this sensory channel, so fundamental for feeding, navigation and reproduction in other large marine predators?

Our research aims to establish, through a multidisciplinary approach (behavioural, anatomical and chemical), whether cetaceans are able to perceive and use the chemical indices found in their environment. The behavioural component of this study has enabled the observation of toothed (*Odontoceti*) and baleen (*Mysticeti*) whale reactions to food-related chemical *stimuli,* thanks to an innovative protocol using drones. **The cetaceans that were studied were able to perceive chemical compounds, such as, in the case of *Odontoceti* (bottlenose dolphin and pilot whale), dimethyl sulphide, a volatile molecule emitted in areas of high marine primary productivity.** As for humpback whales (*Mysticeti*), they were attracted to the chemical signal's source when prey extracts (krill) were used. In parallel, an anatomical study of oral and nasal mucosa was initiated on deceased, stranded cetacean specimens, in partnership with the Montpellier Experimental Histology Network (Biocampus Montpellier). Potential pheromones involved in social cetacean communication are also being investigated through chemical analysis of stranded cetaceans' urine and faeces. This component of the study draws upon the support and technical competence of the Platform for Chemical Analysis in Ecology (LabEx CeMEB*). **This research sheds new light on the role of chemical signals in cetacean ecology, and could lead to practical applications for the conservation of these emblematic and threatened species, such as the use of chemical repellents.**

◀ *Aerial image taken by drone showing a group of pilot whales in the Mediterranean Sea.*
© Bertrand Bouchard/CEFE/CNRS

Contacts (CEFE):
A. Célérier, aurelie.celerier@cefe.cnrs.fr
and S. Campagna, sylvia.campagna@cefe.cnrs.fr

* The Mediterranean Centre for the Environment and Biodiversity Laboratory of Excellence

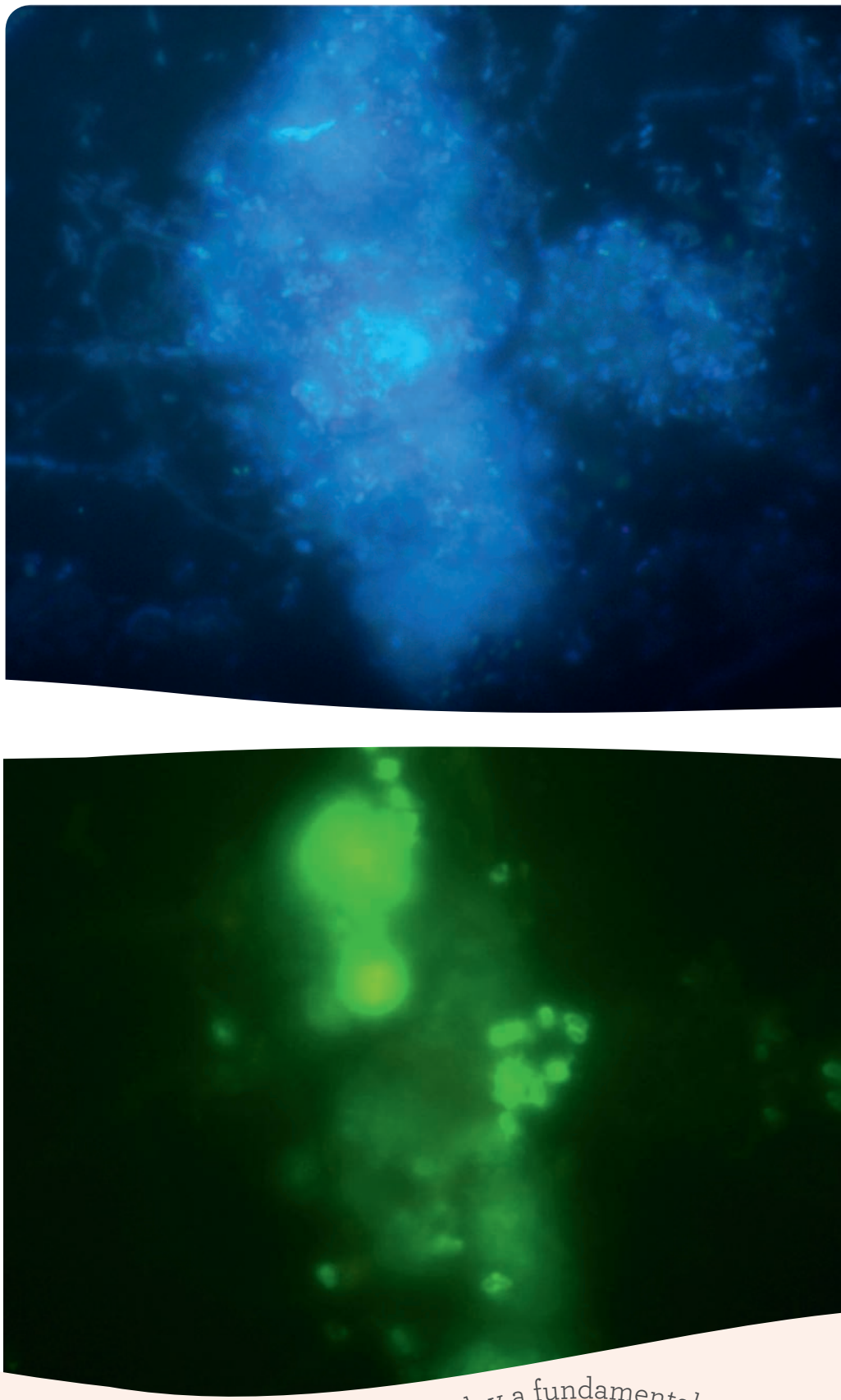
Close encounters of the third kind: *Archaea*

Marine microorganisms are very abundant (several million specimen per millilitre), accounting for a much higher biomass in marine environment than does fish biomass. Among marine microorganisms, *Archaea* represent a significant portion of both microbial biomass and biodiversity. Their recent detection in the marine environment indicates that **they could be one of the most important oceanic sources of nitrous oxide (N_20) and methane (CH_4) emissions, two powerful greenhouse gases that contribute significantly to global warming. Estimating *Archaea*'s contribution to the emission of these gases by studying their dynamics is therefore a true societal challenge.** Not to mention the many secrets that *Archaea*'s diversity study might reveal. However, the difficulties involved in cultivating these microorganisms are a barrier to assessing their role in marine ecosystem functioning.

The EUREKA* project, in which MARBEC, LECOB and LMGE** are involved, aims to remove this barrier by replacing traditional cultivation methods with new molecular approaches based upon massive sequencing of these microorganisms' gene pool. This project also aims to more precisely investigate *Archaea*'s dynamics, and in particular the dynamics involved in greenhouse gases emission, through the study of historical data series (samples collected monthly for approximately ten years) obtained from the Banyuls and Thau Lagoon Mediterranean biological observatories. This investigation will enable estimation (and prediction) of *Archaea*'s contribution to greenhouse gases emission, reflecting the variability of coastal water physicochemical parameters.

Contacts: J.-C. Auguet (MARBEC), jean-christophe.auguet@cnrs.fr and P. Galand (LECOB), pierre.galand@obs-banyuls.fr

* EUREKA project (ANR): Functional role and ecology of non-cultivable *Euryarchaeota*, essential *Archaea* in aquatic ecosystems.
** LMGE: Microorganisms Laboratory: genome and environment, located in Clermont-Ferrand, France.



▶ *Photograph of total marine microorganisms using an epifluorescence microscope (x1000) (top).* Archaea *are specifically targeted by a probe in order to be counted (bottom).*
© J.-C. Auguet

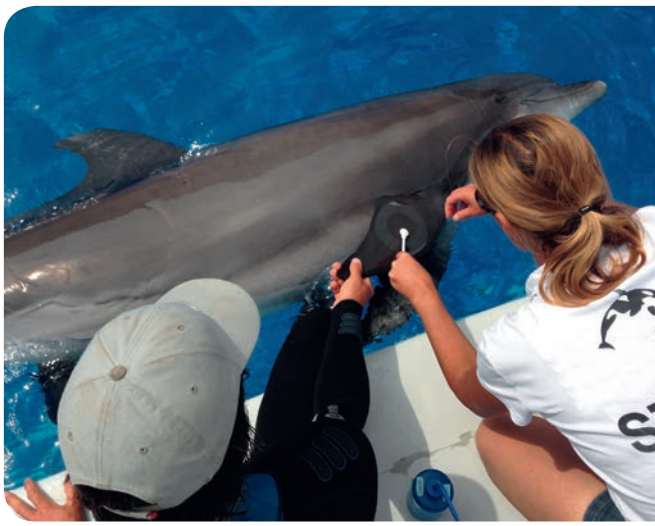
Microorganisms are foundational to all ocean ecosystems and play a fundamental role in the Earth's biogeochemical cycles, such as the Carbon cycle.

The microbiome of marine organisms, a gigantic reservoir of still unknown diversity

The latest expeditions that assessed marine planktonic biodiversity identified over 35,000 species originating from all the world's oceans. Nonetheless, the diversity of the microbiome associated to marine organisms may be much higher. The microbiome represents all symbiotic, commensal and pathogenic microorganisms directly or indirectly associated with larger organisms (vertebrates, molluscs, etc.). These microorganisms are present everywhere on the surface of marine organisms, in the mucus layer, but also in key organs such as the digestive tract. The study of marine microbiomes has grown considerably since 2010. Like exploring a new world, it is first necessary to identity these microorganisms and their functions, then to estimate their variability both between individuals and species, and evaluate the possible existence of geographical trends and their causes. To date, knowledge of marine microbiomes, and particularly their roles are very scarce. There are a handful of studies that suggest a **protecting role of their hosts from pathogens and environmental disturbances.**

Is the microbiome crucial for the health of their hosts? This question deserves particular attention at all trophic levels, in order to assess if microbiomes really contributes to the intrinsic functioning of marine animals and finally to their conservation. MARBEC laboratory is involved in this field of research on biological models such as seabream, European bass, sardine, tuna, shark, marine mammals and invertebrates (e.g. corals), in the Mediterranean Sea, and in tropical Atlantic, Indian and Pacific Oceans.

Contacts (MARBEC): T. Bouvier, thierry.bouvier@cnrs.fr and Y. Bettarel, yvan.bettarel@ird.fr



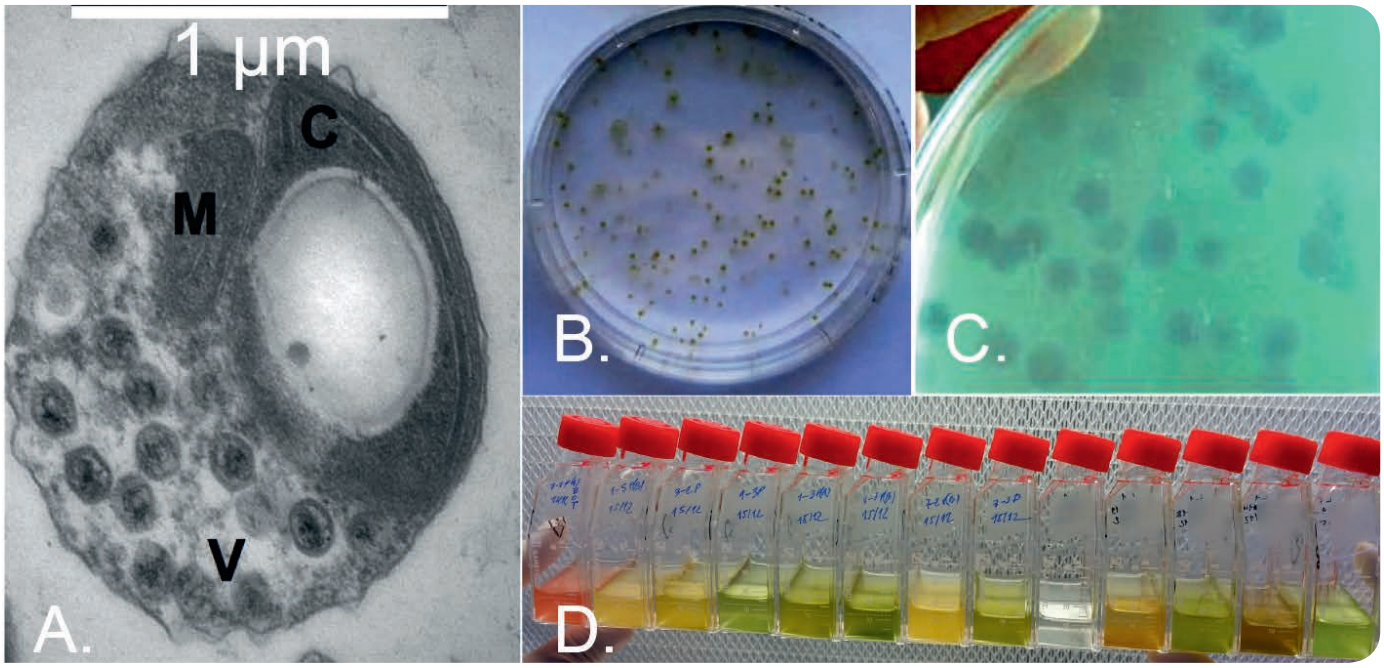
▲ *Microbiome sampling performed on a dolphin at the Marineland* Antibes Sud de la France. *© Marlène Chiarello*

Phytoplankton diversity and viral interactions

The photosynthetic organisms and viruses of ocean plankton represent an exceptional, yet under-exploited, reservoir of biodiversity on our planet. However, phytoplankton produces half of the O_2 that we breathe, and includes many species with high biotechnological potential in the fields of dietary supplements (nutraceuticals) and biofuels. **Population dynamics in phytoplankton communities are regulated by viruses, in particular DNA viruses of the 'giant virus' family, known as the prasinoviruses,** which are ten to one hundred times more prolific in the natural environment than microalgae. **Our understanding of microalgae-virus interactions is therefore at the heart of the models forecasting the evolution of plankton communities faced with environmental changes that affect their atmospheric CO_2 consumption.**

Our Phytoplankton Genomics team (GENOPHY) has developed methods for isolating and analysing phytoplankton microalgae and the viruses infecting them. Hundreds of new strains have been isolated, some of which are new emerging single-cell models for the study of biological interactions. Data on the physiological characteristics of these genetic resources was obtained thanks to the Banyuls-sur-Mer Oceanologic Observatory (OOB)'s bio2mar (Biodiversity and Marine Biotechnologies) and PCI (Cytometry and Imagery Platform) platforms. In combination with bioinformatics methods, this data makes it possible to estimate microalgae and prasinovirus diversity, and to study their diversification mechanisms. The study of interactions is approached both from a short-term perspective, by monitoring the emergence of viral infection resistant microalgae and the molecular mechanisms involved in the process, and from a long-term perspective, by analysing the genomic signatures of host-virus coevolution and their consequences on speciation.

Contact (BIOM): G. Piganeau, gwenael.piganeau@obs-banyuls.fr



▲ *Biological models for microalgae-phytoplankton virus interactions. A. Electron microscopy of a prasinovirus-infected microalgae. B. Microalgae clones isolated in gel. C. Viral plaques resulting from microalga infection. D. Diversity of microalgae collected in the Banyuls-sur-Mer bay.*
© Gwenaël Piganeau, GENOPHY team, BIOM – UMR 7232 (Sorbonne University-CNRS)

Origins of marine species revealed by genome analysis

How do new species emerge? And, what mechanisms are involved in the process responsible for biodiversity? The use of genomic data now enables genome sequences to be translated into a historical record of species evolution. By studying the species tree's most recent branches, it is possible to access the time scale over which genetic changes enabling the evolution from one into two species take place. In order to determine which evolutionary mechanisms and timelines are involved, genomic polymorphism data is compared to various hypothetical scenarios modelled by simulation. In this way, it is possible to identify the speciation process' key parameters, such as the time periods or epochs of species divergence and of any genetic exchanges between emerging species. This reconstruction of species divergence demographic history is a prerequisite for the identification of the functional changes involved in the evolution of reproductive isolation and in local adaptation processes.

By applying these approaches to marine species, ISEM's work has revealed the **existence of evolutionary lineages undergoing speciation in many common species, such as mussels, Pacific oysters, European bass, anchovies and sea horses.** In most cases, these evolutionary lineages, which do not show morphological differences, were unknown prior to the use of genetic tools. The events leading to the formation of these so-called 'cryptic' species often appear to be related to past geographical isolation caused by Quaternary climatic variations. The most surprising revelation of these discoveries is the **existence of either past or current genetic exchanges between lineages during their divergence processes. Thus, genetic differences between cryptic species are continuously remodelled by alternating phases of isolation and contact, which makes each ongoing speciation event a reversible experiment that does not always succeed. This research work therefore reveals the existence of a level of diversity rarely taken into consideration within the field of conservation biology.** Cryptic species are relevant conservation units due to both their diverse geographical distribution and their ecological differences. Genomic approaches are beginning to uncover the specific adaptations of these lineages to their respective environments, thereby providing evolutionary and functional information to better guide future conservation measures.

Contacts (ISEM): P.-A. Gagnaire, pierre-alexandre.gagnaire@umontpellier.fr, F. Bonhomme, francois.bonhomme@umontpellier.fr and N. Bierne, nicolas.bierne@umontpellier.fr

◀ *Formation mechanisms of new marine species revealed through genomes.* © ISEM

Aesthetic perception and diversity of marine habitats

The aesthetic value of landscapes and species is a key element of biodiversity conservation as it brings into play the affective and emotional dimensions of our relationship with nature. Yet, the relationship between biodiversity and aesthetic perception is rarely studied in relation to ecosystem services. Two studies* conducted on marine habitats (coralligenous and coral reefs) have provided better understanding and quantification of the relationship between biodiversity and our aesthetic perception of these habitats. A series of surveys, drawing upon photographic questionnaires hosted on the LabEx CeMEB MBB platform (Montpellier Bioinformatics Biodiversity), has enabled the assessment of human aesthetic preferences for (i) benthic communities of Mediterranean coralligenous reefs and (ii) communities of tropical coral reef fish (see opposite). These aesthetic preferences were then linked to various measures of the respective systems' biodiversity (taxonomic, phylogenetic and functional diversity). Results showed that **biodiversity and species composition have a positive influence upon our aesthetic preferences. These results confirm the importance of biodiversity in our perception of aesthetic value, a perceptual trait that could have major consequences on how we protect our environment**. This convergence between ecology and aesthetic perception provides a genuine opportunity for biodiversity valorisation and conservation from a 'biodiversity-beauty' perspective.

Contacts: A.-S. Tribot (ISEM), anneso.tribot@free.fr, J. Deter (MARBEC), julie.deter@umontpellier.fr and N. Mouquet (MARBEC), nicolas.mouquet@cnrs.fr

Partners: ISEM and MARBEC UMRs, *Andromède Océanologie*, Rhone Mediterranean Corsica Water Agency, Mayotte University Centre, *Fondation de France* and OSU OREME.

* Doctoral Project conducted from 2014 to 2017: Tribot, 2017. Aesthetics and Biodiversity of Marine Ecosystems (*Esthétique et Biodiversité des écosystèmes sous-marins*). Thesis. https://hal.archives-ouvertes.fr/tel-01665278 (Funding *Fondation de France*/CNRS)

A. © Andromède Océanologie on behalf of the Rhone Mediterranean Corsica Water Agency

B. © A.S. Tribot/UMR MARBEC

▶ *Example of photographs used to measure aesthetic preference for communities of (A) Mediterranean coralligenous reefs and (B) tropical coral reefs.*

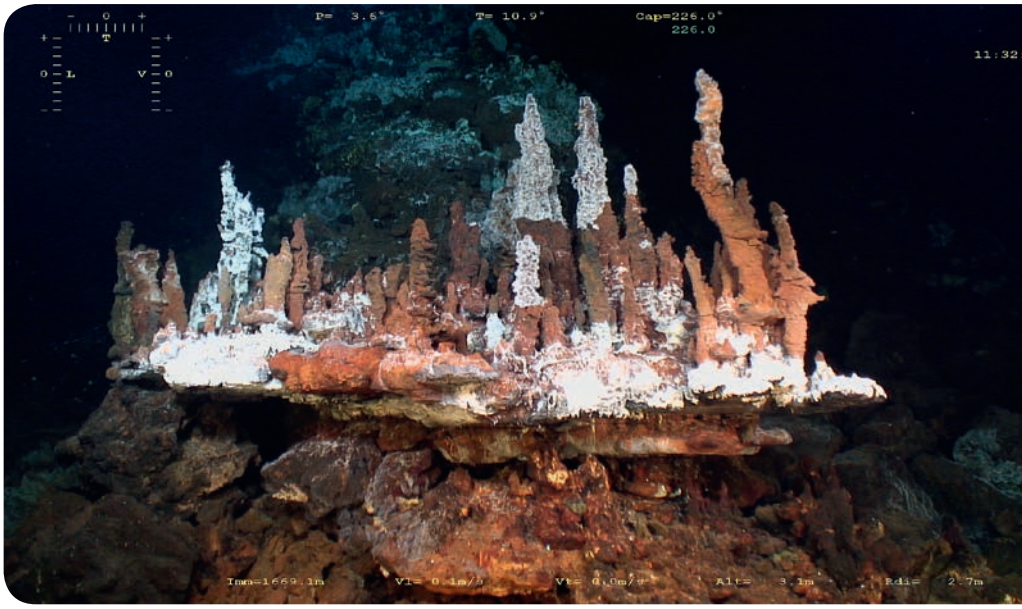
Hydrothermal fluids and their microbial populations

The occurrence of water circulation in both marine sediments and the oceanic crust was confirmed in the late 1970s through direct observation of low and high temperature fluid discharge (from a few dozen degrees to 410°C) at the bottom seafloor. In addition, important biological ecosystems, a rarity at such depths, cluster around hydrothermal vents. The discovery of hydrothermal systems along ocean ridges and volcanic arcs is one of the major scientific events over the last forty years', and has led to an upheaval in our scientific approach to the thermal, geochemical as well as biological processes on Earth.

Hydrothermal circulation is caused by the penetration and percolation of seawater into the oceanic crust and marine sediments. During this process, a great number of chemical reactions takes place, altering the rocks and transforming the original seawater into an acidic and hot (up to 410°C), or alkaline and cold (<100°C) hydrothermal fluid. Thus, a number of major seawater elements are stored in rock, while heavy metals (Fe, Mn, Cu, Zn etc.) and alkalis are enriched sometimes by as much as 10^6-fold compared to the background seawater. On the ocean floor's surface, these hydrothermal fluids and the neutral, cold and oxygenated ambient seawater mix, generating an environmental chemical gradient appropriate for ecosystem development. In particular, **in a deep marine environment without light, microbial communities use the chemical flows of hydrothermal fluids in order to survive: these communities are known as chemosynthetic communities**. The objective of our research is to study the influence of environmental parameters, i.e. chemical hydrothermal flows, on the development of these ecosystems. Results are obtained through the advanced instrumental and analytical platform of the Midi-Pyrénées Observatory (PANGEE) which allows us to identify the element concentrations (e.g. iron, manganese, methane, nitrogen etc.) that are indispensable for these organisms' survival, and to study their impact upon microbial population diversity.

Contact (GET):
V. Chavagnac, valerie.chavagnac@get.omp.eu

For further information:
www.emso-fr.org/EMSO-France



▲ *Capelinhos hydrothermal site in 2013.* © ROV Victor6000/IFREMER/CNRS

Understanding and inferring marine connectivity to better manage resources

Dispersal distance (separating offspring from their parents) is a key parameter in the understanding of the ecological and evolutionary dynamics of spatially subdivided species populations and communities. Unknown in many marine organisms, in plankton dispersal occurs during a microscopic larval phase, while adults are sedentary. This major difference between juveniles and adults, which is widespread in marine species, makes it impossible to monitor larval dispersal in water. In order to trace larval dispersal, researchers from the Marine Connectivity Research Group* are combining different multidisciplinary approaches:

- Current modelling, combined with larvae behavioural parameters, can predict larvae movement in water bodies.
- Chemical analysis, by studying the calcification of the inner ear of fish or of mollusc shells, can determine the environments through which a larva has moved during its development.
- The genetic method analyses kinship between individuals, as well as the geographical distance between them. High throughput DNA sequencing enables the analysis of a very large number of individuals at low cost. Its routine use provides information on population dispersal and size (e.g. fishing stocks).

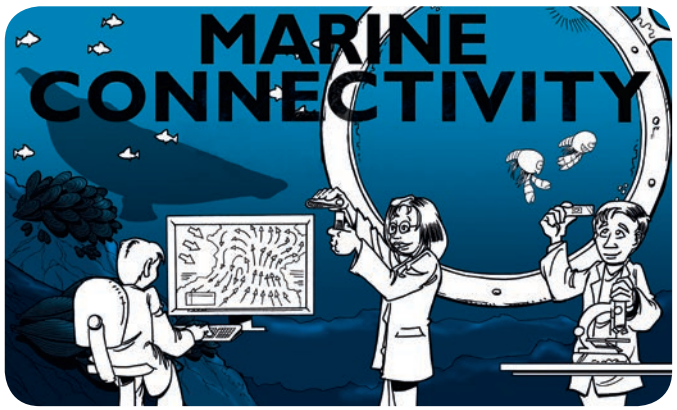
By considering more distant kinship relations on a smaller number of individuals, the genetic approach makes it possible to estimate genetic connectivity (long-term dispersal, averaged over a large number of generations), which is important for the evolutionary processes that take place over time scales that are longer than those of ecological processes.

The combined use of these three methods will provide an understanding of eco-evolutionary dynamics, in order, for example, to define fishing zones and quotas, or to prevent potential risks of extinction. The ultimate objective is to contribute to improving marine resource management and to move towards the sustainable development of maritime activities.

Contacts: N. Bierne (ISEM),
nicolas.bierne@umontpellier.fr
and S. Arnaud-Haond (MARBEC),
sophie.arnaud@ifremer.fr

For further information:
https://youtu.be/L-Y6I5SHILU

* MarCo Research Group (CNRS-IFREMER) led by ISEM and MARBEC UMRs: wwz.ifremer.fr/gdrmarco



▶ *Oceanographic modelling, chemical analysis and genetics are used by researchers to understand and infer marine connectivity.* © Sébastien Lerigoleur

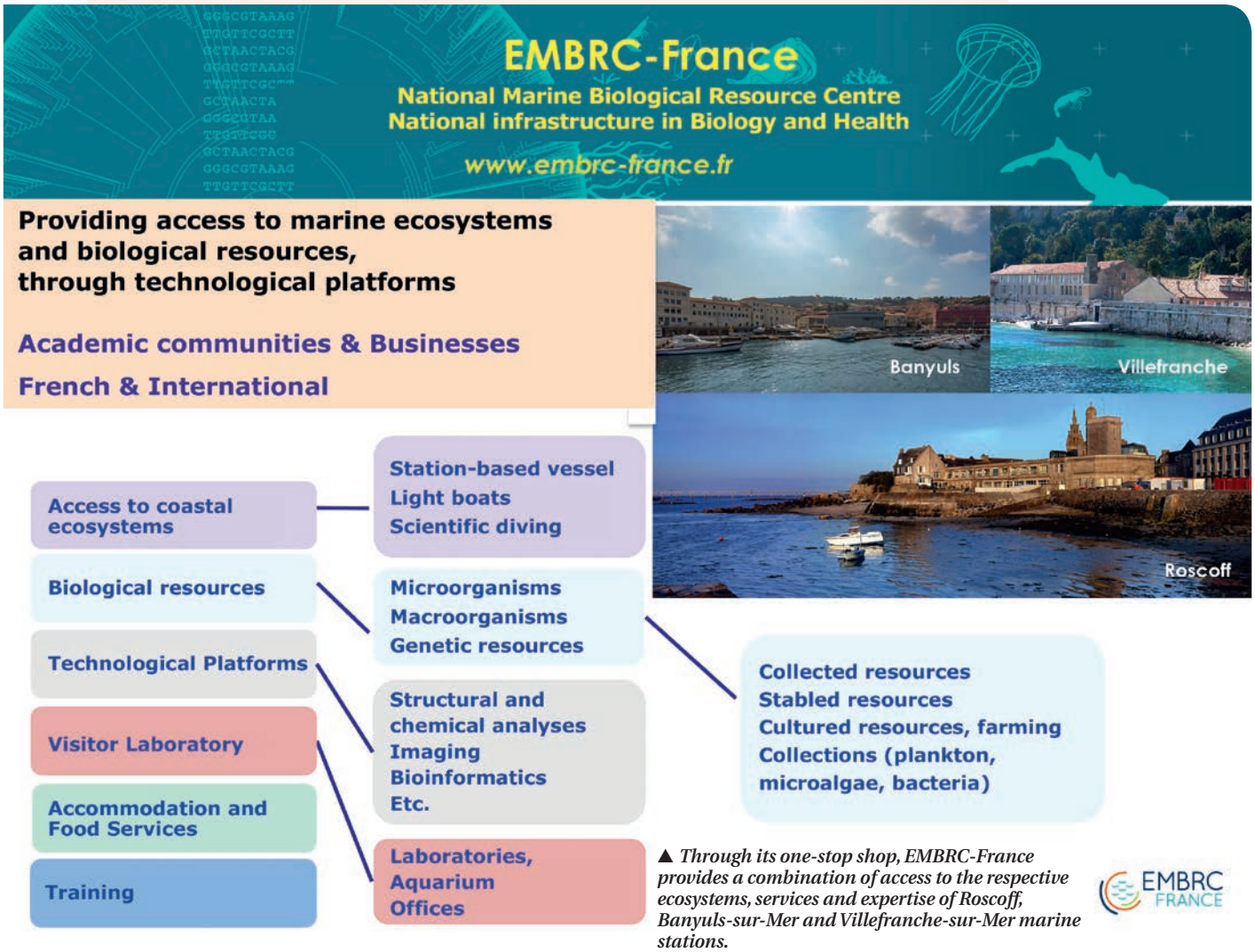
Marine organisms: biological models and experimental platforms

EMBRC-FRANCE: A NATIONAL RESEARCH INFRASTRUCTURE FOR ACCESSING AND STUDYING MARINE BIODIVERSITY AND COASTAL ECOSYSTEMS

With the 'Investments for the Future' programme, and in particular the 'National Infrastructures in Biology and Health' call for proposals, the goal of the French government was to provide the country with large infrastructures of both national stature and high competitiveness internationally. The National Marine Biological Resource Centre (EMBRC-France) is the only French infrastructure in the field of marine biology. EMBRC-France encompasses the activities and expertise of three marine stations within the Sorbonne University and the CNRS: Roscoff *Station Biologique* (SBR), Banyuls-sur-Mer Oceanological Observatory (OOB) and Villefranche *Institut de la Mer* (IMEV).

Exploiting marine resources and their diversity is a true challenge with multiple repercussions in various fields: fishing, aquaculture, biotechnologies, ecological engineering, marine geosciences and oceanography. In the face of societal challenges, marine stations are naturally filling their role as vital links in marine resource related innovation processes. Each station, via EMBRC-France's one-stop shop, provides and facilitates access for all academic communities and businesses, to the three stations' marine ecosystems, located on the Atlantic (SBR) and Mediterranean (OOB and IMEV) sea basins, and to their respective services. The Banyuls-sur-Mer station provides, with a number of specificities, means of transport and access to the sea (boats, sailors, divers, etc.), aquariums and laboratories supplied with running seawater, analytical platforms, as well as accommodation facilities. Its main feature is its capacity to provide microbial, animal or vegetal models representing major evolutionary lineages that are not found in terrestrial ecosystems, as well as access to the genetic resources of prokaryotic and eukaryotic model organisms. EMBRC-France is an outstanding tool for promoting research in marine biology and ecology, drawing upon a strong potential for innovation. In addition, EMBRC-France is the French node of the European EMBRC infrastructure, whose headquarters are based in France.

Contacts (EMBRC-France):
N. Pade, nicolas.pade@sorbonne-universite.fr
and N. Turque, nathalie.turque@embrc-france.fr



▲ *Through its one-stop shop, EMBRC-France provides a combination of access to the respective ecosystems, services and expertise of Roscoff, Banyuls-sur-Mer and Villefranche-sur-Mer marine stations.*

Experimental studies of climate change impact on marine plankton networks

Plankton networks underlie the functioning of marine pelagic ecosystems and coastal marine systems that are very rich in exploited resources. For over two decades, the impact of various stressors, in particular climatic changes, has been studied experimentally on marine plankton networks under controlled conditions, in so-called mesocosms (hermetic enclosures of several m^3). Results show that coastal areas, due to their shallow depths, are very reactive to changes, in particular to temperature increases. Indeed, ***in situ* simulation of a 3°C temperature increase, led to a cascading upheaval in Thau Lagoon plankton networks, through consecutive interactions between the heterotrophic organisms of this network** (e.g. copepods, ciliates, flagellates, bacteria). In fact, copepod *nauplii* turn into the adult phase more quickly under the effect of temperature, thus reducing ciliate abundance and enabling the multiplication of heterotrophic flagellates, which ultimately decreases the abundance of heterotrophic bacteria. This result was unexpected, as previous studies, which did not encompass all plankton network organisms, had suggested the opposite. Our results also show an increase of primary production following the 3°C increase in the lagoon water temperature.

Assuming that the various types of plankton respond differently to climate change induced temperature increases, we recently (April 2018) conducted further experiments in mesocosms (see opposite). The objective of these experiments was to test this hypothesis in Thau Lagoon plankton communities, which were divided into two zooplankton predator size categories (< 1,000 µm *versus* < 200 µm), and to study potential consequences on phytoplankton production, and on matter accumulation and transfer to the upper trophic levels. These experiments were conducted within the framework of the National Research Agency (ANR) Photo-Phyto* project, with the participation of approximately twenty researchers and students, including several European colleagues benefiting from the Transnational Access scheme made available under the European AQUACOSM* project.

▲ *Experiments related to the study of temperature increase effects on marine plankton network functioning, conducted through MEDIMEER platform* **in situ** *mesocosms immersed in Thau Lagoon (April 2018).* © *Behzad Mostajir*

Contacts: B. Mostajir (MARBEC), behzad.mostajir@umontpellier.fr, behzad.mostajir@cnrs.fr, S. Mas (OREME), sebastien.mas1@umontpellier.fr, D. Parin (OREME), david.parin@univ-montp2.fr and F. Vidussi (MARBEC), francesca.vidussi@univ-montp2.fr

*** For further information:**
Photo-Phyto project (Global warming effects on marine phytoplankton bloom triggering: photoperiodism, composition and adaptation): www.umr-marbec.fr/IMG/pdf/photophyto_fiche_projet_fr.pdf
AQUACOSM project (Network of leading European aquatic mesocosm facilities connecting mountains to oceans from the Arctic to the Mediterranean): www.aquacosm.eu

Marine biological models utility

The main objective of the emerging evo-devo (evolutionary developmental biology) discipline is to understand how the evolution of developmental mechanisms have contributed to the emergence of the morphological diversity in multicellular organisms. The working methodology is based on the comparative analysis of processes involved in embryogenesis, in different organisms, in order to differentiate between conserved (and therefore ancestral) mechanisms, and mechanisms that are divergent, and have therefore potentially generated diversity throughout evolution. In order to answer this question, the two following aspects are fundamental: (i) the possibility to use different developmental biology techniques on selected organisms, and (ii) access to model organisms located at key evolutionary positions, which will depend on the specific question addressed.

In this sense, the marine environment is vital. Indeed, the oceans represent the largest volume of life on Earth and the most important reservoir of biodiversity, a diversity that reflects all the major steps in the evolution of living organisms since life emerged on the planet and until the present day. Thus, **representatives of 33 existing metazoan *phyla*, of which 12 are exclusively of marine origin, are found in this environment. Therefore, the marine environment offers a range of model organisms suitable for the study of a large number of questions addressed by evo-devo studies**. The UMR BIOM focuses on the morphological evolution within the chordate phylum. To this end, different teams are studying the mechanisms controlling several aspects of the embryonic development of species located at key positions in the chordate's evolutionary lineage, such as lancelets (*Cephalochordata*), ascidians (*Urochordata*) and several vertebrate species, including the small-spotted catshark and the lamprey (*Cyclostomata*). These so-called 'non-conventional' biological marine models have provided answers to several fundamental questions that cannot be answered by conventional models. As a result, they have become indispensable to the discipline.

Contact (BIOM):
H. Escriva, hector.escriva@obs-banyuls.fr

▼ *Juvenile of small-spotted catshark,* Scyliorhinus canicula. © *S. Mazan/UMR BIOM*

Life cycles and larval development in model organisms. Metamorphosis and recruitment

Almost all marine fish have a life cycle that can be divided into two distinct phases: a pelagic larval phase, during which the larva remains in the plankton, and a juvenile, and then adult, phase during which the animal is generally benthic. The transition between these two phases represents a true metamorphosis. BIOM's Eco/Evo/Devo team, in collaboration with CRIOBE's unit, showed that, in coral fish, this transition is controlled by thyroid hormones (as in the case of the tadpole's metamorphosis into a frog). Thus, it is thyroid hormone secretion, triggered by the hypothalamo-pituitary-thyroid axis, under the control of the organism's environment and physiological state, which triggers this phenomenon. Moreover, thyroid hormones orchestrate the smooth evolution of this phenomenon over time and, as a result, determine the quality of the juveniles generated by this transformation. Therefore, an alteration of thyroid secretion during this process results in juveniles that no longer properly fulfil their ecological function and therefore more easily fall prey to predators. This is, for example, the case of **animals that have been exposed to environmental pollutants (such as chlorpyrifos) that interfere with thyroid function. *Larvae* that have been impaired by exposure to such molecules become juveniles of lesser quality than those resulting from non-exposed larvae**.

A great deal of data suggests that the same type of phenomenon exists in Mediterranean fish. In these species, harbours effectively become nurseries in which young juveniles continue to grow in a calm and relatively protected environment. However, and unfortunately, ports are very often polluted by diverse harmful substances. This function of port nurseries has been exploited in recent years in an attempt to increase the production of juveniles of several fish species. Further research is required in order to understand how the different pollutants affect fish in early life stages, and to better comprehend the resilience mechanisms they can develop.

Contact (BIOM): V. Laudet, vincent.laudet@obs-banyuls.fr

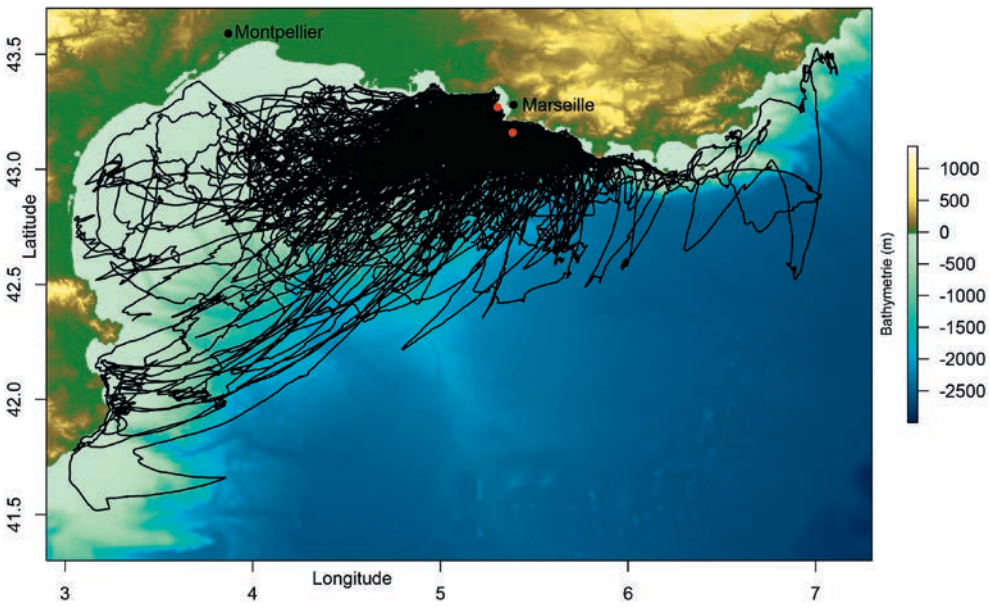
For further information:
http://biom.obs-banyuls.fr/fr/equipe-e6-biologie-integrative-de-la-metamorphose.html

▼ *Coral fish larvae, such as the larvae of the convict surgeonfish,* Acanthurus triostegus, *transform during larval recruitment. This transformation is a genuine metamorphosis regulated by thyroid hormones. A similar transformation occurs in Mediterranean fish, and conditions the quality of future juvenile fish, and therefore, in the long term, adult population preservation.* © M. Besson/UMR BIOM/USR CRIOBE

Feathered detectives. What birds teach us about their environment

Visible to all, birds provide us with information on the state of their living environments. They are exposed to plastic and chemical pollution, pathogens, the impacts of climate change and the over-exploitation of natural resources. **Seabirds, recognized as *bona fide* bioindicators, display qualitative and quantitative responses to global changes and emerge as excellent environmental sentinels.** Thus, research focussing upon yellow-legged gulls (*Larus michahellis*) in the western Mediterranean, makes it possible to study these gulls' exposure to various infectious agents (in particular, the avian influenza virus and antibiotic-resistant bacteria), while taking into consideration the modes of transmission of these agents and their possible links with human activities. In addition, the long-term study of Scopoli's shearwater (*Calonectris diomedea*) breeding in the islands of Marseille is quantifying the impact of fish resource collapse upon coastal marine ecosystem structure, as well as the suitability of management measures, such as the establishment of marine protected areas. Regular sampling on gulls and shearwaters contributes to the surveillance of pollutants (heavy metals, hydrocarbons, endocrine disruptors) found in these ecosystems. Finally, monitoring bird movements at sea, using GPS beacons, makes it possible to determine the impact of diverse anthropisation factors, such as maritime traffic and offshore wind farm installation. All of these studies are co-developed by CEFE's and *Tour du Valat*'s* research teams, together with the managers of the protected natural areas (*'espaces naturels sensibles'*) concerned, in particular the Camargue Regional Natural Park, Calanques and Port Cros National Parks. Research work is conducted under the leadership of the French Biodiversity Agency and OREME Sciences of the Universe Observatory*, in collaboration with multiple international organisations**.

▲ *Bellow-legged gull nesting on the islands of Marseille, Calanques National Park, France.* © *David Grémillet*



▲ *GPS movements tracking of 133 Scopoli's shearwater during the 2011-2017 breeding seasons in the islands of Marseille, Calanques National Park, France.* © *Nicolas Courbin*

Contacts:
D. Grémillet (CEFE), david.gremillet@cefe.cnrs.fr, M. Vittecoq (*Tour du Valat*), vittecoq@tourduvalat.org
and T. Boulinier (CEFE), thierry.boulinier@cefe.cnrs.fr

*** For further information:**
https://tourduvalat.org/en/
https://oreme.org/observation/ecopop

** For example: www.isprambiente.gov.it/it - www.ub.edu/web/ub/en - www.birdlife.org

The oceans are the world's largest reservoirs of biodiversity, and as such provide a wide range of biological models to address many scientific issues.

Hippocampus guttulatus.
© P. Louisy

Scientific evidence of ocean vulnerability

Coastal erosion is a natural phenomenon linked to the action of the wind, swell and the currents it generates, sea level variations, the volumes of sedimentary input from coastal rivers, geology and local morphology. Anthropogenic factors (coast artificialisation, sand dune destabilisation, dam-induced sedimentary input reduction) often compound these natural factors and can considerably exacerbate the phenomenon.

Marine flooding is caused by atmospheric effects (wind, depression), storm wave breaking (setup), uprush (run-up) and, to a lesser extent in the Mediterranean, the tide. Since marine storms and continental floods are partly caused by the same phenomena, both types of events can occur simultaneously (flooding and sea level rise). Potentially dangerous events will generate risk when something of value is at stake: people, assets or various infrastructures, which may suffer damage as a result of their being exposed to hazards (coastal erosion or marine flooding).

Coastal regions concentrate significant economic activity (40% of the European Gross Domestic Product [GDP]). These regions depend both directly and indirectly upon the maritime economy, and are growing faster than the European economic average. The significant length of European coastline (68,000 km) is an economic and ecological asset as well as a factor of attractiveness for Europe. In this context, damage to the marine environment is increasing: coastal artificialisation, coastal development of urban, residential and tourist activities and constructions, increase in pollutants and non-degradable macro-waste discharge. This threat to habitats and biodiversity can have significant social, economic and biological consequences.

In the Occitanie region, a number of research teams throughout the territory are studying sea level variations and shoreline evolution, and devising forecasting tools to assist decision-makers. Beyond shoreline and coastal modifications, numerous teams are also investigating marine biodiversity damage. Such damage is the result of a growing human population and a rapidly expanding economic activity, requiring ever-increasing renewable (fishing) and non-renewable (mineral, energy) resources. However, it is difficult to distinguish changes resulting from natural constraints (climate related factors) and changes induced by human activities. Several contributing factors affect marine biodiversity, at the genetic, species and ecosystem level. Among these, five major factors are widely recognized: fishing, chemical pollution and eutrophication, the physical degradation of habitats, invasive alien species and climate change. Attributing the extinction of species, breeds or varieties, or the degradation of ecosystems or ecosystem services, to any one of these instigating factors is not easy, as they all act simultaneously, and at times even interact with synergistic effects.

Fishing is the main factor threatening marine fish biodiversity. Indeed, worldwide, over 40 local populations of marine fish have disappeared due to over-exploitation. The impacts of fishing upon biodiversity have been extensively studied and described. These impacts include the effects on the species targeted by fishing, effects on the genetic structure of populations, on bycatch, marine communities, trophic networks and habitats. Recent studies have shown that overfishing leads to a decrease in fish size and age, in age class diversity, and age at sexual maturity. Moreover, fishing not only affects biomass. It also affects the composition of the exploited fish populations.

Furthermore, human activities are responsible for the introduction of a large number of substances into the marine environment. According to the United Nations Environment Programme (UNEP), 80% of marine pollution is of land-based and anthropogenic origin. The industrial sources of pollution are compounded by domestic and urban effluents as well as diffuse agricultural pollution. The impact of marine water pollution is poorly quantified. However, it is believed to be responsible for significant lethal and sublethal effects on marine organisms. Pollution has repercussions at all trophic levels, from primary producers to higher-level consumers, and, therefore affects the functioning of ecosystems.

Our general understanding of how pollution and different contaminants affect marine biodiversity is limited. From a management perspective, the main questions are: Which marine habitats are most vulnerable to contaminants? And, which classes of contaminants are most likely to cause negative impacts on biodiversity? In addition to the traditionally monitored substances (metals, organochlorines, pesticides, hydrocarbons), the potential effects of many other chemical substances found in household products, cosmetics and pharmaceuticals (antibiotics, hormones, steroids) are also of major concern. These other substances are referred to as 'emerging contaminants'.

Macro-waste pollution is a widespread pollution problem that affects all the world's oceans. This threat to the marine environment has long been ignored, and its seriousness has only recently been recognized. Many marine species (turtles, albatrosses, seals, whales and fish) are injured or killed by macro-waste, either because they are trapped by the waste or because they mistake it for prey and swallow it. Macro-waste physically traps and lures marine biodiversity. 10% of the 260 million tonnes of plastics produced annually in the world ends up in the sea.

Philippe Lebaron (Sorbonne University, CNRS, USR LBBM)

Sea level variations and impact on the shoreline

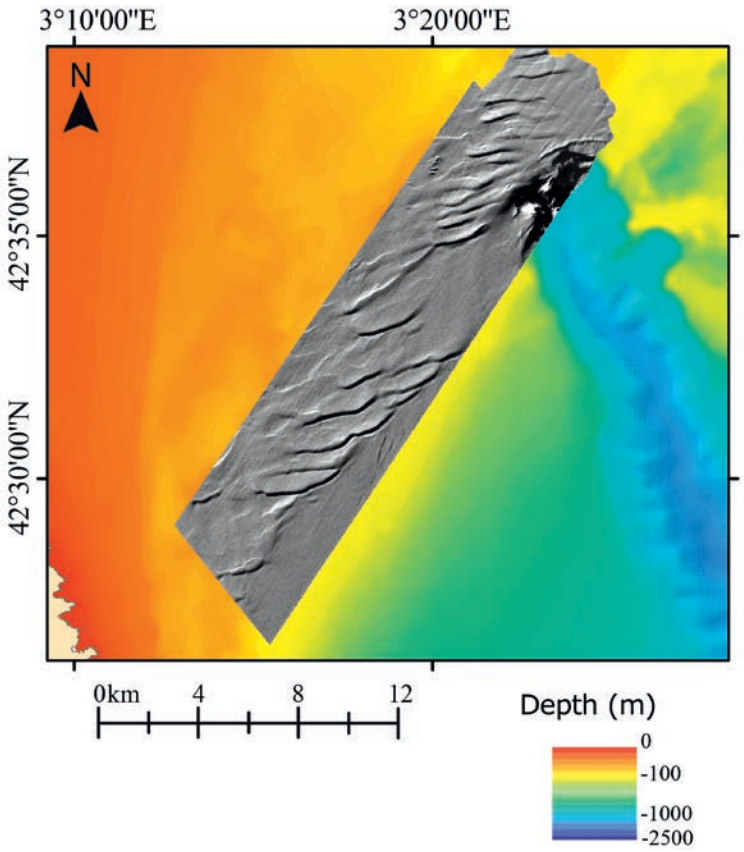
Climate variations and sedimentary deposit in the Gulf of Lion

The climate and eustatic variations that occurred during the Quaternary (2.6 million years) are recorded and accessible for study in marine and continental sediments throughout the world. Over the last few decades, the accuracy of the resulting reconstructions allowed by the study of sedimentary records has enabled the integration of this data into future climate forecast models. The Mediterranean, a densely-populated region around a semi-enclosed sea, is particularly vulnerable to climate and sea level changes, even changes of small amplitude. Within the framework of European and national projects, CEFREM is focusing upon the characterisation of Gulf of Lion sedimentary deposits, by combining seismic, sedimentological and geochronological methods, coupled with numerical modelling. This work has put in evidence the impact of sea level variation on marine sedimentary system evolution over the past 500,000 years, and has enabled the dating of the ravinement surface and shelf deposits posterior to the last glaciation (approximately 20,000 years ago), which are structured as sedimentary bodies (sandbanks, dunes), the upper part of which is periodically altered during storm events (see fig. 1).

CEFREM is focusing upon quantifying changes in Rhone water resource supply, over the Holocene timescale (the last 11,700 years), as recorded in subaqueous deltas and shallow contourites* (see fig. 2). Recent work shows that the Holocene Epoch, although hitherto considered a period of great climate stability, was affected by significant climate changes (related to solar activity and volcanism), which have influenced the development of civilisations. **The use of the sedimentary archives contained in underwater deltas and shallow contourites is a new approach in paleoclimatology (which used to mainly focus upon hemipelagic sediments from deep basins). Analysis of these sedimentary bodies makes it possible to access to very high resolution archives (annual or decennial) and to establish a direct land/sea link thanks to the continental and marine proxies preserved in these environments.**

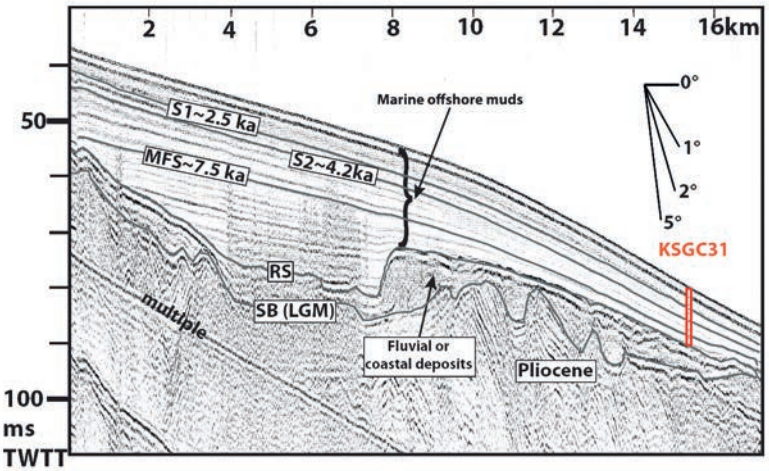
Contact (CEFREM):
M.-A. Bassetti, maria-angela.bassetti@univ-perp.fr

* Contourites: sedimentary deposits resulting from the reworking of ocean sediments by bottom currents.



▲ *Fig. 1. Submarine dunes at the edge of Gulf of Lion continental shelf.*
*From Alonso Y., 2016. Morpho-structural Characterisation of Gulf of Lion submarine dunes, Lacaze-Duthiers canyon (*Caractérisation morpho-structurale des dunes sous-marines du golfe du Lion, canyon de Lacaze-Duthiers*). Internship thesis, UPVD, France. (CARTHAM –AFB Campaign).*

▼ *Fig. 2. Cross-sectional NW-SE seismic profile of the mud belt from the Holocene in the Gulf of Lion continental shelf.*
From Bassetti et al., *2016.* Clim. *Past. 12: 1539-1553. https://doi.org/10.5194/cp-12-1539-2016, 2016*



Coastal erosion in the Gulf of Lion

Global erosion of Languedoc-Roussillon foreshore (from Argelès to the Boucanet) between 1895 and 2009 has been demonstrated by CEFREM, via calculation of the global sediment budget (-26.1 million m^3 over this period, see Fig. 1), with a few nuances: this budget was in surplus between 1895 and 1984 (4.1 million m^3 of gains, see Fig. 2) and subsequently in deficit (-30.2 million m^3) as of 1984. There has therefore been a shift from a context of slight surplus (1895-1984) to a context of foreshore erosion (1984-2009).

Nuances have been observed between compartments: Roussillon, Narbonne Area, Sète Lido, the Gulf of Aigues Mortes (see Fig. 2):
- Between 1895 and 1984, accretion was observed in the compartments corresponding to the southern half of Languedoc-Roussillon —Roussillon (9.4 million m^3) and Narbonne Area (8.7 million m^3)—while the compartments of the northern half of the Region were subject to erosion—Sète Lido (-1.1 million m^3) and Gulf of Aigues Mortes (-12.8 million m^3).
- Between 1984 and 2009, all compartments were subject to erosion, with erosion losses of: -6.3 million m^3, -15.7 million m^3, -3.2 million m^3 and -4.8 million m^3 respectively for Roussillon, Narbonne Area, Sète Lido and the Gulf of Aigues Mortes. Therefore, during this period, erosion spreads to all compartments, with an intensification in the North and a trend reversal in the South.

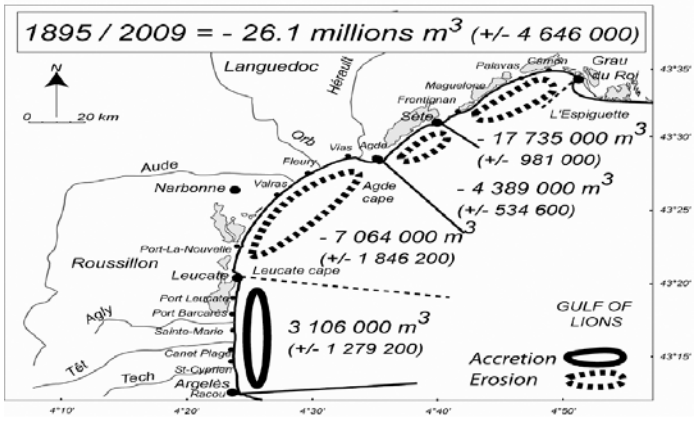
Moreover, the volumes gained over 89 years (1895-1984) are seven times smaller than the volumes lost to erosion over 25 years (1984-2009)! **There has been therefore a significant intensification of foreshore erosion processes at the Languedoc-Roussillon scale during the 20th century.**

In light of this observation, the GLADYS group (see p. 75), through the DYNALIT* National Observation Service (SNO), is conducting long-term monitoring of a number of representative sites, such as the Maguelone retrograding Lido and the 'La Franqui' prograding beach, in order to correlate observed changes with average hydrodynamic forcing.

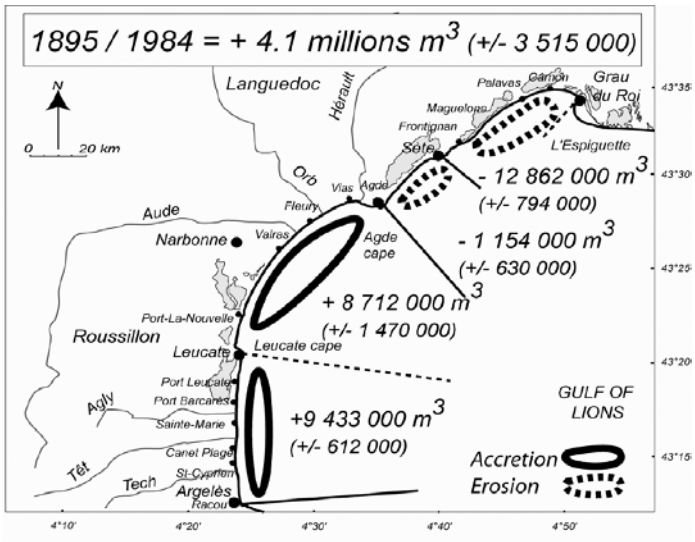
Contact (CEFREM):
R. Certain, certain@univ-perp.fr

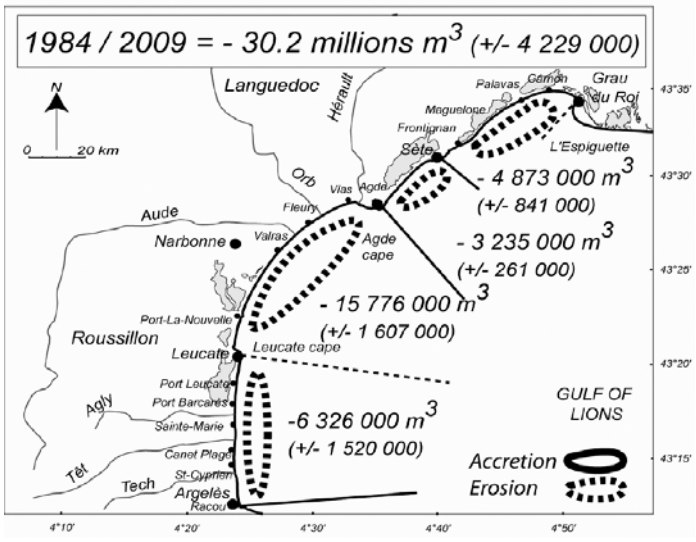
For further information:
https://elmusca.wordpress.com

* DYNALIT National Observation Service: www.dynalit.fr/dynalit_uk



▶ *Fig. 1. Sediment budget between 1895 and 2009 by compartment and margins of error (m^3, from Argelès to Boucanet).*
From Brunel et al., *2014.* Geomorphology. *204: 625-637.*





▼ *Fig. 2. Sediment budget between 1895/1984 and 1984/2009, by compartment and margins of error (m^3, from Argelès to Boucanet).*
From Brunel et al., *2014.* Geomorphology. *204: 625-637.*

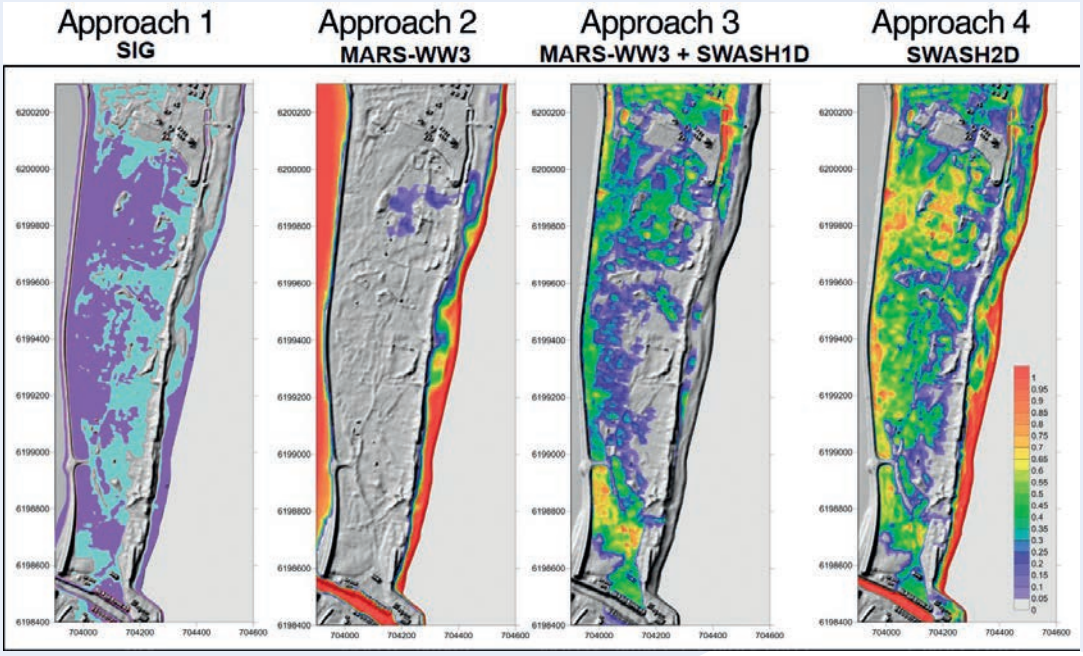
Storm surge and swell are the main triggers of sea level variations in the Mediterranean.

MEASURING VULNERABILITY TO EROSION

Marine flooding is temporary flooding of the coastal area by the sea during adverse weather and ocean conditions (low atmospheric pressures and strong onshore winds blowing, in the case of tidal seas, during high tide). These events can last from a few hours to a few days. Although the modelling of marine flooding phenomena (storm surge, wave set-up, uprush, wave overtopping and overflowing mechanisms) is feasible using an 'all models' approach, the application of these tools remains costly in terms of calculation time. Therefore, simplified approaches are often used in order to assess marine flooding hazard. In 2017, a methodological study was conducted at the Leucate-Le Barcarès pilot site in order to compare different flooding assessment techniques, ranging from ultra-simplified GIS type approaches, to wave-to-wave modelling approaches. Simulation reliability was validated thanks to the observations of the Occitanie '*Réseau de suivi des tempêtes et de leurs impacts*' network*. **The tools developed made it possible, in addition to the assessment of risk and hazard, to significantly improve the understanding of wave overtopping/overflowing mechanisms, as well as the effects of coastal barrier breaching during extreme storms.**

Contact (BRGM): Y. Balouin, y.balouin@brgm.fr

* http://littoral.languedocroussillon.fr/suivi-des-tempetes-et-de-leurs-impacts.html



▲ *Comparison of flooding height related results obtained using simplified approaches (GIS method 1)* versus *increasingly complex modelling approaches (2 to 4). From Nicolae-Lerma* et al., *2018.*

Storm surges: a phenomenon that contributes to sea level variations

Major sea level variations are mostly driven by three distinct dynamics: tide, storm surges and swell. In the Mediterranean Sea, due to its limited tidal range, the main factors of sea level variations are storm surges and swell. Offshore storm surge is mainly due to atmospheric pressure differential between different basin areas, more or less following the inverted barometer effect: a one millibar decrease in atmospheric pressure leads to a compensation in the ocean whose level rises by one centimetre. In a severe storm event, a 100 millibar drop in atmospheric pressure results in a one-metre storm surge. Along the coast, the continental barrier enables the wind to amplify this storm surge by pushing ocean water bodies towards the coast, where their accumulation is combined with the pressure effects. Swell waves breaking on the coastal strip also cause a rise in sea level (wave setup), which can reach a height of half a metre (over and above wave oscillations). When these three factors combine, storm surges of two metres or more, occurring throughout the whole storm duration (i.e. generally approximately ten hours) become a potential occurrence, thereby creating the conditions for dramatic coastal flooding, with waves penetrating into coastal constructions, buildings, infrastructures, etc., not to mention the triggering impact of these waves on coastal river floods, with rivers being inflated by concurrent rainfall and hampered in their natural flow. Today, the study and precise forecasting of these phenomena through numerical modelling remains a major challenge mobilising oceanographic, atmospheric and hydrological communities. **LEGOS is, at global scale, developing and transferring ocean storm surge phenomenon modelling configurations that are routinely used by operational services working on satellite altimetry data processing (NASA/CNES/ESA).** Furthermore, LEGOS is participating in regional-scale studies, in particular in European seas, providing its tidal and storm surge high resolution modelling capacities in order to support national and international research teams, in collaboration with the national Centre for Topographic studies of the Ocean and Hydrosphere (CTOH, OMP).

Contact (LEGOS):
F. Lyard, florent.lyard@legos.obs-mip.fr

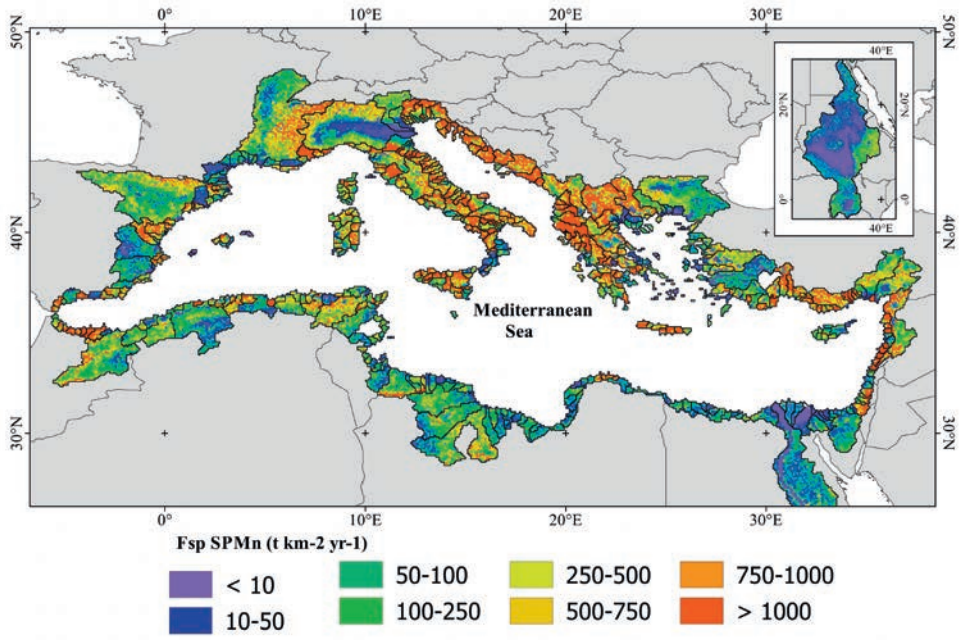
For further information: www.aviso.altimetry.fr/en/data/products/auxiliary-products.html

Effects of continental inputs on coasts

River water inputs: vectors of the impact of global change upon the sea

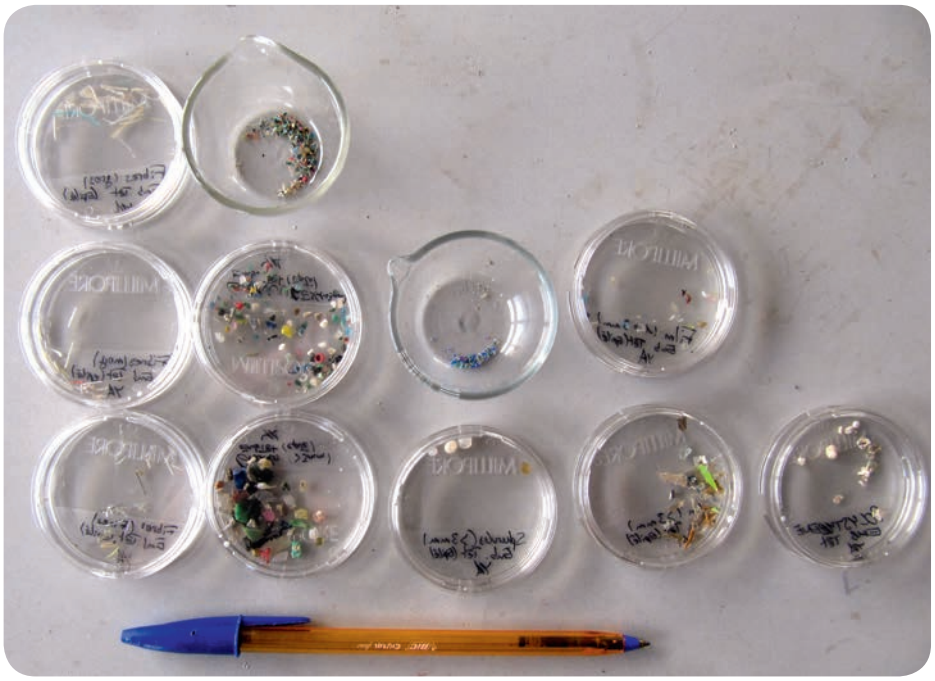
The Mediterranean, a semi-enclosed sea, is highly exposed to river inputs, now largely controlled by the human activities in the river catchments. The study of matter transfer along the Mediterranean land-sea continuum is one of CEFREM's specificities. Within the framework of a number of European projects, the laboratory has focused its expertise upon the implementation of a detailed geographical information system to the Mediterranean and the Black Sea drainage basin areas, as well as on the retrospective and prospective modelling of the associated water, sediment, nutrient and contaminant inputs, as a function of climatic and anthropogenic forcing processes. This work has highlighted the significant trends that characterize these inputs and their considerable impacts upon coastal water productivity.

At the Gulf of Lion scale (the laboratory's priority study area), CEFREM has initiated a systematic coastal river monitoring programme in order to compare coastal river inputs with the inputs of the Rhone, today the largest river in the Mediterranean. This work, which began within the framework of an interdisciplinary CNRS project, was perpetuated thanks to the integration of two automatic sampling stations on the Rhone and Têt rivers (the latter is managed by CEFREM) into MOOSE SNO*. **Research on the Gulf of Lion rivers has enabled quantification of the terrigenous particle inputs in both continental shelf sedimentary dynamics and on the offshore export of these particles,** and has also provided quantitative information relating to the transformations of terrigenous particles within the Earth's major biogeochemical cycles, such as the Carbon Cycle. By coupling terrigenous inputs with their associated contaminant—heavy metals (see p. 45) and, more recently, plastic debris (see p. 48)—this work is being used to identify areas of anthropogenic pressure at sea, thereby providing valuable information to the Gulf of Lion Marine Park for its sustainable marine resource management mission. **Within the catchment basins themselves, this work helps to quantify the impact of human activities on water quality and aquatic biodiversity, and contributes to the development of mitigation strategies addressing the threat of climate and anthropogenic changes.**



▲ *Specific sediments flows (t km^{-2} year^{-1}) from catchment basins to the Mediterranean Sea.*
From Sadaoui et al., *2018.* Progress in Oceanography. *163: 94–111. https://doi.org/10.1016/j.pocean.2017.08.003*

▼ *Assemblage of plastic particles collected at Têt river's mouth.* © *Ph. Kerhervé*



Contact (CEFREM):
W. Ludwig, ludwig@univ-perp.fr

* MOOSE National Observing System: Mediterranean Ocean Observing System for the Environment.

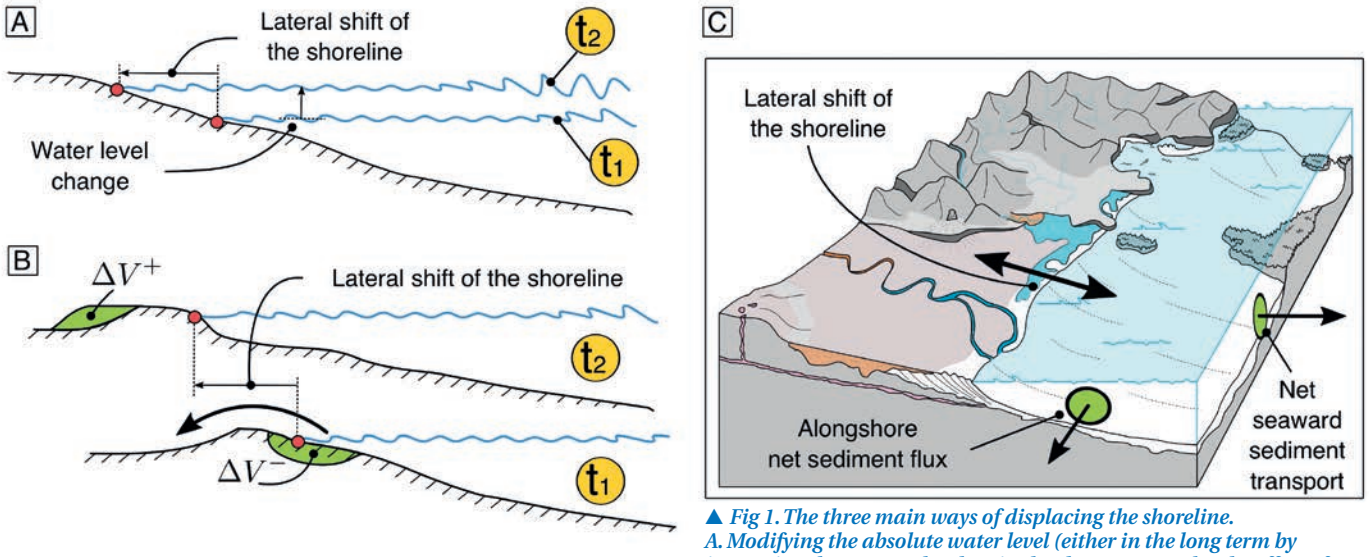
Modelling shoreline and marine flooding dynamics

The shoreline is undoubtedly the most emblematic element of coastal landscape as it marks the border between the terrestrial and marine worlds. Indeed, its characteristics (sandy, shingled, rocky, with mangroves, reef-based, protected or exposed, with tide or not, etc.) determine our habitat and land-use planning practices, our recreational activities and even our lifestyles. The shoreline's evolution over time—particularly it's recession—fuels all manner of fantasies, and is being discussed in a great number of societal debates, in relation to: sea level rise, beach sand resource overexploitation, river sediment input deficit, supposed recrudescence of storms.

However, the shoreline is a complex entity, whose highly non-linear dynamics are rather poorly understood. Indeed, shoreline position results from the continuous (instantaneous and average) competition between water level dynamics and the dynamics of sedimentary inputs within/outside of the coastal system (see Fig. 1). This complexity is why the coastal research community is focusing its attention upon the mathematical, numerical and experimental modelling of these two families of mechanisms. The major issues are (i) the exact modelling of storm surge taking into consideration 3D coupling between wind, swell, current and tide, and (ii) the physical-mathematical modelling of the shoreline's non-linear instabilities (see Fig. 2, 3 and 4), which unfold according to mechanisms that are almost impossible to reproduce with the engineering tools currently available. A number of different research teams from the Occitanie Region (GLADYS, Montpellier University [UM], Perpignan Via Domitia University [UPVD], UMR GM, IMAG, L2C, LA) are working on these issues together, making sure that they regularly reformulate their results in order to improve R&D storm surge and coastal morpho-sedimentary dynamics forecasting tools.

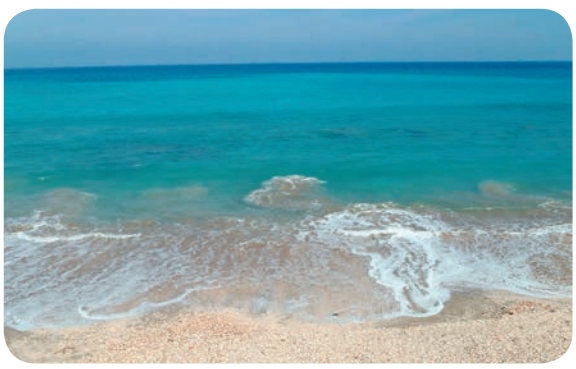
Contact (GM): F. Bouchette, frederic.bouchette@umontpellier.fr

For further information:
www.bouchette.org/research

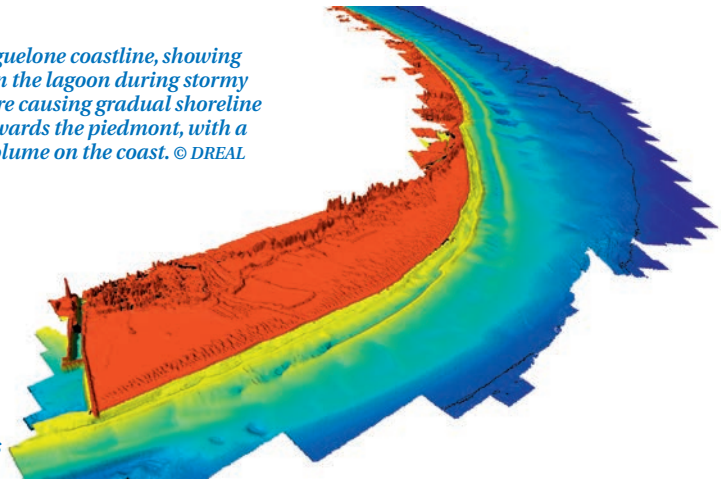


▲ *Fig 1. The three main ways of displacing the shoreline.*
A. Modifying the absolute water level (either in the long term by increasing the average level, or in the short term under the effect of storm surges).
B. Displacing a constant volume of sedimentary matter from the sea to the lagoons, usually during stormy periods.
C. Modifying the sedimentary budget of the entire coastal system, by creating variations of longitudinal sediment flow or offshore losses, resulting in a modification of coastal sandy sediment stock.

◀ *Fig. 2. The Maguelone coastline, showing storm deposits on the lagoon during stormy periods, which are causing gradual shoreline displacement towards the piedmont, with a constant sand volume on the coast.* © DREAL



◀ *Fig. 4. A shoreline developing so-called V-shaped notches* (chevrons de plage)*, auto-cyclic instabilities responsible for the shoreline's short-term dynamics.* © F. Bouchette



▲ *Fig. 3. A LIDAR (airborne laser scanning) image of the Espiguette beach, France. The shoreline (yellow/red shift) and very characteristic underwater morphologies of coastal sedimentary dynamics are visible. These morphologies are very difficult to model because of the complex couplings between hydrodynamics and sediment transport at all scales of space and time.* © F. Bouchette/GLADYS

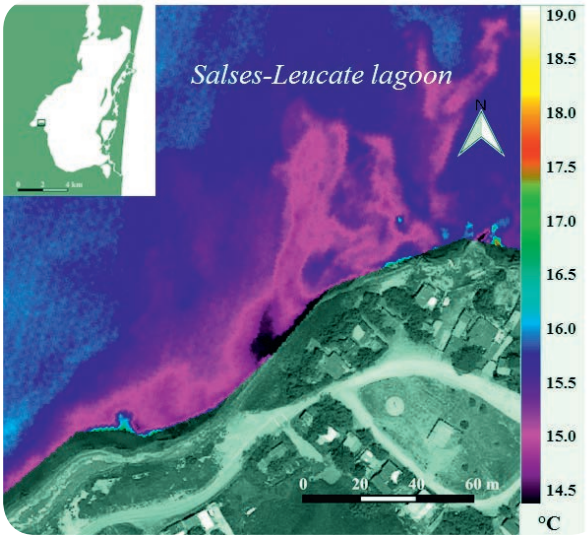
Submarine groundwater discharge along the Gulf of Lion: wide open 'taps' between the continents and the sea

Many karstic springs, discharging into the sea and into coastal lagoons, are found along the French Mediterranean coast. **These groundwater discharges are a source of, as yet still undetermined, matter and chemical elements that may impact the coastal water quality and functioning of coastal marine ecosystems.** Furthermore, these springs may be considered to generate a net loss of fresh water, as the water discharged is not used for human activities. These groundwater resources are usually enriched with nutrient salts that can support phytoplankton development (including toxic species) and also transport pollutants (e.g. mercury). On a global scale, submarine groundwater discharge accounts for approximately 6% of the river water flux flowing into the ocean. However, in the Mediterranean, the quantities of nutrients originating from groundwater are equal to, if not higher than, local river inputs (except for those of the Rhone).

The study of these systems is complicated by the challenges involved in accurately detecting them and by the frequently diffuse nature of the discharges (see opposite image). An innovative approach combining the use of airborne thermal infrared images (CNES/LEGOS) and *in situ* analyses obtained during field campaigns, has been implemented within the framework of the MED-SGD project* (2016-2018) by laboratories from the Occitanie Region —LEGOS and GET (Toulouse), LOMIC (Banyuls-sur-Mer), HSM (Montpellier)—in collaboration with other French and foreign laboratories. The measurement of natural radioelements such as radium (analysed in the Ariège-based LAFARA laboratory, which specializes in the detection of low levels of radioactivity, with support from the Occitanie Region and the European Union; FEDER SELECT) has enabled groundwater discharge to be traced and the flux of water and chemical elements associated with these systems to be quantified. In parallel, biogeochemical measurements have shed light on the influence of elemental stoichiometry** upon local microbial populations.

* MED-SGD project (ANR funding): Submarine groundwater discharge: study of a hidden source of chemical elements flowing into the ocean.
Collaboration with the European Centre for Research and Teaching in Environmental Geosciences, the UMR Oceanic and Continental Environments and Paleoenvironments, the Mediterranean Institute of Oceanography, the Autonomous University of Barcelona, Heidelberg University, Woods Hole Oceanographic Institution and Stony Brook University.
** Respective proportions of chemical compounds found in the environment and used in biochemical reactions.

Contacts: P. van Beek (LEGOS), vanbeek@legos.obs-mip.fr, P. Conan (LOMIC), pascal.conan@obs-banyuls.fr and S. Bejannin (LEGOS), simon.bejannin@gmail.com



▶ *Use of airborne thermal infrared imaging to detect a groundwater plume discharging into Salses-Leucate Lagoon, France.*
From Bejannin et al., *2017.* J. Hydrol. Reg. Stud. *13: 72–90.*
https://doi.org/10.1016/j.ejrh.2017.08.001

Why monitoring coastal dynamics through the analysis of heavy metals?

Coastal areas, which represent only a small part of the marine environment, are nonetheless a key environment at the crossroads of the continental, oceanic and atmospheric domains. They are a 'reactor', in which natural and anthropogenic inputs can be stored in the sediment, redistributed and even exported further offshore through hydrodynamic processes (currents, swell, storms, cascading, see p. 17). Trace metals (e.g. Pb, Zn, Cu), often considered to be harmful contaminants for the environment, have a diversity of origins (whether natural via soil erosion or anthropogenic via industrial activities, agriculture and urban waste, etc.) and are receiving particular attention in the Mediterranean and in the Gulf of Lion.

▲ *Atmospheric deposition collecting system at Cap Béar, France.* © *D. Aubert*

Over the past ten years, CEFREM has been monitoring trace metals fluxes flowing into the Gulf of Lion. This activity has been integrated into the MOOSE SNO. Continental river inputs are being measured for the Rhone and for five coastal rivers (Hérault, Orb, Aude, Agly, Têt) flowing into the Gulf of Lion, in order to quantify and study the seasonal and interannual variability of these inputs. The atmospheric compartment is included by collecting atmospheric deposition at two coastal stations of Cap Béar (Port-Vendres) and Frioul Island off the coast of Marseille. It is clear that the meteorological and climatic events (heavy rain episodes, floods, Saharan dust episodes, etc.) that periodically affect the region have a major influence on metal fluxes. In the North-Western Mediterranean, the matter exported out of the continental shelf is mainly exported southwards, through the submarine canyons that incise the continental shelf. Exported pollutant quantities are estimated thanks to particle traps placed in these strategic sites, and these estimates contribute to the assessment of 'coastal purification'. **The continued comprehensive and long-term monitoring of heavy metals in this part of the Mediterranean will provide an understanding of both the meteo-climatic and anthropogenic changes that determine 'coastal purification' dynamics.**

Contact (CEFREM):
D. Aubert, dominique.aubert@univ-perp.fr

For further information:
www.moose-network.fr/?page_id=269

Consequences of industrial and anthropogenic activities on the sea and on coastal areas

The impact of sand extraction on benthic macrofauna

Given the current erosion issues and the drive to replenish the sand beaches of our tourist coast, it is essential to be able to measure the impact of sand extraction activities upon the environment, and assess both the resilience capacity of marine habitats and the time required to return to equilibrium. In order to answer these questions, LECOB is involved in the IMPECAPE project*, funded by the French Biodiversity Agency, and implemented (as far as the Mediterranean in concerned) in partnership with the *Communauté d'Agglomération Hérault Méditerranée*. This project aims to bring together quantitative data on anthropogenic physical pressures and biological data, to precisely define the stages of benthic habitat restoration that follow these pressures.

▲ *Upper fine sand habitat, typical of the Languedoc coast's shallow areas.* © *Andromède Océanologie*

The sand extraction area under study is located at the *Domaine des Orpellières* in the municipality of Valras-Plage, within the Natura 2000 *Côtes sableuses de l'Infralittoral Languedocien* site. The sediment extracted using a suction dredger was used to replenish the sand beach of Vias, subject to strong erosion. Benthic macrofauna (fauna larger than 1 mm that lives in close relation with the sediment) was sampled in March 2015 just before the beginning of dredging work, and then again one month, seven months and one year after the work had ended. Despite its semi-desertic aspect, this habitat is home to exploited species emblematic of the seabed, such as *Solenidae* (razor shells) and *Donax* (bean clams). **Results show that the impact is very localized, and that, one year after the end of dredging work, the benthic environment has not yet fully recovered.** Based on the site's hydrodynamic characteristics, a faster return to equilibrium was expected. Ecological monitoring will therefore be continued.

Contact (LECOB):
C. Labrune, labrune@obs-banyuls.fr

* IMPECAPE project: Studying human activity induced pressures and impacts on coastal benthic habitats in order to develop indicators and protocols for monitoring the ecological status of these habitats.

The impact of health products on organisms and ecosystems

The presence of pharmaceutical and personal care products (PPCPs) in the environment was first recognized in the 1970s. However, it is only in the last 10 to 15 years that analytical techniques have improved enough for it to become possible to quantify the presence of these substances in water (domestic wastewater treatment plant effluents, surface water, groundwater, etc.), in soils and in living organisms, even at very low concentrations. PPCPs are introduced into the aquatic environment via municipal sewage systems and wastewater treatment plants effluents, and are also directly introduced via bathing, as in the case of sunscreen products. Since the wastewater treatment technologies used in municipal sewage systems are not fully efficient in eliminating these substances, a fraction of these products end up *in fine* in sewage sludge, some of which is used for spreading in agriculture.

The presence of PPCPs in the environment has become a societal challenge, and public authorities are being called upon to implement prevention and mitigation measures. A significant research effort as well as more efficient capitalisation of the information already acquired are required in order to address the exposure levels and long-term impacts of these substances on human beings and ecosystems. One of Banyuls LBBM's objectives is to determine exposure levels (consumption, contamination sources, concentrations in the different environmental compartments), hazards and risks for both the environment and organisms. Particular attention is also being given to the standards and methods used to analyse the risks associated with the presence of these molecules, with a view to contributing to regulatory improvement.

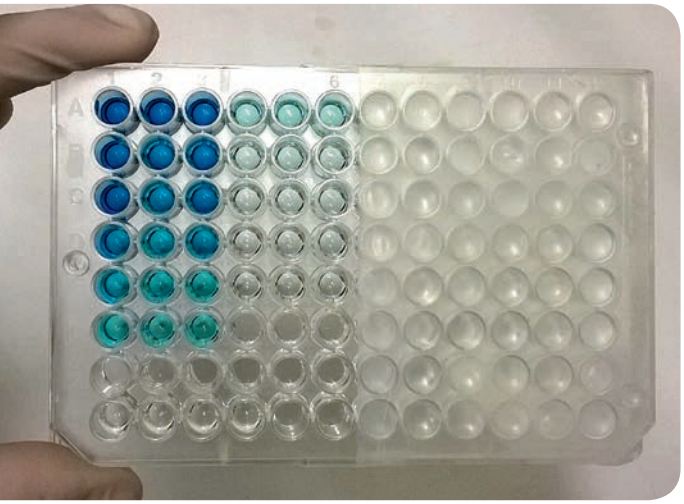
Contact (LBBM):
P. Lebaron, philippe.lebaron@obs-banyuls.fr

For further information: http://usr3579.obs-banyuls.fr/fr/activites_de_recherche/theme_3/degradation_personal_care_products2.html

◀ *Collioure beach in summer time (France).* © *Philippe Lebaron*

In situ biosensor-based monitoring of pathogenic microorganisms in coastal environments

A certain number of climate change and coastal population growth impacts on marine bacterial communities living in coastal waters, and on the occurrence of emerging or re-emerging bacterial pathogens are already measurable. Given the health repercussions and economic losses associated with contaminated aquaculture resources, microbiological monitoring of coastal water quality remains a major focus of surveillance. Today, real-time and *in situ* monitoring of dynamic variables can be performed using autonomous sensors. The monitoring of sensitive areas (bathing water, aquaculture production areas) is now possible thanks to the installation of measuring buoys enabling on-site and high frequency analysis of mainly physicochemical parameters (temperature, salinity, pH, dissolved oxygen, nutritive salts, etc.). However, automated analysis of bacterial contaminants is not yet feasible. With this in mind, the LBBM and associated team 'Biosensors-Analysis-Environment' (UPVD) are working towards the **development of DNA biosensors for monitoring bacterial contaminants in aquatic ecosystems. Biosensors for detecting *Escherichia coli* (an indicator of water quality degradation induced by faecal contamination) and the bacterial genus *Vibrio* (many species of which are pathogenic) have already been developed.** These biosensors use a sandwich format hybridisation to trap and determine a RNA sequences that are specific to the contaminants being investigated. Two detection methods—colorimetric and chemiluminescent—have recently been evaluated in naturally contaminated waters in the Salses-Leucate Lagoon (Aude). Adaptation of these two methods towards electrochemical detection methods will make it possible to miniaturize the sensors that have been developed, thereby offering new prospects for continuous and on-site bacteriological surveillance of coastal waters.



▲ *Colorimetric biosensor for bacteria detection.*
Blue colour intensity is proportional to the amount of target nucleic acid trapped by the sensor. © Elise da Silva

Contacts (LBBM):
J. Baudart, baudart@obs-banyuls.fr
and L. Barthelmebs, barthelm@univ-perp.fr

Understanding and predicting marine bivalve multifactorial diseases: the case of the oyster

For decades, the study of infectious diseases has been simplified to experimental pathosystems that minimize the influences of host and pathogen diversity, as well as the influences of biotic and abiotic environments. These reductionist approaches have made it difficult to characterize diseases with complex aetiology. Such aetiologically complex diseases are causing massive and recurrent mortality in many species of particular ecological and economic interest, such as pollinators, corals and exploited marine molluscs.

The work coordinated by IHPE as part of ANR DECIPHER project* has successfully elucidated one such aetiologically complex disease, affecting one of the most globally exploited species of marine invertebrates, the *Crassostrea gigas* hollow oyster. Mortality, which mainly affects the juvenile stages of this oyster, has continued to increase since 2008, both in France and throughout the world, thereby endangering shellfish farming. To address this challenge, we adopted an integrative approach combining the use of ecologically realistic experimental protocols with in-depth molecular analyses (transcriptome and microbiome study), which we applied to oyster families with contrasting vulnerabilities to the disease. The results obtained showed that **the first and necessary step of pathogenesis is infection of the oyster by a herpesvirus (*OsHV-1 µvar*), which induces an alteration of its antimicrobial defences and a destabilisation of its microbiota**. This process leads to secondary infection by potentially pathogenic opportunistic bacteria that multiply in the infected tissue, causing irreversible tissue damage that leads to the death of the oysters. **This work also enabled the identification of candidate genes for oyster resistance, thereby paving the way for new oyster farming strategies, via the implementation of disease-resistant oyster selection programs.**

▲ *Field monitoring of oyster mortalities, in the framework of the ANR DECIPHER project.*
© Y. Gueguen/IFREMER

Contacts (IHPE):
J. de Lorgeril, jdelorge@ifremer.fr,
Y. Gueguen, ygueguen@ifremer.fr
and G. Mitta, mitta@univ-perp.fr

* DECIPHER Project: Deciphering multifactorial diseases: the case of oyster mortality (ANR funding). The project consortium includes IHPE, LEMAR (Laboratory of Environmental Marine Sciences), I2BC (Institute for Integrative Biology of the Cell) and MARBEC UMRs as well as the CRCM (*Comité Régional de Conchyliculture de Méditerranée*).

Origin, impact and solutions for microplastic pollution in the Mediterranean Sea

CEFREM and LOMIC are investigating microplastic (MPs < 5mm) pollution in the Mediterranean Sea through the development of innovative approaches.

Where does this pollution come from? Catchment basins are the main source of MPs. Monthly monitoring conducted by CEFREM on the Rhone and on a small coastal river (the Têt) has demonstrated the importance of rainfall events in the transfer of these MPs towards the sea. It is estimated that **80% of marine pollution comes from the continent.**

What impact do MPs have on marine environment? Beyond visual pollution, plastics can be swallowed by certain species (turtles, fishes, birds, etc.) and cause their death through the obstruction of their respiratory tracts or the accumulation of pollutants adsorbed on plastics (hydrocarbons, PCB, etc.). LOMIC has demonstrated that plastics are also colonized by a large number of bacteria ('the platisphere'). The detection of cyanobacteria (which fix CO_2) and the particularly high activity of heterotrophic bacteria (which produce CO_2) now raise the **question of the platisphere's impact upon the carbon balance of the oceans.**

What are the potential solutions? Raising consumer awareness is still necessary today, as **households are the main source of this pollution, due to negligence and lack of satisfactory waste collection.** The manufacture of 'biodegradable' plastics is also a topical issue, even if such plastics account for less than 5% of today's plastic market. The OOB is currently working with the Ministry for the Ecological and Inclusive Transition. A new company hosted by OOB and called Plastic@Sea offer services to evaluate the fate, biodegradability and toxicity of plastic at sea.

Contacts: J.F. Ghiglione (LOMIC), jean-francois.ghiglione@obs-banyuls.fr and P. Kerhervé (CEFREM), kerherve@univ-perp.fr

▼ *Example of the volume of microplastics collected during the TARA-Mediterranean mission, after 1 hour of surface water sampling using a Manta net.* © *Noélie Pansiot*/Fondation TARA-Expéditions

80% of marine pollution comes from the continent.

The loggerhead turtle, a species indicative of marine plastic pollution

Our plastic litter is omnipresent in marine ecosystems. It interacts with species at all trophic levels, mainly by ingestion and entanglement, leading to direct or indirect mortalities, and altering individual feeding and protective capacities. Sea turtles are significantly affected by litter ingestion. As a consequence, the loggerhead turtle (*Caretta caretta*) has been proposed as a bio-indicator of litter impact upon marine fauna, within the framework of European directives aiming at assessing the efficiency of measures designed to restore the marine environment's Good Environmental Status (GES) for the Marine Strategy Framework Directive (Europe) and the regional sea conventions OSPAR (North-East Atlantic) and Barcelona (Mediterranean Sea).

In order to implement the indicator 'Litter ingested by marine turtles' (>1 mm), it is urgent and necessary that we adopt a global and standardized approach and define a threshold (the 'Good Environmental Status', GES) under which litter does no longer cause damage to species. This was one of the tasks of INDICIT project (INDICator Impact Turtles), funded by the European Commission and coordinated by CEFE (2017/2019) and pursued by INDICIT-II project.. This programme involves partners from five European countries (Portugal, Spain, France, Italy, and Greece) and two non-European countries (Turkey, Tunisia), working in close partnership with networks collecting sea turtles and the litter that they have ingested. In France, researchers collaborate with rescue centres, stranding networks, and veterinarians, in order to gather standardized data* collectively. The stomach contents of over 1,200 turtles have been analysed and described during the INDICIT programme. **The occurrence of litter ingestion in the analysed stomach contents was 55% for the loggerhead turtle in the Mediterranean and 74% in the Atlantic area of the project (results from September 2018).** This data will enable to define the threshol (GES) and to evaluate the long-term efficiency of policies aiming at reducing plastic use.

Contacts:
G. Darmon (CEFE), gaelle.darmon@cefe.cnrs.fr and
C. Miaud (CEFE-EPHE), claude.miaud@cefe.cnrs.fr

For further information: https://indicit-europa.eu/

* Collaboration with the French National Museum of Natural History, the Centre for Research and Conservation of Mediterranean Sea Turtles (CestMed), the French Mediterranean Sea Turtle Network (RTMMF), Gard *Laboratoire d'analyses vétérinaires départemental*, IFREMER and La Rochelle Aquarium Research and Care Centre for Sea Turtles (CESTM).

▶ *Stomach content of a stranded marine turtle.*
© S. Ciccione/Meeting of regional museums/Kélonia

Bioassays: a tool for assessing ecological risk associated with coastal pollution

The marine environment is considered to be the ultimate repository for a wide range of pollutants that originate from the continent and often accumulate in coastal areas, which is home to high biodiversity. The protection and restoration of aquatic environments are subject to voluntary based national regulatory development, promoted at the European Union level by the 2000 Water Framework Directive (WFD), the 2005 REACH Regulation on chemicals, and the 2008 Marine Strategy Framework Directive (MSFD). Following the 2006 and 2009 WFD campaigns, which reported an 'average status' for the Vermeille coast's coastal waters, OOB was commissioned by the Gulf of Lion Marine National Park to investigate sources of pollution and assess their effects on the area's environmental quality. The VERMEILLECOTOX* (2012-2015) and ECOLEAU (2016-2017) projects, also supported by the European Maritime Fisheries Fund (EMFF), the *Conseil Général* of Pyrénées-Orientales Department, and the CNRS, **have identified the sources of water and sediment pollution, respectively, as pesticides at the outlets of wastewater treatment plants and heavy metals in ports.** The dangerousness of these pollutants for marine organisms was evaluated by combining several bioassays using tests on living organisms to assess environmental toxicity. Taking into consideration that each organism has specific susceptibilities to pollutants, we tested several marine model organisms: the bioluminescent bacteria *Vibrio fisheri*, the sea urchin *Paracentrotus lividus,* the cephalochordate *Branchiostoma lanceolatum* and the European sea bass *Dicentrarchus labrax*. Considerable work was done thanks to the involvement of over 30 scientists who analysed over 30,000 pieces of data from water and sediments samples collected monthly in 14 different sites (ports, wastewater treatment plants, rivers, coastal areas). **The results of this work have enabled the establishment of a strategic plan for the reduction of risks directly related to uses. This strategic plan will be implemented through the Gulf of Lion Marine Natural Park.**

*VERMEILLECOTOX project (Chemical and ecological quality of Vermeille coast's coastal waters): http://lomic.obs-banyuls.fr/fr/axe_4_ecotoxicologie_et_ingenierie_metabolique_microbienne/vermeillecotox.html

Contact (LOMIC): J.F. Ghiglione, ghiglione@obs-banyuls.fr

For further information: http://lomic.obs-banyuls.fr/fr/axe_4_ecotoxicologie_et_ingenierie_metabolique_microbienne/projets-theme-3.html

◀ *Seawater conditioning procedure on board the Néréis II research vessel for laboratory analysis of marine environment chemical and ecological quality.* *© Jean-François Ghiglione*

Endangered resources

Shellfish farming vulnerability to environmental quality

Monitoring of the sanitary quality of lagoon and coastal waters is conducted on a monthly basis as part of a regular surveillance programme, and on a weekly basis when there are water quality alerts. If bacteriological contamination standard levels are exceeded, the commercialisation of shellfish is prohibited, which can be very detrimental to operators. CEE-M has participated in two European projects that assessed these damages for the Thau Lagoon. Based upon the simulation of current induced contamination diffusion (MARS3D model) and turnover geolocation as a function of shellfish farm type and area of productivity, it was possible to determine a turnover per mesh (100 m*100 m squares) and, as a result, to estimate the economic cost of commercialisation interruption periods according to their average duration. **Over the 2000-2005 period, this economic cost was estimated at an average of €2.8 M during the Christmas period, and €2.2 M during the summer.** These estimates do not take into account the damage to Thau Lagoon's image or the deferment of orders by suppliers that could not be supplied. Subsequently, over the 2005-2009 period, a more precise analysis of shellfish farming vulnerability was conducted, taking into consideration farm exposure, susceptibility and adaptive capacities according to production unit types and distribution channels. The attribution of vulnerability scores enables the distinction of four shellfish farm categories according to a decreasing vulnerability gradient, with a fairly balanced distribution of companies between the four categories. **The analysis also shows how valuable adopting diversification strategies and equipping shellfish farms with purification tanks can be in the reduction of vulnerability.**

Contact (CEE-M): H. Rey-Valette, helene.rey-valette@umontpellier.fr

© Syndicat Mixte du Bassin de Thau

The Mediterranean's marine resources face multiple threats: fishing, hydrocarbons, pollution, etc.

Consequences of juvenile oyster massive mortalities in Thau Lagoon

Since 2008, massive mortalities of juvenile oysters, linked to a viral infection, have been observed along the entire French coast. When these massive mortality phenomena occur, diseased individuals and cadavers are not removed from the environment. What are the consequences of these practices on the organic matter cycle, on plankton communities and on the transfer of pathogen from confined environments, such as the Thau Lagoon? By coupling laboratory and field based experiments, the MORTAFLUX and FATE project results have shown that (i) viral infection induces a decrease in oyster metabolism while flesh decomposition causes nutrient production in the water column, (ii) microbial plankton communities evolve significantly at the time of infection and with the first observations of moribund oysters, as illustrated by the proliferation of pico (< 3 µm) phytoplankton and heterotrophic bacterivorous organisms, (iii) during these same periods, juveniles consume picoplankton through filtration of larger flagellates and ciliates (10-30 µm), (iv) the herpes virus is observed in oyster flesh in association with suspended matter of pico (0-3 µm) and nano (3-20 µm) plankton sizes, (v) viral DNA transfer is observed close to pre-growing lanterns one week before the first symptoms of the disease, with maximum values recorded in the presence of moribund oysters and decomposing flesh. Transmission of the disease probably occurs through the filtration of decomposing flesh and the associated microbial organisms. The herpes virus can cause mortality in other species as early as in the larval stage, which could have an impact on coastal ecosystem biodiversity. **It is therefore recommended that oysters carrying the herpes virus not be introduced into the environment. The farming filter-feeding shellfish species capable of directly retaining picoplankton could operate as a bio-filter to contain disease transmission.**

Contact (MARBEC):
M. Richard, marion.richard@ifremer.fr

For further information:

MORTAFLUX Project (DS IFREMER, EC2CO, 2014-2016): Integrated study of the impact of oyster spat mortality on the flows associated with benthic-pelagic coupling in a lagoon ecosystem, Thau Lagoon, France, 2015-2017. http://doi.org/10.1016/j.aquaculture.2017.03.026

FATE Project (*Devenir*): case study developed in the framework of the European VIVALDI project Preventing and Mitigating Farmed Bivalve Diseases (2016-2020): www.vivaldi-project.eu/What-is-the-Vivaldi-project/Presentation
https://pole-lagunes.org/vivaldi-un-projet-europeen-pour-repondre-aux-mortalites-massives-des-coquillages/

Pelagic enclosure deployed in Thau Lagoon in the framework of the MORTAFLUX project.
© J. Oheix/IFREMER

Overexploitation of fishery resources in the Gulf of Lion

For approximately the last fifteen years, four commercially important species of fish, either overexploited or in a state of ecological imbalance, have been subjected to regular and scientific monitoring in the Gulf of Lion. Monitoring results vary depending upon the species:

- **Hake stock is in an overexploitation status. The total biomass and the spawning stock biomass decreased in the recent years reaching their lowest levels in 2016.** Since 2007, the recruitment* of this species has been declining and has now reached its lowest level. Since 2010, the fishing mortality is increasing, reaching the highest values in 2016. The exploitation level currently above the level estimated to be sustainable is mainly concentrated on young fish. Despite a significant decrease (approximately 50%) in the number of French trawlers since 1998 (and an even greater decrease since 2011), hake stock remains overexploited.
- **Red mullet stock is also overexploited. However, red mullet biomass is relatively high and its recruitment is increasing.** Currently, fishing mortality is fluctuating with no clear trend, and spawning-stock biomass is displaying a tendency to increase. Exploitation is mainly concentrated on young individuals (0-2 years).
- While anchovy and sardine stock biomass has dropped in the last ten years, leading to a fishery crisis, the abundance (number of fish) of these stocks has remained stable (anchovy) or even increased (sardine). **The important drop in the catches of these two species is not due to their depletion, but rather to a decreased fishing effort in response to the absence of a market for the fish that are now smaller and leaner than before**. Our research has demonstrated that the changes observed in anchovy and sardine populations (smaller, leaner and younger fish) are not due to fishing pressure (since 2013, the sardine exploitation rate has fluctuated between 0 and 2%, a far cry from the 40% ratio usually adopted as a sustainable exploitation target). Rather, they seem to be due to environmental modifications (changes in plankton communities, see p. 27). For these reasons, sardine and anchovy stocks are currently considered to be in a state of ecological imbalance.

▲ *Trawlers, Sète, France.* © *Isabelle Cheret, 2008*

Contacts (MARBEC):
A. Jadaud, angelique.jadaud@ifremer.fr
and C. Saraux, claire.saraux@ifremer.fr

For further information:

www.fao.org/gfcm/reports/technical-meetings

* Recruitment is the arrival of juveniles (new age group) in the fish stock. The age of recruitment varies according to species.

Impact of trawling in the Gulf of Lion

In order to improve marine environment management, it is necessary to describe both marine habitats and the distribution of the main macrobenthic species, to characterize anthropogenic pressure effects and to assess the capacity of benthic ecosystems to adapt to human-induced disturbances. **On the continental shelf, fishing with bottom gears (trawls and dredges) is known to be the major source of disturbance of seabeds.** Our study attempts to assess the impact of bottom impacting fishing activities, in a number of contrasted hydrodynamic and sedimentary environments. This objective will be met through investigating the answers to three questions: How should the ecological status of continental shelf benthic habitats be monitored? For each given habitat, which species should be considered as indicators of the benthic habitat sensitivity to fishing effort? In the different habitats considered, can hydrodynamics mask the effects of fishing, and how can 'good ecological status' be defined without any reference state?

To answer these questions for each habitat type, the combination of seabed sediment and abrasion pressure maps should enable the identification of those stations that are impacted and those stations that are not (or only slightly) impacted by bottom-impacting fishing gears. A differentiation may be made between the effects induced by natural processes (such as hydrodynamism and sediment type) and those induced by trawling. In addition, exhaustive sampling of these stations, using a trawl, a dredge and a video sled, will enable the compilation of complete faunal lists and indicator species to be sought. Furthermore, the deployment of video systems (such as the underwater video system Pagure2, see below) will enable the improved observation of the macro-invertebrate fauna that is fixed to the seabed and constitutes, given its exposure, a very precise indicator of benthic habitat susceptibility to fishing efforts. **Our research should ultimately contribute to the development of mesoscale indicators. If necessary, several observation methods will be combined in order to support the monitoring of the impact of towed fishing gear on benthic habitats.**

Contact (MARBEC): S. Vaz, sandrine.vaz@ifremer.fr

For further information: wwz.ifremer.fr/webtv/Campagnes-a-la-mer/PAGURE-2

▼ *Benthic underwater video sled.* © *Sandrine Vaz/IFREMER*

Young loggerhead turtles, Maguelone, France, 7 October 2018.
© Jean-Baptiste Sénégas

THE MEDITERRANEAN COAST HUMAN–ENVIRONMENT OBSERVATORY (OHM-LM)

The OHM-LM is an interdisciplinary research system created by the CNRS in 2012 and supported by the LabEx DRIIHM* to study of urbanisation and coastal anthropisation in the Mediterranean. In a context of changing coastal management practices (integrated coastal zone management), it addresses four coastal socio-ecological systems, unevenly subjected to artificialisation, tourist and recreational activities, in the regions of Occitanie (Gulf of Aigues-Mortes, GAM), PACA (Marseille coast) and Corsica (Balagne and Biguglia). The OHM-LM brings together research teams and local stakeholders, including institutions and relevant non-profit organisations, around shared issues such as: the management and protection of natural spaces and environments; ecosystem services and environmental amenities; the biological and physicochemical quality of environments and health; the development/functioning of territories; and the quality of life of coastal human populations. Three major issues are relevant for the GAM:

- Coastal urbanisation. Urban sprawl schemes still prevail in the watersheds of the GAM, while flooding and coastal erosion threaten existing developments on the coast. Given the risk of marine submersion and the prospect of relocation of assets and activities exposed to this risk, many questions challenge the way urban developments should be conducted if they are to be sustainable.
- Coastal recreational uses. Many researchers are studying coastal recreational uses to understand their interactions with the environment: the environments visited by people, users' expectations and perceptions towards management measures, and changes in the quality of the environment, focusing in particular on the interactions between bathing water quality, hydroclimatic conditions and tourism.
- Lagoon environments' functioning, integrity and restoration. Given the sensitivity and vulnerability of lagoon environments to the land-sea interface, their functioning, integrity and restoration is a core issue for the GAM. These environments are attracting growing interest from local managers and stakeholders who actively participate and collaborate in research studies.

Person in charge (GAM site): P. Monfort (HSM), patrick.monfort@umontpellier.fr

For further information:
www.ohm-littoral-mediterraneen.fr

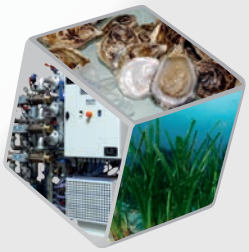
* Interdisciplinary Research Mechanism on Human–Environment Interactions: www.driihm.fr

▲ *Aerial view of the coast of the Gulf of Aigues-Mortes, with, from bottom to top, Palavas-Les-Flots, Carnon, La Grande Motte, France.*
© P. Monfort

▲ *Aerial view of La Grande Motte.*
© P. Monfort

© Sophie Fallourd

The basics of sustainable development of the 'sea system'



Historically viewed as hostile and dangerous environments reserved only for fishing, the coastal regions and the sea are today attractive spaces in which a significant part of the population live and where there is substantial economic activity. According to the National sea and coastal observatory, about 10% of the metropolitan population live in coastal communities, representing at least 365 inhabitants per square kilometre of 500 meters of shoreline! With a rate of construction 4 times higher than the national average (most notably for secondary residences). Specific tools and knowledge are, therefore, necessary to reconcile and regulate the inevitable tensions between often divergent interests. The coastal regions have also been defined in France as areas that are shared between "those who live there, those who make a living there, and those who come to visit" (Datar, 2004**).

Integrating sustainable development into the marine and coastal environmental field is often made reference to in the Coastal Zone Management Act that was passed in the United States in 1972, the same year the United Nations held their first conference on the human environment in Stockholm. The idea of 'integrated management of coastal zones' was introduced in 1972, but it was not until 1989 that its form and methods were defined during an international research seminar in Charleston (South Carolina, USA). This awareness developed as a reaction to the urbanisation and the increasing and often unregulated artificialisation of the coast. In parallel, the development of 'systems' approaches, research and policies in ecosystem and biodiversity conservation, introduced new regulatory mechanisms and spatial controls, through, for example, diverse forms of marine protected areas or integrated programs that expand the perimeter of research to watersheds.

In light of this historical information, the principles of sustainable development of marine and coastal environments were developed well before the 1992 Rio Conference, which explains the rapid transfer of the principles and recommendations that were defined at Charleston into experimental programs that involved researchers and public decision makers alike. Since then, we have witnessed a movement from sectorial research, which is often mono-disciplinary, to cross-cutting issues and concerted mobilisation of multidisciplinary teams. New approaches, such as 'green economy', for example, have emerged along with new pluri-disciplinary scientific communities within associations and in journals such as Ecological Economics at the international level or *Natures Sciences et Sociétés* at the French level.

Research on implementing sustainable development expanded for each domain: fishing, aquaculture, tourism, maritime transport…, the interactions between use, activities, nature and ecosystems generated targeted ecosystem approaches. In fact, from 2005, with the Millennium Ecosystem Assessment and the concept of ecosystem services, it is no longer just about ensuring the sustainability of activities, but also of questioning and acting on their contribution to sustainability within territories in which they are implemented and within which they interact.

As a result, new research questions on the articulation between levels have also emerged: migrant or invasive species, for example, or characterizing biological, chemical or physical flux. Scientific knowledge produced in this way can serve to guide and support changes in practice of economic actors, citizens and public decision makers, in favour of processes and uses that are more respectful of the environment.

Here, we are referring to sustainable and inclusive fishing and aquaculture, for example, that have been developed through the input of research in countries in the South and which have mobilized references of livelihoods in the social and cultural context as well as differential policies. More recently, knowledge about ecosystems gave birth to two new fields of research: (1) Ecological Restauration, in which development is stimulated by regulations meant to reduce or compensate for anthropic impacts on the environment, and (2) Agroecology that should provide a way to create production systems, in aquaculture for example, which rely on the functions offered by ecosystems.

Primarily limited to the coast and coastal areas, the issue of sustainable development is progressively expanding out towards the sea as evidenced by new directives defined by the European Union on environmental marine quality and maritime spatial planning. Furthermore, the 'blue growth' concept is currently directing research and exploitation activities, assumed to be sustainable and reasonable, of marine environments and resources. Consequently, off shore energy production (wind, geothermic, tidal energy…) is a sector that drives technical innovations and that has also led to the expansion of (1) the social representation domain of the sea as well as (2) researches on arbitration of coastal and maritime conflicts.
This blue growth issue is strategic for France, which has the 2nd largest exclusive maritime economic zone in the world (close to 11 million per km^2, of which 100,000 is located in the Mediterranean) and has generated a surplus value if €35.6 M in 2013 (IFREMER economic data). France also has assets as well as important responsibilities in this domain. Moreover, the dramatic increase of intercontinental maritime traffic has made its regulation vital.

Sustainable development is part of a larger issue that includes ecosystem resilience, marine species and territories that are confronted with climate change and its impacts: acidification and warming of sea water, a rise in sea level, marine submersion that increases the severity of the damages caused by storms… which points to the need to study and manage the vulnerabilities of the environment and society. It is, therefore, important to explore new fields of knowledge, test new regulation tools that are integrated, collaborative and adapted over the long-term. Above all, however, is the need to put into place conditions for a change in value, a type of Copernican revolution that could lead to a different way of viewing man's relationship to nature, and not as a dualism between two separate worlds, but as a duality of two sides that come from the same process of a millennia-old co-evolution.

Continued on next page…

For example, in order to maintain the beauty of the coastal territories, the occupational principals of the territories should be reviewed, and the regional solidarity between territorial collectivities as well as types of residents, users of these territories, and more broadly between citizens at different levels, should be revisited. Within this domain, the region of Occitanie is a territorial leader in France and in the Mediterranean, where new development doctrines promote the relocation of buildings and infrastructures most vulnerable to marine submersions, and to reconvert these zones (through revegetation, sand nourishment, etc.) into areas capable of playing or replaying their protective role.

These thematical issues, and the methodologies that will allow us to develop solutions, are driven by a plethora of research projects currently being conducted in Occitanie through multiple collaborations between disciplines and laboratories, but also through the involvement of public decision makers and private businesses that have made a commitment to solve these new issues. This chapter is structured around 6 issues that reflects the research conducted in the Mediterranean: (1) basic functional knowledge for ecosystem-based management of fishing and aquaculture, (2) identification of issues related to maritime traffic and industrial and port activities, (3) biotechnologies and bioengineering and their applications to restore ecological environments, (4) assessment of coastal risks and adaptation to the impacts of climate change, (5) marine protected areas and bio-conservation strategies, and (6) perspectives on marine energy.

Hélène Rey-Valette (UM, UMR CEE-M)
and Bernard Hubert (INRA, EHESS, Agropolis International)

* 1.1 million people within 500 m and 8.1 million within 10 km of coastline.
** DATAR, 2004. Construct together a balanced development of the coast. *La Documentation Française*, 155 p.

KEY INITIATIVE SEA & COAST: A TOOL FOR SCIENTISTS AND BLUE GROWTH STAKEHOLDERS IN OCCITANIE

The MUSE I-SITE project 'Montpellier University of Excellence' gathers the forces of 19 institutions towards a common ambition: to create in Montpellier a thematic research-intensive university, internationally recognized for its impact in the fields of agriculture, environment and health. Among the initiatives underway, is a call for proposals that focused on thematic and transversal mechanisms to assert the unique identity of MUSE in its territory, and to foster synergies across research, training and the economic sphere. Among the identified thematic areas, one, as of June 2018, deals with the Sea and the Coast. The aim of MUSE Key Initiative (KIM) Sea & Coast is for MUSE to be recognized for its dynamism in marine and coastal sciences in the Mediterranean, southern countries and elsewhere in the world. This initiative's legitimacy lies in the multidisciplinary local forces (biodiversity, environment, geosciences, modelling, marine engineering, human and social sciences, etc.) invested in the major societal challenges related to the Sea and the Coast, including 300 permanent scientists coming from 20 Joint Research Units of MUSE. This asset is embedded in the dynamism of the Occitanie region that has identified the Sea and the Coast as a priority, setting up, within its administration, a Directorate of the Sea, and creating a Parliament of the Sea in 2013.

The KIM Sea & Coast therefore represents a unique project on the Mediterranean coastline, embracing at the same time MUSE's specific aspiration for Southern countries.

Launched in June 2018, this initiative's first objectives are to create a local 'sciences and society' community around issues related to the sea and the coast, making it visible and attractive internationally. This results in particular in the implementation of international calls for proposals, Masters Challenges and promotional scientific initiatives (summer schools, public conferences, scientific awareness days, etc.). The KIM acts as a simple structure to bring together local blue growth local stakeholders, and to allow the emergence of multidisciplinary synergies between socio-economic stakeholders, researchers and students.

Contact: L. Dagorn (MARBEC), muse-kimsc@umontpellier.fr

For further information: http://muse.edu.umontpellier.fr/territoire-et-societe/key-initiatives-muse/sea-coast

▼ *Sea bream fish farm off Monastir coast in Tunisia.*
© L. Dabbadie/CIRAD

THE REGION CONTRIBUTES TO THE FAO 'BLUE GROWTH' INITIATIVE

In order to avail from 'blue growth' benefits, many countries around the globe are adopting cross-sectoral strategies. Indeed, the transition from a conventional economy to a blue economy, while thriving on traditional approaches, goes beyond sectoral visions. It enables complementarities that contribute to strengthen the sustainability of exploited ecosystems, while creating value (blue economy), inclusive economies, wealth and employment. In order to provide guidance to its Member States and to ensure that the national blue growth strategies are aligned with international instruments such as the Code of Conduct for Responsible Fisheries or the Ecosystem Approach to Fisheries and Aquaculture, the Food and Agriculture Organisation of the United Nations (FAO) has developed the Blue Growth Initiative (BGI) in which the CIRAD has participated, in particular on aspects related to aquaculture. The BGI advocates for suitable ways to balance economic growth, social development, food security and sustainable use of living aquatic resources. It is already being implemented in several regions, including in the Mediterranean and in the Small-Island Developing States. In the long term, this strategy will lead to new economic dynamics at territorial level, and will contribute to countries' efforts towards achieving the sustainable development goals of the 2030 Agenda.

Contacts: L. Dabbadie (CIRAD), lionel.dabbadie@cirad.fr
and J. Catanzano (FAO), joseph.catanzano@fao.org

For further information:
www.fao.org/policy-support/policy-themes/blue-growth
https://uved-formation-aquaculture.cirad.fr
www.fao.org/blogs/blue-growth-blog/en/

Ecosystemic management of fisheries and aquaculture

Managing Bluefin tuna: a history of over-exploitation and recovery

In ancient times, the Phoenicians and then the Romans had already established over a hundred sites around the Mediterranean to exploit the seasonal migrations of Bluefin tuna. The species was thus fished sustainably for almost two thousand years, despite major natural fluctuations in its abundance. The boom in the sushi market in the 1980s, for which Bluefin tuna is a 'flagship' species, was to destroy this long-run balance. The high market value of this species, together with its ineffective management at both national and international levels, resulted in significant over-capacity, i.e. the use of a fishing fleet of far greater capacity than could be supported by the available fish stocks. This over-capacity resulted in a staggering increase in captures and, eventually, over-fishing of stocks. Although the International Commission for the Conservation of the Atlantic Tunas (ICCAT) set a quota in 1998, this was well above the level advised by scientific opinion and no real controls were put in place. Captures therefore remained far too high until the 2000s, creating a serious risk of collapse in the fisheries and in the population of Bluefin tuna. In the end, strong pressure from environmental NGOs and public opinion forced ICCAT to pay more attention to scientific opinion and to put an effective recovery plan in place. Since then, stocks of Bluefin tuna have recovered rapidly, showing that **it is possible to improve the status of over-exploited and high-value stocks when there is real political will.** The challenge now relates to reducing the uncertainties inherent to all scientific opinion and, for this, the development of more robust stock assessment models and independent fisheries monitoring data is needed. The MARBEC Joint Research Unit (UMR) has been conducting regular aerial monitoring since 2000 to determine Bluefin tuna populations in the north-west Mediterranean and is using electronic tagging to better understand their migration routes. More science, less uncertainty and better management recommendations should, ultimately, result in sustainable medium- to long-term management and, in the end, increased incomes for the fishing industry.

Contacts (MARBEC): J.-M. Fromentin, jean.marc.fromentin@ifremer.fr and T. Rouyer, tristan.rouyer@ifremer.fr

© IFREMER

The spatial dimension of fisheries management: territorial rights

Aquatic resources are often over-exploited, requiring policies that are able to reconcile fishing productivity with conservation. To resolve this issue, concessions are increasingly employed to manage fisheries in many countries. This system raises a potential challenge: limited-tenure concessions grant spatially-located user rights while the species is able to move (via migratory processes) outside the area controlled by any given operator. This can have an impact on incentives to manage the resource sustainably, each concession holder focusing exclusively on her area without taking these movements into account. The Centre for Environmental Economics - Montpellier's work on territorial rights focuses on analysing this concession system in order to solve the problem. When several areas are affected by this instrument, a contract is offered that grants limited-tenure property rights over each area to an operator (one concession holder per area), with the possibility of renewal provided certain conditions are satisfied. The regulator announces minimum stock levels for each area below which the concession holder must not harvest. The results show that **the duration of tenure and the particular features of the species (spatial mobility) deeply affect the concession holders' incentives to cooperate.** In ongoing work we consider the ability of this kind of instrument to account for ecosystemic management practices. Indeed, many types of concession are designed to manage a given species but these abstract from the ecological interactions that exist with other species. The CEE-M analyses a concession system's capacity to meet economic and conservation goals when these interactions are taken into account.

Contact (CEE-M): N. Quérou, nicolas.querou@supagro.fr

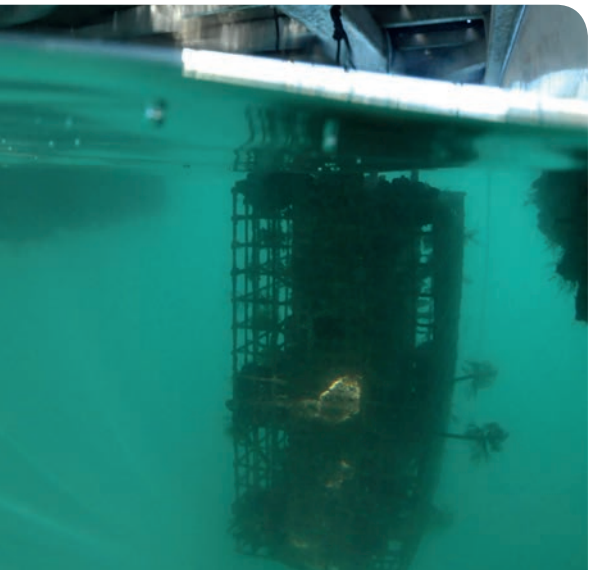
For further information on the ANR GREEN-Econ project:
https://sites.google.com/view/anr-green-econ/home

Ecological restoration and fish stock development

One of the major challenges of the 21st century is to find a balance between protecting the marine environment and maintaining, even developing, the human activities that rely on it (fishing, tourism...) Sustainable marine resource management relies on a good understanding of the different components of, and challenges facing, the maritime system, whether ecological, economic or social, in order to implement joint actions between the different actors: scientific, managers or users of the environment. The Centre of Education and Research on Mediterranean Environments (CEFREM) is working on the multi-scale modelling of human impacts, whether direct (fisheries) or indirect (coastal urbanisation), on the Mediterranean environment and, more particularly, on the fish populations found within it. The laboratory has begun regular monitoring* of professional and recreational** fishing, in cooperation with the management team of the Gulf of Lion Marine Nature Park. This monitoring, together with awareness raising activities, has enabled time series data to be established aimed at identifying the pressures, real or potential, exerted on the environment and its populations in order to adapt practices and thus minimize, even prevent, human impacts. At the same time, the laboratory is looking into preserving and restoring the habitats necessary to each stage of the life cycle of fish and their functions by establishing different ecological restoration systems, from artificial reefs to artificial port nurseries conducive to the development of juvenile fish. **Such artificial habitats along the wharfs or under the pontoons help to rehabilitate the functions of nurseries and thus support natural fish populations*****. This research relies particularly on UPVD's CREM-IEEM (Intervention and Expertise in the Marine Environment) technological platform, hosted by the Centre for Marine Ecosystem Research (CREM) at Port-Barcarès.

Contact (CEFREM): P. Lenfant, lenfant@univ-perp.fr

* PechGere Programme cofinanced by the French Biodiversity Agency and the Region of Occitanie.
** This relates, by definition, to non-commercial fishing: the species caught are intended solely for domestic consumption and cannot be sold.
*** RESPONSE Programme financed by the Rhône-Méditerranée-Corse Water Agency..



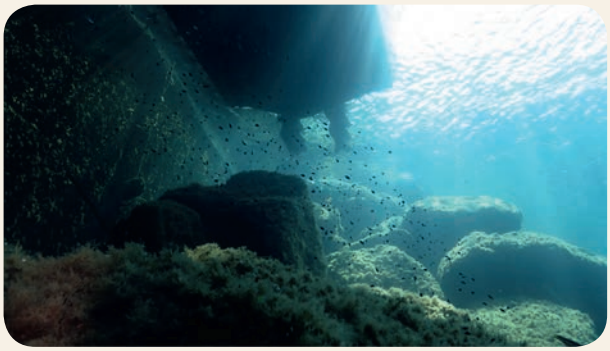
◀ *Artificial habitat for juvenile fish, placed under a port pontoon*
© M. Mercader

SOLUTIONS FOR SHALLOW COASTAL WATER RESTORATION

Shallow coastal waters have been subjected to considerable anthropogenic terrestrial and marine pressures for many years. Yet, they are essential to the life cycle of coastal fish as they provide shelter for nursery habitats. Over the past 5 years, under the impetus of the Rhone Mediterranean Corsica (RMC) Water Agency, the Mediterranean Sea Competitiveness Cluster and a number of local authorities, multiple R&D projects have been implemented in Occitanie. The objective of these projects have been to define technical solutions for restoring nursery habitats, test them within pilot initiatives, and deploy successful solutions on a large scale. Today, a new field of expertise has established itself in Occitanie, driven by the University of Perpignan UPVD (CREM/CEFREM), which has produced three theses on the topic, ECOCEAN (a Montpellier-based SME and world leader in this sector), environmental consultancy firms (*Andromède Océanologie*, Biotope, CREOCEAN, etc.) and, to a lesser extent, by both large groups such as *Egis Eau* and SUEZ and very small local businesses (VSB). Nursery habitat restoration is now integrated into the Region of Occitanie's regional innovation strategy (SRI/3S), and a number of technologically mature tools are available for a few technically and scientifically proven solutions, some of which are already being commercialized (see p. 68). However, for most of the solutions, Technology Readiness Levels are currently medium or low, and have yet to be consolidated (see Table below). Twenty-three marinas (of which eight in Occitanie) and two commercial ports are thus engaged in a NAPPEX approach (Artificial Nurseries for Exemplary Ports, see p. 69).

Contacts: S. Fonbonne (ECOCEAN), sebastien.fonbonne@ecocean.fr, G. Lecaillon (ECOCEAN), gilles.lecaillon@ecocean.fr and P. Lenfant (CEFREM), lenfant@univ-perp.fr

For further information: www.nappex.fr/?lang=en



▲ *Below the surface of a port.* *© Rémy Dubas / ECOCEAN*

Restoration Solution Type	Operationality	Ecosystem-Based Approach Relationships
Creation of artificial habitats for marine fish larvae and juveniles in port areas	Proven	Proven; relationship with fishing economy and small trades
Creation of artificial habitats in coastal areas	Proven	Proven; relationship with fishing economy and small trades
Compensation for the absence of functional nurseries or the dysfunction of larval colonisation (post-larvae capture and laboratory nurseries)	To be strengthened	Proven; relationship with fishing economy and small trades
Restoration of plant communities	To be strengthened	Not proven

▲ ***Main types of solutions developed since 2013 for shallow coastal waters restoration.*** *From RMC Water Agency, in ASTEE, 2018,* **Ecological Engineering Applied to Aquatic Environments. For Whom? For What Benefits?** (***Ingénierie écologique appliquée aux milieux aquatiques. Pour qui ? Pour quels bénéfices ?*).**

Research for sustainable development of marine fish farming

Understanding 'animal—rearing system—environment' interactions is essential in order to propose sustainable development of temperate and tropical fish farming, combining economic viability, environment preservation and social acceptability. Research studies carried out by MARBEC Unit and its partners* (in Sète, Montpellier and on IFREMER'S experimental platform in Palavas-les-Flots) focuse on understanding the adaptation and adaptability processes of organisms and systems subject to natural and anthropogenic variations in their environment. These studies address:

- The genetic, genomic, physiological and behavioural architecture of organisms' adaptation and performance. For fish, targeted characteristics are: feed efficiency, disease resistance, genetic determinism of sex, adaptation to farming conditions and adaptation to different terrestrial and/or marine ingredients of fish diets.
- Aquaculture system flexibility and hosting ecosystem resilience, and in particular: (1) effluent characterisation, modelling and bioremediation by extractive species acting as trophic links within integrated multi-trophic aquaculture systems, (2) Valorisation of these trophic units (bivalves, detritus feeders, algae) and (3) Evaluation of the environmental carrying capacity.
- Interactions between the changing environment and aquaculture ecosystems. For example, the impact of microbial community fluctuations on oyster growth and reproduction, or the impact of oyster mortality on ecosystem functioning.

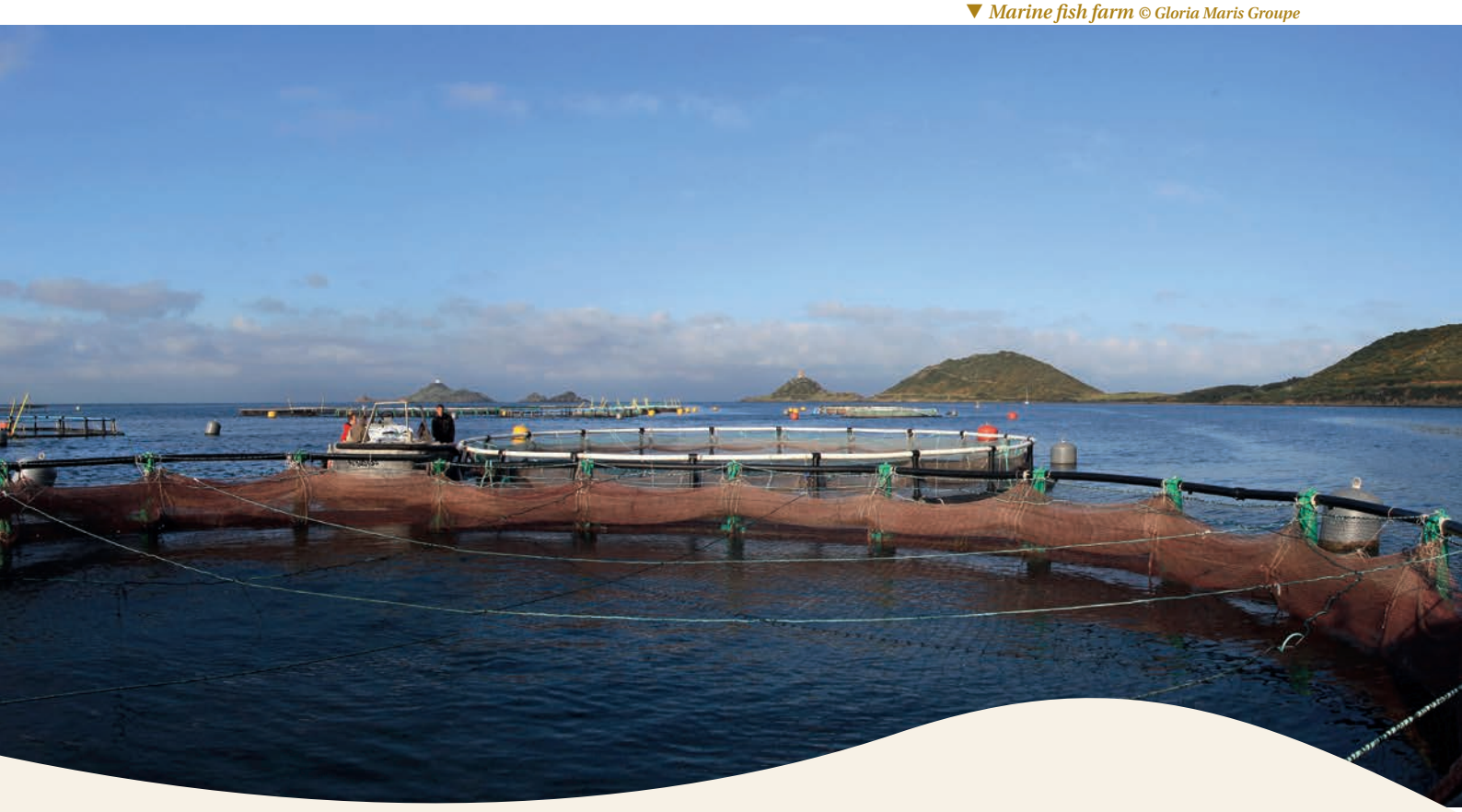
The Palavas-les-Flots experimental platform is one of the European centres of excellence involved in aquaculture research (AquaExcel[2020] project). It is also a place that supports both the research-economic sector dialogue, through the 'Fish Farming Tomorrow' *(Pisciculture Demain)* Scientific Interest Group (GIS PsD) and the public policy, in particular through its collaboration with the Maritime Fisheries and Aquaculture section of the Ministry of Agriculture and Food.

* Main partners: INRA (French National Institute for Agricultural Research), CIRAD (French Agricultural Research Centre for International Development) and IHPE Unit (Research Unit on Host-Pathogen-Environments Interactions).

Contacts (MARBEC): E. Roque, emmanuelle.roque@ifremer.fr, T. Laugier, thierry.laugier@ifremer.fr and M. Callier, myriam.callier@ifremer.fr

For further information:
www.umr-marbec.fr/en/research/sustainable-aquacultures,070.html?lang=en
https://uved-formation-aquaculture.cirad.fr/10-la-production-durable

▼ *Marine fish farm* © *Gloria Maris Groupe*



Adopting a systemic approach to fisheries and aquaculture reconciles conservation and exploitation objectives.

▲ Posidonia *meadows (*Posidonia oceanica*) in the Mediterranean.* © *Laurent Ballesta/Andromède Océanologie*

Economic valuation and perceptions of marine ecosystem services

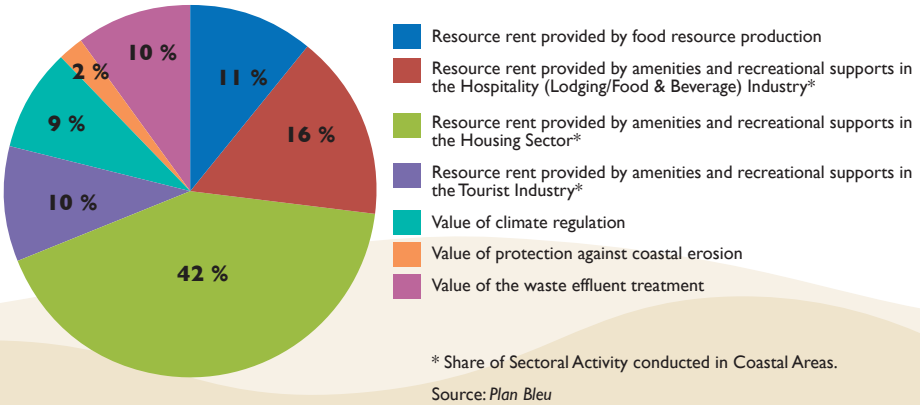
The economic valuation of ecosystem services measures the contribution of ecosystems to human well-being and can therefore support public decision-makers in making better choices for territorial development. Within the framework of the UNEP (United Nations Environment Programme) Mediterranean Action Plan, the CEE-M has evaluated seven ecosystem services (see Figure below) provided by five major types of marine ecosystems in the Mediterranean. **In 2005, the value of sustainable benefits related to the ecosystem services provided by marine ecosystems in the French Mediterranean, was over €26 billion, mainly attributable to the amenities and recreational infrastructures and services (approximately €18 billion) provided by three industrial sectors: Hospitality (Lodging/Food & Beverage), Real Estate, and Tourism (68%).**

The CEE-M also contributed to studying *Posidonia* meadows, which are in steep decline despite being protected. *Posidonia* meadows provide many ecosystem services that are worth identifying using the reference list recommended by the Common International Classification of Ecosystem Services. Due to incomplete data, only seven goods and services** (out of a total of 11) were economically evaluated, totalling €25.3 to €45.9 billion per year, i.e. €283 to €513 per hectare per year, two-thirds of which are accounted for the sole coastal protection function.

The CEE-M also analyses the perceptions that various panels of users, stakeholders and citizens have of the different types of ecosystem services. The aim is to comprehend the levels of knowledge and rank the services that are relevant to specific target groups or territories, in order to reflect the diversity of points of views and anticipate possible conflicts between interest groups and/or organisational levels. Additional information pertains to the levels of familiarity, experiences, emotions and feelings that can influence behaviour. These elements help identify both the perceptions that are conducive to pro-environmental behaviour, and the existing needs in relation to (1) Awareness-raising and training in this area, and (2) Adaptation of governance mechanisms, so as to ultimately strengthen the preservation of these services. By prioritizing voluntary measures, these approaches are in line with the 'reconciliation ecology' trends, which aim positive coexistence between human beings and nature.

Contacts (CEE-M):
J.-M. Salles jean-michel.salles@supagro.fr,
A. Mangos, anaimangos@gmail.com and
H. Rey-Valette, helene.rey-valette@umontpellier.fr

** Use of dead leaves as materials or bio-indicators, protection against coastal erosion, water purification by filtration, carbon sequestration, water oxygenation, fishing habitat and spawning grounds, contribution to scientific knowledge.



* Share of Sectoral Activity conducted in Coastal Areas.

Source: *Plan Bleu*

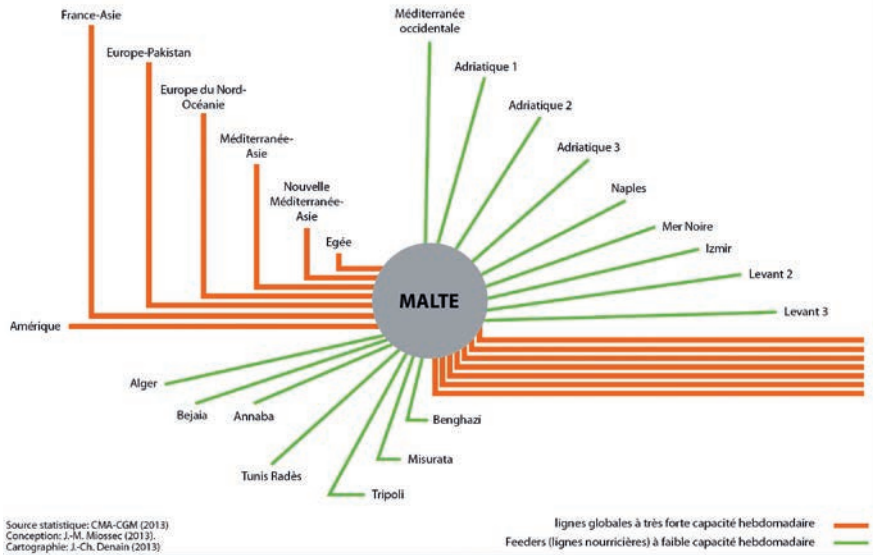
▲ *Value Distribution by Type of Service Provided by Mediterranean Marine Ecosystems.*

Maritime traffic, industrial and port activities

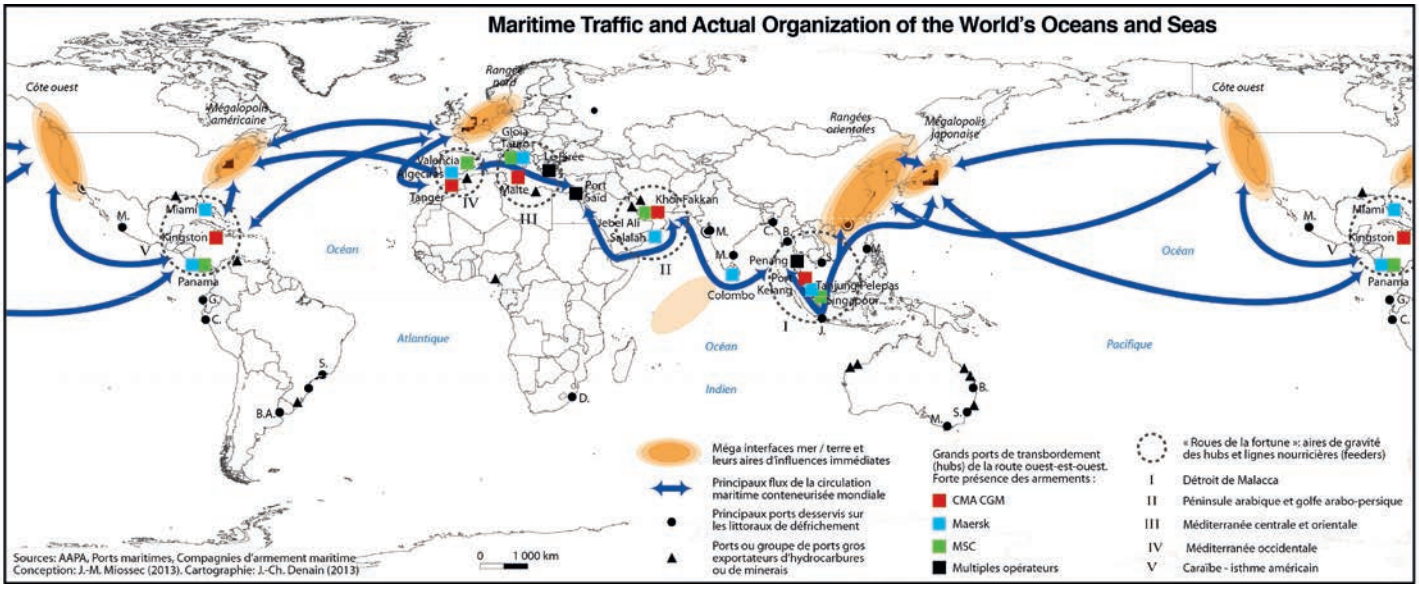
Container shipping: the Mediterranean at the crossroads of global traffic

In the last few decades, shipping has been revolutionized by the widespread use of containerisation. The standardized 'container' has now become a unit of measurement (twenty-foot equivalent unit, or TEU) and the symbol of 'maritimisation' and globalisation. The adoption of multimodal logistics (containers can be loaded onto any mode of transport) has transformed ocean and coastline geography. On a global level, new 'factory countries' have emerged. China is the most notorious of these countries, steadily weaving its global trade web. Both new communication networks and new maritime lines have emerged, connecting major epicentres in which transhipment ports (hubs) are concentrated: the Malacca Strait (Singapore, Port Kelang, Tanjung Pelepas), the Persian Gulf (Jebel Ali, Khor Fakkan, Salalah), the Mediterranean Sea (Malta, Gioia Tauro, Piraeus), the Strait of Gibraltar (Algeciras, Tangier Med) and the Caribbean (Kingston, Port of Spain). The major interoceanic canals have been recalibrated (Suez, Panama, and, in the near future, the Bosphorus), and new inland corridors are appearing and opening up inland territories (Ethiopia, Kazakhstan, Western China). The containerisation—'maritimisation'—globalisation dynamic has infiltrated large parts of the continents, and both Latin America and Africa, which are lagging behind, are gradually opening up. In this context of increasing containerisation, it has become necessary to adjust port and terminal management methods. This has involved the multiplication of concessions and the emergence of very large port governance operators alongside strengthened maritime shipping companies: approximately ten shipping companies and ten terminal operators now dominate the shipping world. They are all either European or Asian. **These evolutions call into question the initial hierarchy of ports and coastlines, as cards are being reshuffled by both downgraded and emerging ports. Maritime transport and handling techniques have been improved both to increase productivity and to minimize risks of damage to the environment.** The shift from heavy fuel oil to gas as a propellant energy is underway. The opening up of the Arctic Ocean to commercial traffic is pending significant deglaciation, and most major ship-owners are already prepared for this (e.g. Chinese hub in Iceland).

Contact (GRED): J.-M. Miossec, jean-marie.miossec@univ-montp3.fr

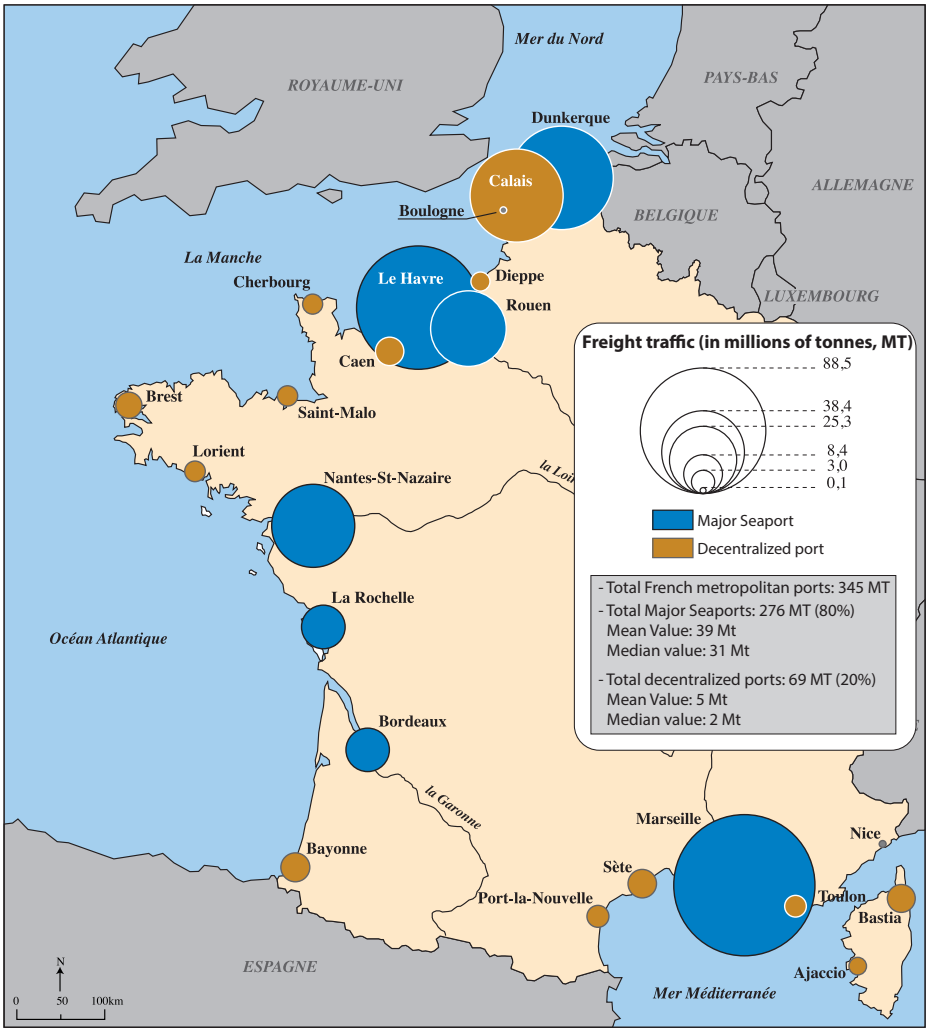


▲ *Malta CMA CGM Trans-shipment Terminal (Hub): Articulating Global Lines and Regional Feeder Lines.*



Port management and conflict

On the coasts, commercial ports are becoming contentious areas, as they are subject to contradictory objectives and to various threats, including: the need for maritime transport equipment (the €10 billion goods shipped in 2016 represented 80% in volume and 70% in value of total world trade), threats to ecosystems (coast artificialisation, biodiversity degradation etc.), and threats to social systems (unemployment, technological risks, pollution and nuisances etc.). **Therefore, the major challenge that must be addressed by port management is the reconciliation of the industrial-port development accompanying economic globalisation and the increased requirements in terms of ecosystem conservation and population quality of life.** In a sector dominated by technical engineering, this reconciliation requires human and social science research. Thus, the objective of port research is to identify the respective concerns of the different stakeholders in and around the ports, and to analyse the balance of power at stake. Research focuses upon scientific inquiry into (1) The forms of political power and the place of citizens in port territories, (2) The level and modalities of port disputes, and (3) The gaps between port management and port territories' past experiences and perceptions of these.



▲ *Map of French ports and their freight (2011).*
© Valérie Lavaud-Letilleul/ART-Dev (design)-Stéphane Coursière/ART-Dev (production)

Port research draws upon various methodologies, including long-term territorial diagnosis, port project and policy appraisal, interview-based surveys of institutional stakeholders, users and inhabitants etc. In this field, the ART-Dev research unit has acquired expertise of the Occitanie Region ports, in particular Sète-Frontignan and Port-la-Nouvelle, and, more broadly, on the French Mediterranean coast (Marseille-Fos, Toulon, Nice etc.), adopting a comparative perspective (see map). The unit develops partnerships with national and international scientific teams (Europe, North and South America), as well as with public stakeholders (port authorities, local authorities etc.) and civil society representatives (non-profit organisations, inhabitants etc.). Its work is articulated into the main networks involved in maritime-port research (International Association of Cities and Ports, OHM-LR, *Fondation de France* etc.).

Contacts (ART-Dev): V. Lavaud-Letilleul, lavaud.letilleul@club-internet.fr and I. Berry-Chikhaoui, berry-chikhaoui.isabelle@neuf.fr

Port territories and socio-ecological transition: a circular economy analysis

Port territories are places of transit and massive transformation of materials and energy. Their evolution is driven by local specificities as well as by global dynamics. **Studying port territories can provide valuable information relating to the progress of socio-ecological transition (SET) at local and global levels.** This transition can be influenced by the implementation, on a territorial scale, of circular economy approaches (Industrial and Territorial Ecology, ITE). IMT Mines d'Alès (LGEI) has been studying these issues for over 10 years, through several collaborative research projects. An international comparative analysis of ITE practices has demonstrated the existence of different ITE implementation typologies, which vary with the representation that different stakeholders have of the spatial and temporal dimensions of their territory (DEPART and REX projects*). A more in-depth analysis of port territories' SET in Europe and Asia has highlighted initiatives aimed at recreating links between the urban, industrial and agricultural dimensions of territories, the breakthrough of renewable energies, and the increased recovery of different types of waste. Knowing how to promote such initiatives has become a primary concern for port territories, both in order to reduce environmental pressures and to increase economic attractiveness. In addition, circular economy requires the implementation of novel forms of territorial dynamics favourable to the co-construction of projects for the territory and by the territory, as illustrated by the EIT-MAMP project**. Finally, joint research efforts, bringing together life cycle analysis specialists (in particular through the regional research group ELSA***), economists and management science experts, aim to develop methods to evaluate the social, economic and environmental externalities generated by these new practices (e.g. MODEVACT project****).

Contact (LGEI):
G. Junqua, guillaume.junqua@mines-ales.fr

For further information:
http://lgei.mines-ales.fr/pages/recherche-1

* Projects financed by ADEME (French Environment & Energy Management Agency):
- DEPART: From Waste Management to a Circular Economy- A Study of the Emergence of New Partnership Dynamics.
- REX: Feedback 'Ports in the Age of Industrial Ecology'
** EIT-MAMP project: Aix-Marseille–Provence Metropolis. Support to Territorial Development Planning; Preparing the Operationalization of a Circular Economy.
*** European project Ecotech Sudoe, industrial Chair ANR (French National Research Agency) ELSA-PACT (Environmental Life cycle and Sustainability Assessment - A PAthway to Competitiveness Through Social & Ecological Transition).
**** MODEVACT project: New Economic Models and Territorial Value Creation – The Roles of Circular Economy, Functional Economy and Industrial Ecology.

Dredged material valorisation, a challenge for coastal areas

In the era of circular economy, waste reuse is a major challenge, and waste management has taken on a strong societal and technical dimension. To date, no structured port dredging sediment valorisation sector exists. However, public policy encourages territory, autonomous port, regional port, and municipal marina managers to work towards virtuous management of their dredged material. Since 2009, IMT Lille Douai and IMT Mines Alès have been developing innovative solutions for dredging and extracted sediment management:

- In 2010, IMT Mines Alès participated in the ECODREDGE-MED project* piloted by the *Régie autonome de Port Camargue* (entity in charge of the management of the Port Camargue marina), in which an on-board process for separating sands and fines was developed. The water and fines are put back in place in the port, and appropriately monitored.
- Since 2009, IMT Lille Douai and the autonomous port of Dunkerque have been developing a process for onshore treatment of non-submergible mud, in particular through the creation of a platform dedicated to the treatment and recovery of these sediments.

To date, port territory contracting authorities and/or investors confronted with a sediment-related problem seek solutions adapted to their specific situation, which can be implemented throughout their territory. For example, the **Occitanie Region has developed a master dredging plan to conduct a comprehensive evaluation of its dredging materials. In terms of recovery, the 'Sédimatériaux approach' makes it possible to set up innovative valorisation processes. As a result, there are significant R&D needs in order to valorise dredged sediments into aggregates or hydraulic binders that may be used for example in construction materials.**

Contacts: J.C. Souche (C2MA), jean-claude.souche@mines-ales.fr, N. Abriak (LGCgE**), nor-edine.abriak@imt-lille-douai.fr, C. Gonzalez (LGEI), catherine.gonzalez@mines-ales.fr and N. Azema (C2MA), nathalie.azema@mines-ales.fr

* ECODREDGE-MED project: Ecotechnology for global and on-board management of port sediment dredging.
** Civil engineering and geo-environment Laboratory (IMT Lille Douai).

▼ *Roadway made of recycled sand-gravel mixture and treated sediments (Razel-Bec Company).*
© J.C. Souche

▼ *Test board made of recycled sand-gravel mixture and treated sediments (LRM quarry).*
© J.C. Souche

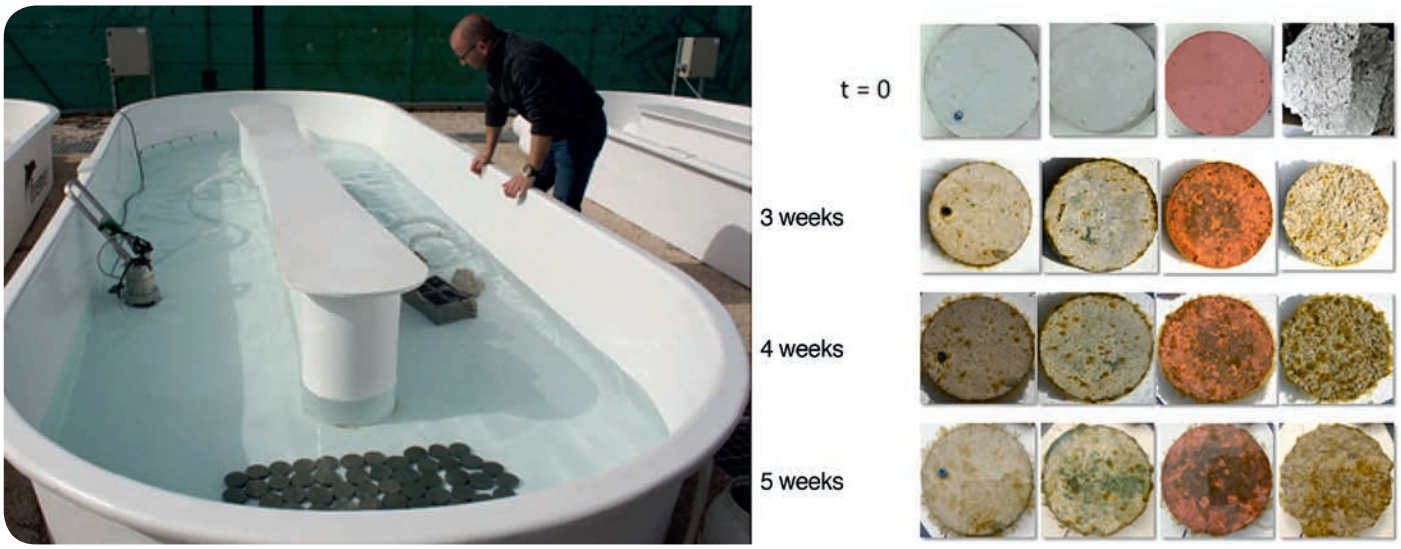
The Mediterranean is one of the main maritime shipping routes for international trade, equipped with a great number of ports and recreational facilities.

Eco-materials and their durability: application to constructions and ships

The transport and construction sectors must control and reduce their impacts on the environment. In order for this to happen, they must limit greenhouse gas emissions, save non-renewable natural resources, and consider demolition and reuse of waste produced, while improving the performance of materials and ensuring the health and well-being of people. **Also, in order to foster a global circular economy, new 'eco-materials' will, ultimately, replace the materials currently in use.** C2MA–IMT Mines d'Alès research centre focuses upon the study of eco-materials made from traditional materials: concrete and polymer eco-composites. In particular, the durability of these materials is studied with a view to increasing their lifespan and minimizing both their maintenance costs and the quantity of waste produced.

C2MA also studies ways in which to optimize binder choice, with the use of lower-dose ecological concrete. Moreover, the performance-based approach enables binder dosages to be optimized according to the environment to which concrete is exposed, and innovative experimentation with more efficient product formulations that reduce cross-sections and therefore increase these materials' durability. C2MA also focuses on eco-composites for the nautical sector. In order to **meet the performance, durability, large-scale process and cost requirements of nautical companies, the development of recyclable laminate from infusible thermoplastic resins and of reinforcement structures from the recycling of long-fibre composites appears to be appropriate.** The use of bio-composites improves the control of mechanical and thermal properties, and provides degrees of inherent adaptability to the associated demolition process.

Contacts (C2MA): M. Salgues, marie.salgues@mines-ales.fr, D. Perrin, didier.perrin@mines-ales.fr and P. Ienny, patrick.ienny@mines-ales.fr



▲ *Test tubes in a controlled environment test at IFREMER - Palavas-les-Flots (left) and an example of results (right).*

Ballast water: management of invasive species

Aquatic invasive species pose a major threat to ecosystems and generate significant economic impacts. The principal vector of invasion is navigation, via ballast water. Ships take onboard large volumes of water to ensure their stability on the high seas, and then off-load once they have reached their destination, so that they can sail in shallower waters. With the increase in volume of shipping trade and traffic, the number of species introduced has increased considerably over the last twenty years. In order to reverse this trend, **an international treaty, ratified by 52 countries representing just over 35% of the world's tonnage entered into force in September 2017. Through their ratification of this convention, countries commit to ensuring that, gradually, all ships adopt ballast water treatment standards, in order to prevent further introductions of invasive species.** The CEE-M focuses its research activities on mechanisms conducive to increased international cooperation in the management of biological invasion. It took 14 years of negotiations, following the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM)'s signature in 2004 to reach the quorum of ratifying countries and make the convention enforceable. Furthermore, there remain many non-signatory countries and, by the very nature of invasive species, the defection of a subset of countries poses a significant threat to the efficiency of any collective action. The challenge of our research is to improve current understanding of the mechanisms conducive to broad cooperation. To this end, we analyse how coalition processes impact the ratified agreement's structure in order to better understand the impact of the agreement's specific characteristics upon levels of cooperation. In particular, **our research analyses the efficiency of the adopted ratification clause and its impact upon the level of cooperation, and looks at which incentive and/or sanction systems can be implemented to widen the agreement to new signatory countries.**

Contact (CEE-M): P. Courtois, pierre.courtois@inra.fr

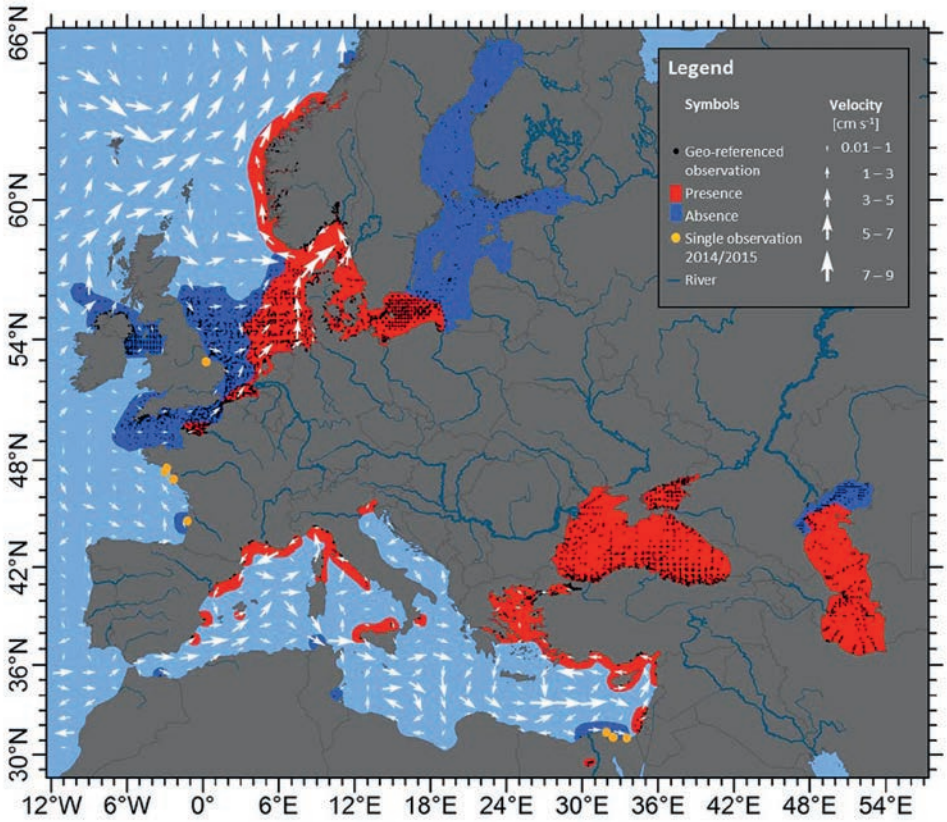
Invisible passengers

The Mediterranean accounts for 30% of global maritime traffic, including 25% of global oil traffic. Nearly 10 billion tons of ballast water are displaced each year due to international shipping, which is the same volume that is displaced by domestic shipping. Of this volume, 22 million tons are displaced solely along the coasts of Metropolitan France. An estimated **7 to 10,000 different species are transported each day in ballast water**. **As a result, numerous harmful and pathogenic aquatic species have been introduced into and have managed to spread through new environments, with significant environmental, social and economic consequences**.

A MARBEC team is studying the capacity of *Mnemiopsis leidyi*, a ctenophore native to the eastern coast of the American continent but introduced via ballast water, to develop in Mediterranean ecosystems. *M. leidyi* has been found in the Bages-Sigean Lagoon (Aude Department) and the Or Lagoon (Hérault Department), but not in the Thau Lagoon (Hérault) where a long-term surveillance program has been initiated (supported by OSU OREME). The organism is hermaphrodite and capable of self-fertilisation. It is able to reproduce when it is very young (13 days after hatching), and each individual can lay a thousand eggs. It is therefore proliferating in most of the places where it has been introduced. A recent study, conducted in collaboration with a group of European researchers, has synthesized this species' invasion dynamics into the Mediterranean Basin (see opposite). Introduced in 1982 in the Black Sea, it was found in the Aegean Sea, the Sea of Marmara and on all Turkish coasts in the early 1990s, in the Caspian Sea in the late 1990s, and in the Berre Lagoon, in Corsica and in the Adriatic Sea since 2005. In 2009, it was spotted in the Balearic Islands and on all the Israeli coasts, and then found in Egypt in 2015. The entry into force of the BWM Convention (see previous text) should enable its propagation to be limited in the geographic areas that are not yet affected.

Contact (MARBEC):
D. Bonnet, delphine.bonnet@umontpellier.fr

▲ Mnemiopsis leidyi *ctenophore.* © *Patrice Got/MARBEC*

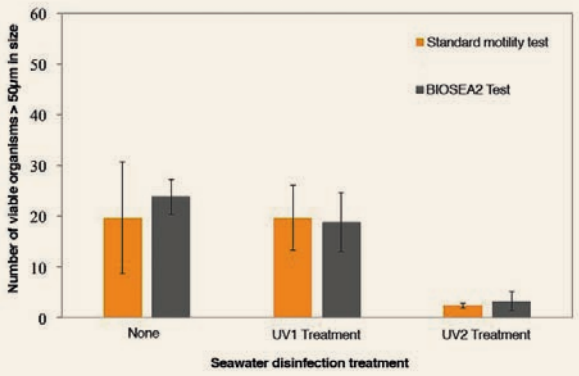


▲ *Ctenophore distribution in the Mediterranean Basin (from 1990 to November 2016).*
From Jaspers C. et al., *2018.* Global Ecology and Biogeography. *1-14.*

BALLAST WATER SURVEILLANCE WITH REAL-TIME DIAGNOSTIC TOOLS

The LBBM – OOB, which specializes in microbial ecology and the development of environmental diagnostic tools, has partnered with BIO-UV Group, a company specialized in water disinfection treatment, in order to create new instruments enabling fast screening of zooplankton and phytoplankton in ballast water. Funded by the European Union (European Regional Development Fund, ERDF) and the Occitanie Region, the BIOSEA2 project has notably enabled the development of two simple, robust and energy-efficient prototypes to be used onboard ships. These prototypes enable the enumeration of total plankton in a few minutes, the detection of viable organisms down to the limits defined by the BWM Convention, and the verification of disinfection efficiency. These tools have been tested and validated on several biological models and on different natural marine communities, and their results have been compared with benchmark analyses. The next step in providing innovative diagnostic tools for the biological surveillance of ballast water onboard ships will be prototype automation.

Contacts (LBBM): J. Baudart, baudart@obs-banyuls.fr and P. Lebaron, lebaron@obs-banyuls.fr



▲ *Effects of different disinfection treatments on viable zooplankton abundance, measured with the motility test (standard test) and the test developed by the BIOSEA2 project.* *© J. Baudart.*

▶ *BIO-UV Group ballast water disinfection system combining mechanical filtration and UV-C treatment.* *Source: www.ballast-water-treatment.com*

Marine construction eco-design: reconciling infrastructure and ecosystems

The mushrooming of human infrastructure is increasing the artificialisation of coastal environments and intensifying anthropogenic pressure on the natural environment. The Paul-Valéry-Montpellier University (UPVM, CEFE) has a long-standing interest in coastal development issues approached from an environmental and societal perspective. IMT Mines Alès, on the other hand, is developing research and teaching programs of excellence in the construction material and maritime construction fields. These two laboratories have been working together since 2008 on maritime developments eco-designed to at once meet structural mechanical stability and material durability requirements and achieve ambitious environmental goals in order to minimize impacts and maximize ecological gains.

To move towards sustainable infrastructure development, technical responses are elaborated using a systemic approach. From the very first steps of the design process, the design integrates engineering sciences and techniques as territorial planning / economic activity organisation tools enabling the minimisation of anthropogenic pressures on the environment. **The working methodology selected focuses upon either the restoration of degraded ecosystems or the creation of new sustainable ecosystems of value to humans and the biosphere.** In order to develop the most relevant technical and economic solutions, it is necessary to combine both theory and empirical knowledge in the fields of ecology, hydraulics, civil engineering and implementation techniques. In parallel, all the disciplines dedicated to understanding the human-natural environment relationship are called upon. By using a multidisciplinary approach, it is possible to draw the best out of each discipline in order to find the technical, economic, societal and environmental compromise most suited to the planned development's specifications.

Contacts: J.C. Souche (C2MA), jean-claude.souche@mines-ales.fr and S. Pioch (CEFE), sylvain.pioch@univ-montp3.fr

For further information: Maritime eco-design examples: www.icriforum.org/sites/default/files/OVERVIEW%20of%20eco-mooring-light_0.pdf

▼ *Example of eco-mooring.* *© S. Pioch*

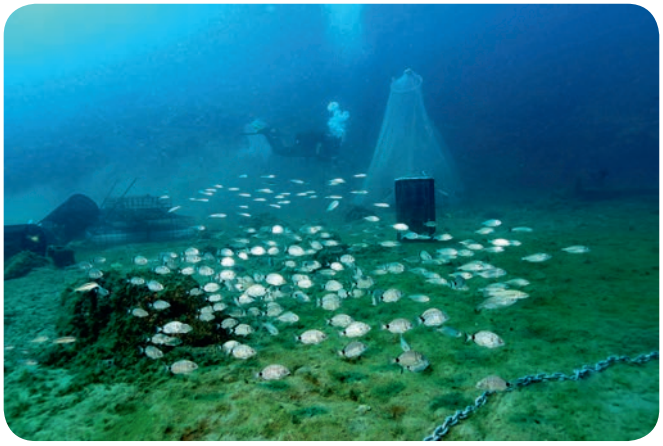
Coastal ecological engineering and coastal infrastructure eco-design

Shallow coastal areas are facing significant territorial planning challenges (20% of the Occitanie Region coast is urbanized), for which French legislation decrees the application of the 'Avoid-Reduce-Compensate' approach. Ecological engineering only comes into play to reduce, or to compensate, an impact, but never before avoidance has been addressed, and only if water quality has returned to normal. Some port contracting authorities/investors voluntarily decide to integrate an eco-design dimension into their projects, be these major structural projects, or environmental initiatives, such as the marina 'Clean Port' *(Port propre)* programmes. In addition, coastal ecological engineering and/or coastal infrastructure eco-design tools have been developing since the early 2010s.

ECOCEAN and UPVD (CREM/CEFREM) have played a pioneering role in the implementation and scientific validation of ecological engineering solutions dedicated to nurseries in shallow coastal waters. The NAPPEX (see next page) and GIREL 3R* R&D projects have scientifically established the utility of equipping maritime port infrastructures with habitats dedicated to juvenile fish (Biohut® Solution: 'fish sanctuaries', see box opposite). The European SUBLIMO* programme has demonstrated the effectiveness of a comprehensive process of capture and culture of coastal marine animals in their post-larval phase in restocking operations (BioRestore® Solution). The BioRestore® and Biohut® solutions are now validated both scientifically and technically, and marketed to twenty-three marinas and two commercial ports. **The transition from fundamental technological research to industrialisation requires significant financial investment by private companies, and in this process, particular attention must be paid to the scientific validation of the ecological value of tools, products and services, in order to avoid greenwashing.** Therefore, tools must be technically and scientifically validated, using standardized and comparable monitoring protocols. Indeed, **the credibility of the regional coastal ecological engineering sector, which is now becoming a European benchmark in the field, is at stake.**

Contacts: S. Fonbonne (ECOCEAN), sebastien.fonbonne@ecocean.fr, G. Lecaillon (ECOCEAN), gilles.lecaillon@ecocean.fr and P. Lenfant (CEFREM), lenfant@univ-perp.fr

* GIREL: Infrastructure management for coastal ecological remediation.
SUBLIMO: Monitoring of fish post-larvae biodiversity in the Western Mediterranean (Life+ funding).



▲ *Fish release during a Biorestore project.*
© Rémy Dubas/ECOCEAN

▲ *Sharpsnout seabream* (Diplodus puntazzo) *juvenile on a 'Biohut'.*
© Rémy Dubas/ECOCEAN

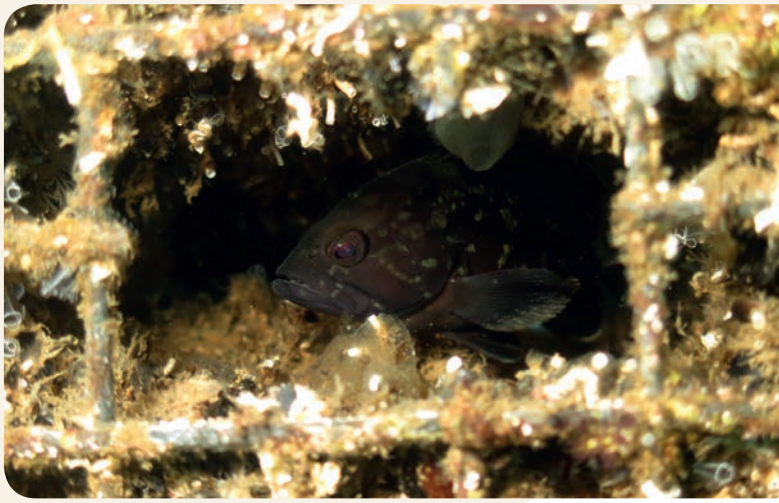
'Biohut dock and Kelp', Port-Vendres, France.
© Rémy Dubas/ECOCEAN

NAPPEX: ARTIFICIAL NURSERIES FOR EXEMPLARY PORTS

The post-larval stage is the ultimate pelagic larval stage of the life cycle, which for most coastal marine animal species, ends with a coastal habitat colonisation phase. During this natural process, some species end up in the sheltered areas of ports, whose design is unsuited to their survival (linear docks, unprotected from predators) making them bona fide traps and causing excess mortality amongst these young recruits. The objective of the NAPPEX project (2013-2014) was to develop a marine ecological restoration technique enabling ecological functions to be restored to port infrastructures. Six ports have been equipped and monitored over 2 years in the French Mediterranean. One port has been equipped and monitored on Morocco's Mediterranean coast. The process implemented, called 'Biohut®', aimed to restore nursery ecosystem service by protecting post-larvae and juveniles from predation, in order to enable them to reach a so-called 'size-refuge' beyond which the predation-related mortality rate is greatly reduced, thus facilitating their recruitment into the adult population. Installed in the sub-surface, along docks or under floating pontoons, these modules consist of a steel cage filled with oyster shells (colonized by the local flora and fauna, thereby providing suitable food for juveniles), enclosed by an empty cage (providing protection against predators). This process was patented in 2013 and scientifically validated through the NAPPEX project, as well as, more recently, by two theses conducted with the UPVD and one in partnership with Mohamed V University in Rabat. To date, over 2,500 units have been deployed along the French and Moroccan Mediterranean coasts, as well as in the United States, the Netherlands, Korea, Denmark and Philippines. Five articles have been published.

Contacts: S. Fonbonne (ECOCEAN), sebastien.fonbonne@ecocean.fr, G. Lecaillon (ECOCEAN), gilles.lecaillon@ecocean.fr and P. Lenfant (CEFREM), lenfant@univ-perp.fr

For further information: www.nappex.fr/?lang=en

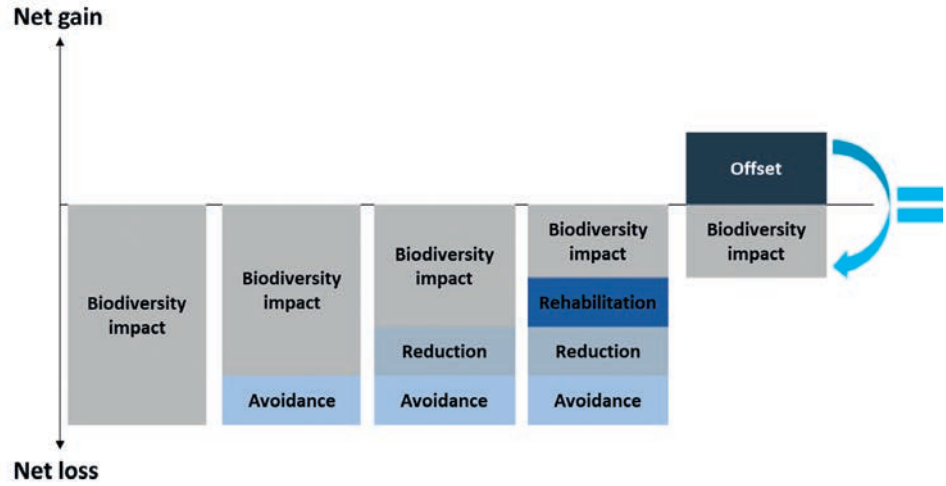


▲ *Dusky juvenile grouper in a 'Biohut®', Port-Vendres, France.*
© Rémy Dubas/ECOCEAN

Maritime infrastructures and 'No Net Loss' of biodiversity: overcoming the absence of negative impact compensation

The application of the mitigation hierarchy in the area of negative biophysical impacts and anthropogenic ecosystem services at sea, is subject to serious dysfunctions. These dysfunctions are demonstrated in environmental impact studies by the quasi-absence of biophysical ('in kind') offsetting for the negative effects of development projects, coupled with a lack of control of the effectiveness of the very rare compensatory measures implemented. In addition, in the **over 350 mitigation measures that we analysed in 55 different impact studies in France (including the French Overseas Departments and Territories), not a single compensatory measure has actually been implemented.** Yet, what emerges from over 1,200 public opinions and questions formulated within the context of three French offshore wind farm projects is that 'consideration of the environment' is people's main concern (~70%). This situation is not specific to France. Indeed, until 2014, none of the offshore wind farms developed in Europe had performed any biophysical offsetting (compensatory measures proposed in the regulatory impact studies).

In a context of increasing offshore development (Blue Growth), there are two courses of action to improve the effectiveness of the mitigation hierarchy application, with a view to 'no net loss' (French Law on the Recovery of Biodiversity, Nature and Landscapes, RBNP, 2016, see graph): i) Strengthening the 'Avoidance' step (mapping ecological and socio-economic issues) at the Sea Basin Strategy Document planning stage *(Documents stratégiques de façade)*, and ii) Improving evaluation of 'Offset' with operational methodological tools that we have developed, the Merci-Cor and/or Miti-Med methods. Indeed, it is in the Mediterranean, in Monaco, that the 'Miti-Med' method for ecological losses and gains evaluation was tested for the first time within the framework of an offshore development project. In conclusion, it would be useful to (re)think 'offshore compensation governance' drawing upon experience-based feedback, notably from the United States, in order to guide the 'no net loss' of biodiversity required by the French 2016 RBNP Law.



▲ *The 'No Net Loss' principle and the mitigation hierarchy.*

Contacts: S. Pioch (CEFE), sylvain.pioch@univ-montp3.fr, C. Jacob (CEFE), celine.jacob05@aptalumni.org and A. Bas (AMURE/CEFE), adeline.bas@gmail.com

Biotechnologies, marine bio-engineering and ecological restoration of environments

Microbial symbiosis in the marine environment: a new source of medicine?

A significant proportion of the pharmaceutical drugs in clinical use today is of natural origin. Pharmaceutical drugs directly derived from or inspired by natural products account for over half of the new chemical entities approved since 1940. This is particularly true for anti-infectious and anti-cancer agents. Indeed, 79% of the antibacterial agents and 87% of the anti-cancer agents approved between 1981 and 2014 are natural products or mimics of active natural products. While many of these compounds are of microbial origin, some microbial communities have received little attention as potential sources of medicinal products. Such communities include, in particular, symbionts of macroscopic organisms, plants, insects, mammals and marine invertebrates. It seems that **in these limited microbial communities, where competition is very high, the role of active substances is to interfere with the development of other competing microorganisms**. Thus, these symbionts can also benefit the host, by suppressing its competitors, grazers or predators, and thereby contributing to improving its adaptive value ('fitness'). The ANR-MALICA project*, in which public research laboratories (LBBM in Occitanie and the Institute of Chemistry in Rennes) partnered with the Pierre Fabre pharmaceutical laboratory, aimed to **use the diversity of natural products derived from bacteria isolated from marine and coastal lichens. New chemical entities have been sought in order to develop innovative pharmaceutical drugs that will combine these compounds with tumour-targeting antibodies, thereby developing more effective and targeted cancer therapies**. The ANR-SECIL project* (a Franco-Swiss partnership) studies microbial interactions in plant leaf endophytes, seeking unique and innovative antibacterial agents, in particular inside two model systems known for the longevity of their leaves or stems: *Astrocaryum sciophilum*, a palm tree endemic to French Guyana's primary forest, and *Posidonia oceanica*, a dominant plant in Mediterranean seagrass meadows.

Contacts (LBBM): D. Stien, didier.stien@cnrs.fr and M. Suzuki, suzuki@obs-banyuls.fr

*** For further information:**
ANR MALICA Project (Marine lichens as an innovative source of anti-cancer drugs): www.obs-banyuls.fr/malica
ANR SECIL (Study of leaf endophytic fungi: exploration and valorization of biosourced innovative antibacterial metabolites): http://secil.obs-banyuls.fr

◀ *Colony of the* **Verrucosispora gifhornensis** *bacterium isolated from the marine lichen* **Lichina pygmaea.**
© Sanjay Antony-Babu

Immunobiology to combat farmed oyster mortality

The innate immune system, which is the first line of defence against pathogens, draws upon ancestral mechanisms that have long been considered non-specific, devoid of memory, and less elaborate than the adaptive response. However, over the past decade, **many discoveries have shown that a wide range of invertebrates can develop an innate immunological memory (known as 'immune priming') that increases their chances of survival upon second exposure to a pathogen.** Research work coordinated by IHPE* undertook the characterisation of this immune priming phenomenon in the *Crassostrea gigas* oyster. This species is currently facing massive recurrent mortality outbreaks, with no existing therapeutic treatment. This syndrome, of complex etiology, involves a number of different types of pathogens, including an emerging pathogen, the OsHV-1 µVar herpes virus. Our results demonstrated that **prior treatment (priming) with a synthetic analogue of double-stranded RNA, called Poly (I:C) led to an effective oyster protection (up to 100%) against subsequent exposure to the virus in the laboratory, be these or in the natural environment, during mortality outbreaks. This protection persisted for up to five months, suggesting the existence of innate immunological memory mechanisms**. The study of this phenomenon's molecular basis revealed that the priming was based upon the activation of an important antiviral immune response limiting the virus' replication and therefore enabling the protection of oysters. This study further supports the emerging concepts of innate immune memory and enables the identification of new avenues of application to limit mortality outbreaks in farmed oysters. This work highlights the essential contribution of application-oriented research in finding solutions to today's major challenges in the areas of marine invertebrate health and rational optimisation of aquaculture farms.

Contact (IHPE):
C. Montagnani, cmontagn@ifremer.fr

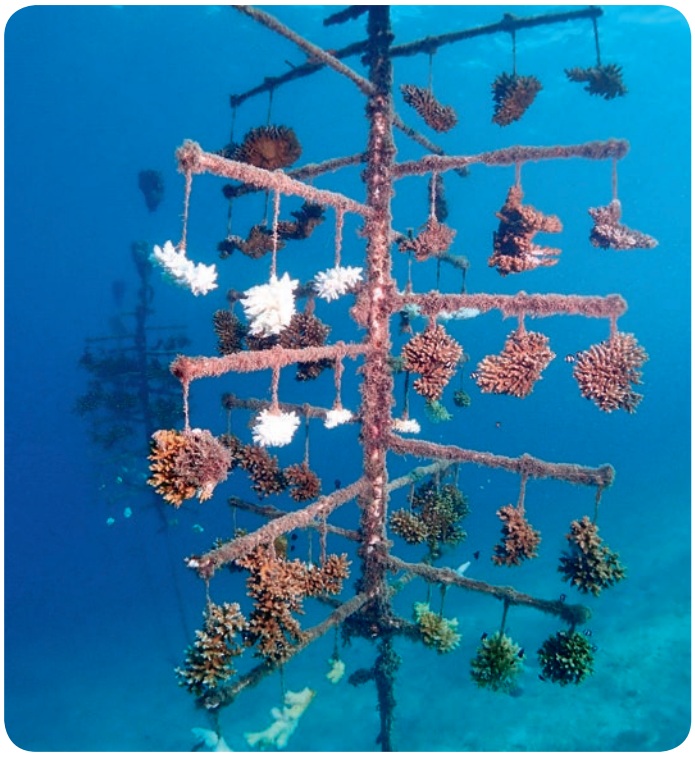
* Antiviral Protection of the Pacific/cupped oyster *Crassostrea gigas* Project (PROVIGAS, Researcher for the future funding Occitanie/ Pyrénées-Méditerranée Region). The project consortium includes the UMR IHPE, the *Comité Régional de Conchyliculture de Méditerranée* (CRCM, Mèze) and the *Centre d'études et de promotion des activités lagunaires et maritimes* (Cepralmar).

C. gigas oyster spat and hemolymph samples.
© C. Montagnani/IFREMER

A coral nursery to cope with climate change

Climate change induced evolutions are going to cause an increase in water temperature whose impacts upon species and environments need to be understood. CRIOBE is investigating the possibility of generating corals capable of coping with these challenges by studying possible reef restoration modalities, in the knowledge that reseeding larvae or transplanting coral fragments into damaged zones will only be effective if transplanted corals are able to survive future environmental conditions. Two different hypotheses were tested within the framework of the AQUA-CORAL project*. **Does the selection of 'winning' coral broodstock (corals that do not bleach) enable the generation, via sexual reproduction, of crossbreeds that are more resilient to increases in temperature?** Research shows that some of the crossbreeding between male and female gametes does increase the generated pelagic larvae's resistance to increases in temperature. However, the breeding colonies' 'winning' or 'loosing' (bleaching corals) nature does not explain observed results. Therefore, we are now seeking to understand why some crossbreeding attempts are more effective than others. The second hypothesis is that developmental plasticity may play a role in the ability of juvenile corals to adapt to higher temperatures.

The results show that **brief exposure of embryos to high temperatures increases their subsequent resistance**. Although encouraging, these results need to be tested over longer periods in order to establish whether organisms maintain this resistance during the course of their development. Coral selection and adaptation in response to the environmental disturbances of the 21st century are two encouraging avenues that should be further explored in the future in order to help corals cope with global environmental changes.



▲ *Example of a coral nursery. Some coral cuttings show signs of bleaching, while others do not.* © *Laetitia Hédouin*

Contact (CRIOBE):
L. Hédouin, laetitia.hedouin@criobe.pf

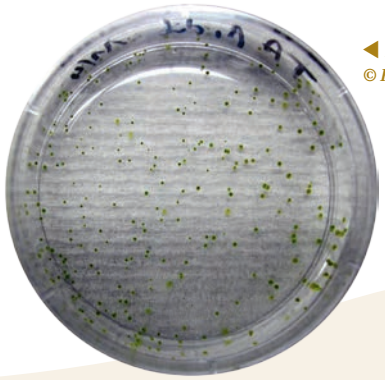
*** For further information on the AQUA-CORAL project (funded by the French Ministry of Overseas):** www.criobe.pf/recherche/aqua-coral/

Production of high added-value compounds in microalgae

Marine phytoplankton microalgae are a source of bioactive molecules of biotechnological interest, in particular in the nutraceutic, comestic and pharmaceutical fields. **Among the compounds of interest in microalgae, carotenoids are powerful antioxidants with anti-inflammatory, antiproliferative, as well as cardioprotective qualities.** LOMIC, works on eukaryotic picoalgae belonging to three *Mamiellophyceae* genera: *Ostreococcus, Bathycoccus* and *Micromonas*. A number of tools for genetic selection and culture under controlled conditions, initially developed with *Ostreococcus tauri,* were later extended to other *Mamiellophycae* species. As part of the European EMBRIC (European Marine Biological Research Infrastructure Cluster) project, LOMIC is contributing to: (1) The identification of new metabolites with antiproliferative or antioxidant activities, (2) The optimisation of carotenoid production through ecophysiological approaches on strains originating from different ecological niches with contrasting light, temperature and/or salinity conditions, and (3) The optimisation of alpha and/or beta pathway carotenoid production through genetic engineering of lycopene cyclase. Results obtained are destined for deployment in partnership with the industrial sector.

Contact (LOMIC): F.-Y. Bouget,
francois-yves.bouget@obs-banyuls.fr

For further information:
www.mdpi.com/1660-3397/16/3/76/pdf

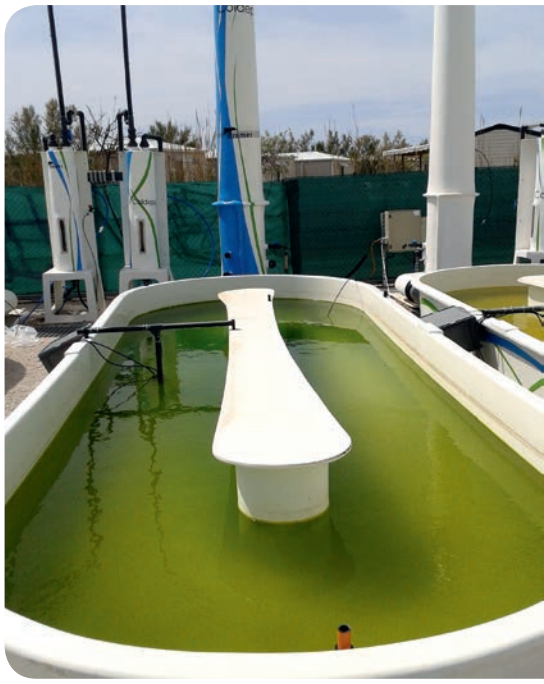


◀ *Petri Dish colonies of* Ostreococcus tauri *microalgae.*
© *François-Yves Bouget/SU-CNRS/LOMIC/Banyuls-sur-Mer*

The marine engineering of the future will be bio-inspired.

Towards algaculture sustainability: microalgae production using polluted waters and industrial fumes

The use of microalgal biomass is presented as one of the innovative solutions for improving the resilience of Mediterranean cities and territories to food, environmental and energy crises (according to a report from IPEMED, the Economic Foresight Institute for the Mediterranean World). Indeed, **the versatility of its applications offers the prospect, within a decade, of the growth of a new bioindustry throughout the Mediterranean and the creation of new food supply sectors. The conversion of the algal bio-resource into chemicals (algal green chemistry), materials and energy is one of the major challenges of this last decade as Blue Growth.** The development and implementation of microalgal culture processes capable of ensuring stable and economically viable production remains an important obstacle to the algal industrial development. In this context, the collaborative projects VASCO2 (ADEME)* and PHYCOVER (ANR)* assess the feasibility of open pond algal production using a diverse algae community using untreated urban wastewater and/or industrial fumes as alternative sources of nitrogen, phosphorus and CO_2. In these projects, MARBEC laboratory is characterizing the bioremediation efficiency and resilience of assemblages of microalgae and associated bacteria to climatic fluctuations and variability of chemical (nature of nutrients, contaminants) and biological (predation, competition/facilitation) factors. Studies focus on the role and importance of interactions between microorganisms, by demonstrating the ability of specific associations, particularly between microalgae and bacteria, in increasing resilience and productivity. Optimized microbial assemblages, artificially created or induced by culture conditions, are proposed and tested first at laboratory scale and then at pilot scale.



▲ *High rate algal pond for experiments on industrial fume remediation (IFREMER platform, Palavas, France).* © *Éric Fouilland*

Contact (MARBEC): É. Fouilland, eric.fouilland@cnrs.fr

*** For further information:**

- VASCO2 Project (Biological valorization of industrial fumes for green chemistry): www.marseille-port.fr/fr/Page/19618
- PHYCOVER project (Sustainable microalgal production through recycling of wastewater phosphorus and nitrogen: towards the next generation of sewage treatment plant): www6.inra.fr/phycover

Restoring Mediterranean lagoons by reducing urban nutrient inputs

Located at the interface between land and sea, lagoons are emblematic ecosystems in Occitanie, covering 40,000 hectares of the region's coastline. Thanks to their high productivity and biological diversity, they support many ecosystem services (shellfish farming, fishing, tourism, Spa tourism, habitats for nursery etc.). Since the 1960s, significant and increasing human pressure on the coast has led to the degradation of Mediterranean lagoons. In particular, eutrophication (see next page) has severely degraded these ecosystems and disturbed traditional activities, producing '*malaïgues*' (anoxia or 'bad waters' in the Occitan language) responsible for shellfish mortality. In the early 2000s, as a result of regional mobilisation, major observation and management efforts were initiated in the lagoons. In this way, works targeted on wastewater depuration systems were conducted in order to reduce inputs from the watersheds. Lagoons responses to management measures is studied through observation networks that monitor the state of these ecosystems in relation to eutrophication. This monitoring has shown that **remediation efforts have resulted in a decrease by 70% in nutrient inputs to Palavasian lagoons. This has led to a significant decrease in phytoplankton production, as well as to the recovery of macroalgae and seagrass meadows, habitats that shelter many aquatic fauna species. In the Thau Lagoon, home to 90% of the regional oyster production, the efforts undertaken over the past 30 years to address wastewater depuration have resulted in improved ecological quality, thereby reducing the occurrence of '*malaïgues*'.** All the studies conducted on lagoons of the Occitanie Region provide information on these ecosystems' ecological restoration time scales. They also demonstrate the importance of reconciling good environmental status and ecosystem services conservation, in particular through the sustainable use of natural resources.

Contacts (MARBEC):
B. Bec, beatrice.bec@umontpellier.fr
and V. Derolez, valerie.derolez@ifremer.fr

For further information:
www.umr-marbec.fr/fr/poles/observatoires/dce-lag,581
http://rsl.cepralmar.org/telecharger.html

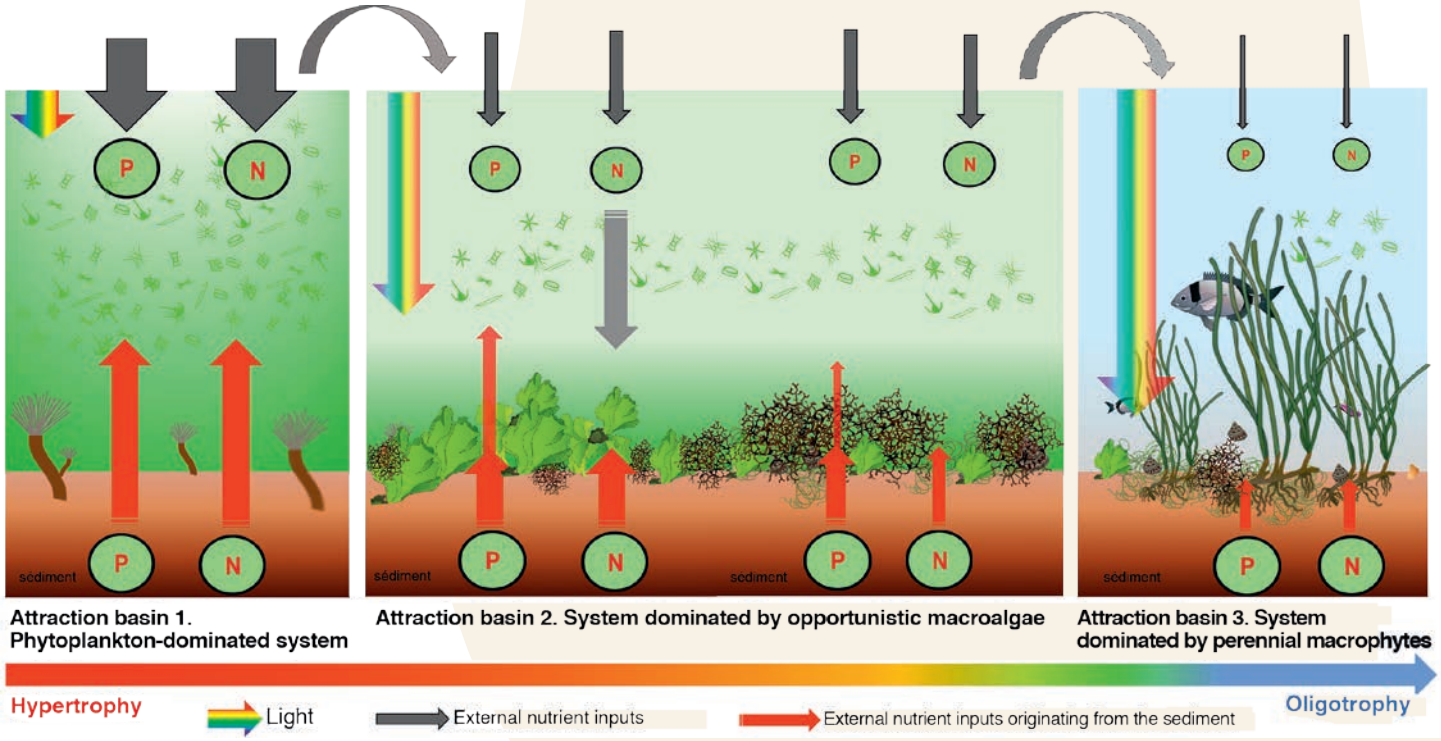
▲ *Evolution of the environmental state of lagoons under restoration.* © *Lagoon Monitoring Network*

COASTAL LAGOON EUTROPHICATION AND RE-OLIGOTROPHICATION

Nutrient inputs (especially of nitrogen and phosphorus) into coastal lagoons have a significant impact on their ecology, and in particular on their plant communities and related trophic systems. Lagoon degradation since the 1960s has mainly been caused by an increase in nutrient inputs leading to a process known as eutrophication. The replacement of plant communities during eutrophication is a well-known phenomenon, and observes the following sequence, i.e. flowering plant meadows (seagrasses) ⟶ opportunistic macroalgae (such as the sea lettuce) ⟶ phytoplankton. Public policy aimed at restoring coastal lagoons by reducing nutrient input (see previous article) therefore raises the issue of the eutrophication phenomenon's reversibility, a process also known as 're-oligotrophication'. Research work conducted by MARBEC aims to improve the characterisation of the ecological processes involved. Thus, during the eutrophication phase, sediments tend to store nitrogen and phosphorus. These nutrients are returned to the environment during the re-oligotrophication phase, thereby generating a time lag for the recovery of good ecological status. However, phytoplankton reacts very quickly when nutrient input is reduced. Thus, a decrease in phytoplankton biomass and changes in its species assemblages have been observed, with the emergence of species using organic matter. Indeed, the plant community replacement sequence appears to be reversible. However, changes are not gradual but subject to non-linear phenomena that have been predicted by the ecological theory of attraction basins and alternative stable states. This theory postulates that ecological feedback loops stabilize the different states of the ecosystems and their associated communities up to specific environmental forcing thresholds; a regime shift to another ecosystem state is only induced when these tipping point are exceeded.

Contact (MARBEC): R. de Wit, rutger.de-wit@umontpellier.fr

For further information: www.umr-marbec.fr/en/research/coastal-systems-of-multiple-uses,069.html?lang=en



▲ ***Succession of plant communities in coastal lagoons during an oligotrophic process.*** *From Le Fur I., 2018.* **Role of macrophytes in the restoration of lagoon environments: ecological successions (Rôle des macrophytes dans la restauration des milieux lagunaires: successions écologiques).** ***Doctoral thesis from the University of Montpellier, France. 214 pp.***

A drastic reduction of the inputs from catchment basins could restore degraded lagoons.

Coastal risk management and adaptation to climate change

Wave attenuation by posidonia meadows, an ecosystem service against coastal erosion

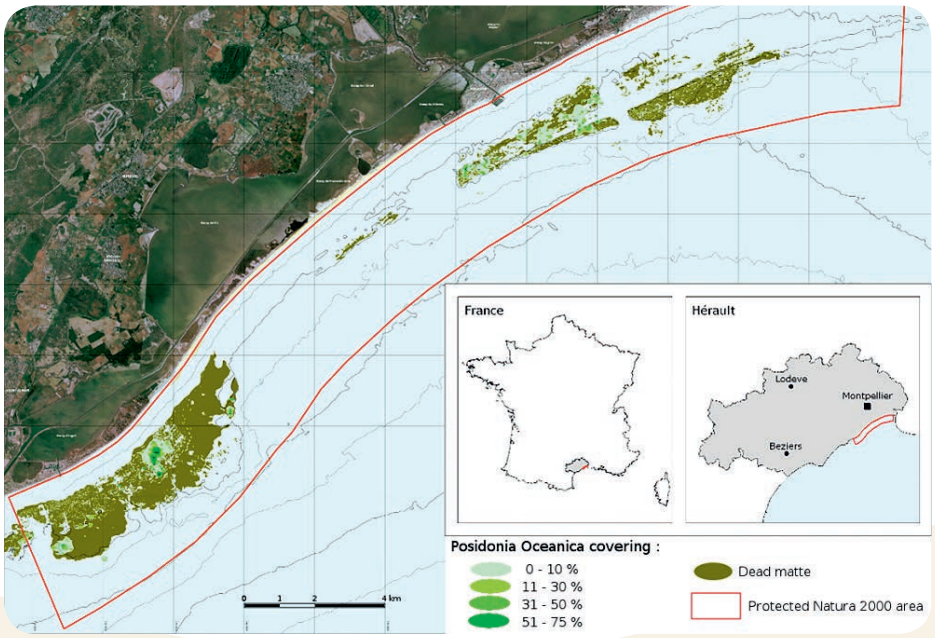
Seagrass beds provide protection against coastal erosion. They act as buffer zones that absorb storm waves. They induce energy dissipation and reduce bottom shear stress. They are also foundational to numerous marine trophic systems, which therefore places them among the most productive ecosystems. Yet, their surface area is decreasing at an alarming rate. Indeed posidonia (*Posidonia oceanica*), a marine species that is endemic to the Mediterranean Sea, has lost between 10 and 30% of its total geographical coverage since the beginning of the 20th century. Between 2000 and 2010, posidonia meadows areas were halved in certain parts of the Gulf of Aigues-Mortes (north-western Mediterranean), in a region that has been suffering from severe coastal erosion due to episodic storms sustained over the past 50 years.

Posidonia meadows' ability to attenuate waves has been studied in the Gulf of Aigues-Mortes using high-resolution numerical modelling made possible by precise mapping*. The numerical *WaveWatch3* wave propagation model was configured with a calculation grid covering the Gulf of Aigues-Mortes and for a real storm event (January 2008). It turns out that the Aresquiers continental shelf is the area in which wave attenuation is strongest, due to the presence of relatively dense seagrass beds. In the area of Carnon/Palavas, however, posidonia play a relatively limited role due to meadow fragmentation and scant density. On the Aresquiers continental shelf, the significant presence of strips of sand causing wave refraction generates significant variability in the height of incoming waves along the coast.

This modelling approach demonstrates posidonia meadows' important role as an ecosystem service for wave attenuation and, ultimately, for coastal erosion control.

Contacts: Y. Leredde (GM), yann.leredde@umontpellier.fr, P. Masaleix (LA), patrick.marsaleix@aero.obs-mip.fr and S. Thorin (Créocéan), montpellier@creocean.fr

* Collaboration between GM, LA and the consultancy firm Créocéan.



◀ *Spatial distribution of posidonia meadows in the Gulf of Aigues-Mortes, France.*
© Andromède Océanologie Mapping

Coastal artificialisation and urbanisation are exacerbating the vulnerability of the Mediterranean.

Relocation policies in response to rising sea level: perceptions and evaluation of avoided damage

Faced with rising sea levels, new relocation approaches for the most exposed assets and activities are being advocated. The aim is to facilitate the preservation of beaches as both storm protection and recreational assets increasing territory attractiveness. The BRGM and CEE-M have assessed potential damages by 2100 for the Occitanie Region if sea level was to rise by one metre, with four contrasted management scenarios (Denial, *Laissez-faire*, Protection by dikes, Relocation of most exposed assets). The assessment covered the housing, business, and agriculture sectors, the salinisation of coastal aquifers, and the ecosystem services related to beaches, wetlands and lagoons. In total, **early adaptation via an asset and activity relocation policy would prevent €31.2 billion worth of damage over the 2010-2100 period, corresponding to €69,000 per inhabitant (considering the study area's 2010 population), or €135 million per km of coastline*.**

Despite the great magnitude of these potentially avoided costs, cost-benefit analysis comparative results favour 'Protection by dikes' over 'Relocation' due to the compensation costs associated with asset relocation and to the fact that medium and long-term benefits are minimized by the discounting process. A research study conducted by CEE-M and EID at the level of a benchmark Mediterranean commune** only produced a positive net present value for relocation upon integrating a combination of economic benefits generated by maintaining tourist attractiveness, environmental gains generated by conserving beaches and seagrass beds, and innovative forms of compensation (purchase of bare-ownership or temporary lease properties). Moreover, perception-based analysis sheds light upon the factors that restrict relocation acceptability. Surveys reveal the determining role of risk perception, with optimism or *status quo* biases for exposed residents, generated by their attachment to the amenities associated to the proximity of the sea. **The complexity of social and psychological determinants is studied with the help of resilience and adaptation capacity indicators including: place attachment, residential mobility, risk perception, trust in management institutions and awareness of the need for anticipation.** Emotions and feelings also play an important role.

Contacts: H. Rey-Valette (CEE-M), helene.rey-valette@umontpellier.fr, C. Hérivaux (BRGM), c.herivaux@brgm.fr, C. Bazart (CEE-M), cecile.bazart@umontpellier.fr and D. Boulet (EID), dboulet@eid-med.org

* MISEEVA project (Marine Inundation hazard exposure modelling and Social, Economic and Environmental Vulnerability Assessment in regard to global changes).
** SOLTER (What territorial solidarities and strategies for coastal resilience to marine submersion?) and Alternalive (Vulnerable coastline – Sea level rise Alternatives) projects.

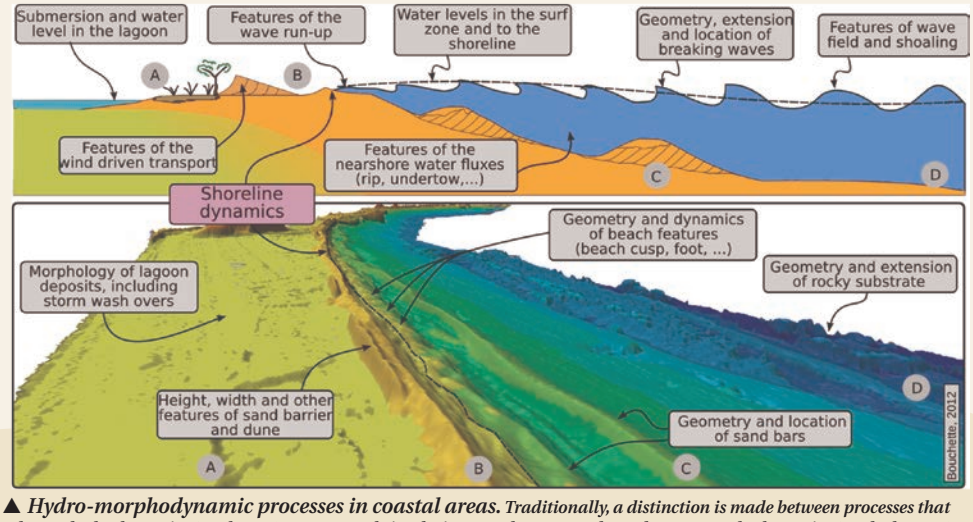
▲ *Palavas-les-Flots, France.* © DREAL

GLADYS: THE NETWORK OF COASTAL HYDRO-MORPHODYNAMICS SCIENCE AND APPLICATION SPECIALISTS

When it was created in 2006, GLADYS was a GEPETO* technical platform in the Languedoc-Roussillon Region dedicated to the management of a pool of equipment specialized in coastal measurement. In just a few years, GLADYS has turned into a collaborative network bringing together almost all the researchers of the French Mediterranean coast specializing in abiotic coastal hydro-morphodynamics and its applications. Hydro-morphodynamics is a term used to describe the complex interactions between the movements of bodies of water, sediment transport, the system's morphological response to the first two families of processes, as well as morphology's feedback mechanisms upon hydrodynamics. From the point of view of physics, geosciences, environmental and/or coastal risk sciences, coastal management and/or costal and port engineering, these complex couplings are at the heart of most of the major questions of current academic research on the coastal environment. GLADYS works on these issues in an interdisciplinary way, using *in situ* measurement approaches (its original activity), wave flume and wave tank experiments, numerical modelling, geophysics and conceptual development work (mathematics and mathematical physics). GLADYS' work supports the development of practical applications related to: Soft Engineering for shoreline protection, quantification of coastal risk, extreme event prediction, water resources in coastal areas, renewable energies exploitation in coastal areas, and the development of innovative solutions for housing, transport and land-use planning in coastal areas. GLADYS' most emblematic research activity is the study of sandy beach shoreline's dynamics at all scales of space and time. A dedicated GLADYS Beach Institute will soon be created in the Grau du Roi.

Contact (GM): F. Bouchette, contact@gladys-littoral.org
For further information: www.gladys-littoral.org

* GEPETO: Large equipment for technological evolution and scientific openness.



▲ ***Hydro-morphodynamic processes in coastal areas.*** *Traditionally, a distinction is made between processes that relate to hydrodynamics (on the top)—waves and circulation—and processes that relate to morphodynamics (on the bottom)—sediment transport and landscape transformation. Based on these two processes, the coastline can be defined as a succession of four main areas: (A) The back-dune area, which is wet, and may include lagoons, (B) The dune belt area, backshore and uprush, (C) The surf zone and (D) The shoreface area, where wave transformation occurs, up to the waves' Depth of Closure, which is the limit for significant sediment mobility during extreme events.*

Understanding the coast and adopting soft engineering approaches to coastal risk management in Occitanie

The Mediterranean coast of the Occitanie Region consists largely of low sandy coasts. Though it is subject to erosion and marine submersion hazards, this part of the coast has remained attractive, and increasingly so, since the 1960s. The coastal development policy implemented by the government of the time has led to demographic and economic growth at the expense of preservation of the existing environment (photo 1): trampling, removal, or even outright levelling. The will to preserve and restore dune belts emerged in the early 1980s, when their importance belatedly began to be understood. Among other things, dune belts act as a natural defence against marine submersion. **In order to address this issue, EID-Méditerranée's coastal hub implements reflection, design and experimentation projects in the field of dune environment protection and remediation**. The hub has developed and used several tools to perform diagnosis and subsequent monitoring of specific sites:

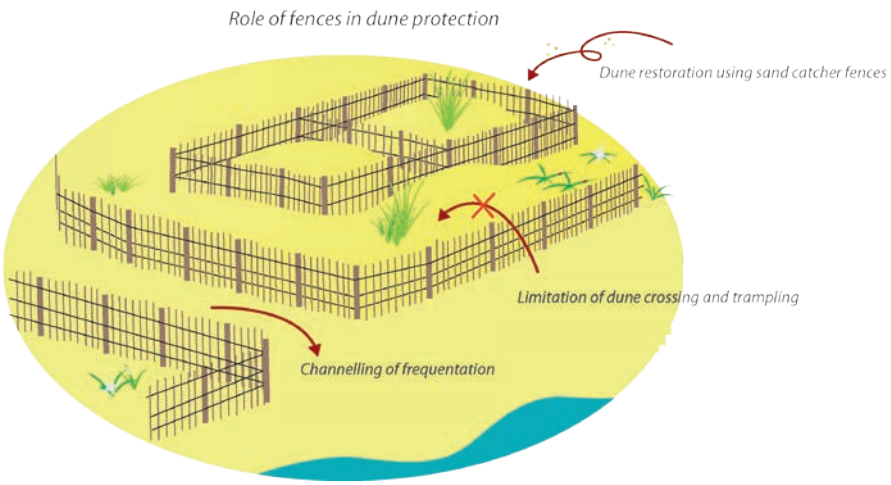
- Databases identifying the dynamic and morphological properties of each sand dune belt and databases identifying protective structures (type, construction date, condition, etc.)
- Topographic and bathymetric measurement tools (GPS cane, sounding device, drone, etc.) (photo 2).

On this basis, EID-Méditerranée's coastal hub makes management recommendations and/or designs ecological engineering–based works for local authorities. Constructions respect the natural dynamic of each site. They may be wood-slatted fences which, depending on how and where they are installed, may play a trapping role or defensive role against trampling (diagram 3). Additional 'innovative' structures are designed and tested to meet the specificities of each site: sticks or low fences to prevent sand filling (*casse-pattes*) to limit public access, removable stairs, stairs with driftwood risers, such as those installed in Vias (Hérault) in 2017 making it possible to channel public access while recycling crushed driftwood and incorporating it into the stairs (photo 4).

Contacts (EID Méditerranée):
D. Boulet and H. Heutefeux, littoral@eid-med.org

▲ *1. La Grande Motte, a coastal resort built during the Racine mission.* © EID Méditerranée

▲ *2. Topographic monitoring on the Orpellières Site in Sérignan (Hérault, France).* © EID Méditerranée



▲ *3. Role of fences in dune protection.* © EID Méditerranée

◀ *4. Construction of dune stairs. The steps are filled with crushed driftwood.* © EID Méditerranée/2017

Marine Protected Areas and biodiversity conservation strategies

Marine Protected Areas (MPAs), between heritage conservation, ocean grabbing and fisheries management

MPAs* have recently emerged as one of the most prevalent forms of ocean use. This enthusiasm for oceans amongst the biodiversity conservation community is developing in the context of a *bona fide* 'scramble for the sea', in which both governments and the industries are striving to consolidate their grip upon oceans and their resources. These new dynamics are being combined with older uses of the oceans, particularly fishing, thereby considerably increasing pressure on fish stocks and, as a result, leading to a re-mobilisation of 'traditional' practices. In this context of 'maritimisation' of economic, political and environmental challenges, MPAs, which act as biodiversity enclaves aimed at preserving marine world heritage, are subject to strong tensions resulting from the confrontation of potentially competing and overlapping territorial approaches. Though the objective of creating biodiversity enclaves is that of preserving nature, such enclaves can also—by limiting their access to and uses of the oceans—negatively affect the populations that are bound to the sea or depend upon it for their livelihood. Thus, MPAs contribute to the very processes of ocean grabbing that they intend to fight, and in particular those processes related to extractive strategies (tuna fisheries, deep-sea mineral resources, etc.).

In terms of both efficiency and management, the creation of MPAs raises questions relating to: their size (large-scale protected areas versus small managed areas, networked areas based upon the principle of ecological connectivity), their nature ('traditional' or 'hybrid' forms versus science-based environmental conservation), their location (coastal areas and/or deep sea areas, protection of international waters), and their integration into unprotected peripheral areas dedicated to different uses (marine spatial planning challenges).

These different tensions, and the way in which they are addressed by conservation policies, explain the diversity of the forms taken by marine biodiversity protection. They fuel controversies over ecological efficiency and the non-ecological functions of these protection mechanisms, in ways that vary with the historical, geographical, biophysical and political characteristics of the seas and oceans concerned. **In this respect, the challenges faced by the Mediterranean, a small semi-enclosed sea, split by major geopolitical dividing lines and surrounded by dense human and industrial activities, are particularly singular in nature. This specificity is reflected in both the fragmentation and closely intertwined nature of its marine challenges (fisheries, pollution, transport, environment) and its conservation mechanisms: a large number of small, scattered MPAs (covering 7% of the marine surface area), sometimes organized in networks. The location of these MPAs, 90% of which are situated in the coastal waters of European Union countries, also clearly reflects the North-South political and economic asymmetry that characterizes the Mediterranean's configuration**.

Contacts (GRED): M. Dégremont, marlene.degremont@gmail.com, É. Fache, elodie.fache@ird.fr, P.-Y. Le Meur, pierre-yves.lemeur@ird.fr and E. Rodary, estienne.rodary@ird.fr

* According to the International Union for Conservation of Nature (IUCN), a Marine Protected Area is: "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment". Therefore, MPAs should be considered as volumes of water rather than surfaces…

Marine worm plume © Thomas Changeux / IRD

MPA sites are selected in response to local political and economic considerations rather than to a *bona fide* regional conservation strategy.

Impact of the Mediterranean MPA network on the conservation and exploitation of living marine resources: the example of the dusky grouper

Although the Mediterranean accounts for only 0.82% of the total ocean and sea surface area, it provides habitat to 4 to 18% of known marine species, with an endemism rate of 8.8%. In order to overcome the overexploitation of numerous fish and invertebrate species in this biodiversity 'hotspot', approximately 200 national MPAs, covering 1.6% of the Mediterranean's total surface area, have been created along Mediterranean coasts*. However, the selection of MPA location is influenced more by local political and economic constraints and opportunities than by a *bona fide* regional biodiversity conservation strategy. Therefore, this degree of connectivity of the Mediterranean MPA network (i.e. its capacity to exchange and disperse marine species to fishing areas) is poorly known. In order to provide quantitative arguments to better plan for future MPA locations, a biophysical model simulating fish larvae dispersal from MPAs has been developed.

It has been demonstrated that **the Mediterranean MPA network is poorly connected, as a result potentially threatening the conservation of emblematic and heavily fished species such as the dusky grouper (*Epinephelus marginatus*). Distances between MPAs average 1 032 km, while the dispersal distance of dusky grouper larvae is only 120 km, which leaves many local populations completely isolated. In addition, MPA distribution remains very heterogeneous, with a low density in the south-east, leaving almost 20% of the continental shelf without any larval input from MPAs. This low connectivity is expected to increase due to climate change,** as a rise in temperature (expected rise of +2.8°C) will increase larval metabolic rates, inducing faster growth and a lower dispersal of individuals, thereby resulting in a **10% reduction in larval dispersal distances over the next century, i.e. an average reduction of 9 km. This climate change related impact upon the efficiency of Mediterranean MPA network, coupled with increased fishing intensity, highlights the urgency of ensuring connectivity between MPAs, and between MPAs and fishing areas**.

Contacts: D. Mouillot (MARBEC), david.mouillot@umontpellier.fr, M. Andrello (MARBEC), marco.andrello@ird.fr and S. Manel (CEFE), stephanie.manel@cefe.cnrs.fr

For further information:
https://twitter.com/reservebenefit?lang=fr
https://reefish.umontpellier.fr/index.php?article8/biodiversa-reservebenefit
www.fishbase.org/summary/Epinephelus-marginatus.html

* http://medpan.org/marine-protected-areas/

▲ *Dusky grouper on Mediterranean rocky shore.* © *David Diaz*

The role of MPAs: connectivity of gorgonian populations in the Gulf of Lion

MPAs have often been selected based on those habitats to which keystone, emblematic or endangered species are bound. Deliberations relating to MPA establishment have notably overlooked the consequences of the migratory patterns of most marine species, including for those species with a sessile adult stage, whose larval dispersal enables the colonisation of distant sites. This dispersal phase can have two antagonistic effects on species persistence: on the one hand, a decrease, due to retention rates that are too low to ensure generation renewal at the local scale, and, on the other hand, an increase, due to the distribution of species over several sites, and the consequent strengthening of species resilience to local disturbances and habitat fragmentation. Thus, isolated MPAs may prove inefficient in ensuring the conservation of species whose life cycle includes a dispersal phase. This explains why, in the Gulf of Lion, MPA managers are paying particular attention to gorgonians. Indeed, gorgonians are among the most remarkable sessile species in subtidal hard substrate communities, and play an essential ecological role as an 'umbrella species' providing habitat for small epifauna and refuge for many fish. Within the framework of the LITEAU IV* project, LECOB has worked on gorgonian population connectivity in the Gulf of Lion, by combining numerical simulations of larval dispersal and gene flow observations. This work demonstrates **the relevance of applying a networking approach to MPA management. Indeed, MPAs from the centre to the west of the Gulf of Lion** are connected by larval flows that, for instance, support the white gorgonian *Eunicella singularis*' regional resilience to recurrent local disturbances.**

Contacts (LECOB): K. Guizien, katell.guizien@obs-banyuls.fr and L. Bramanti, lorenzo.bramanti@obs-banyuls.fr

*RocConnect project (Connectivity of populations living in the fragmented rocky habitat of the Gulf of Lion): www1.liteau.net/index.php/projet/liteau-iv-2011-apr/roc-connect-connectivite-des-habitats-rocheux-fragmentes-du-golfe-du-lion
** Agde coast MPA, Cerbère-Banyuls Marine Reserve, Gulf of Lion Marine Park, Cap Creus Marine Park.

Landscape of the white gorgonian Eunicella singularis' *habitat in Cerbère-Banyuls Marine Reserve on the Vermeille Coast, France.* © *Katell Guizien*

Development of conservation strategies for the bottlenose dolphin in the French Mediterranean

Cetacean conservation is an important but complicated issue for marine biodiversity conservation because of the high mobility of cetaceans. There are a number of different protective legal frameworks in existence today: at the local level through MPAs, at the national level through the French Marine Environment Action Plan (01/07/2017 Decree) and at the European level, in particular through the European Union 'Marine Strategy' Framework Directive. Cetacean conservation requires the development and implementation of large-scale strategies that integrate the various objectives and constraints of the legal frameworks applicable in the areas where cetaceans are found. **The network of over sixty MPAs covering the French Mediterranean coast can provide a suitable mechanism for cetacean conservation, in particular for the bottlenose dolphin (*Tursiops truncatus*), which is the sole coastal cetacean species for which the establishment of Special Areas of Conservation in the Mediterranean is required.**

▲ *Bottlenose dolphin* (Tursiops truncatus). © *Hélène Labach*

The Scientific Interest Group for Mediterranean Marine Mammals (GIS3M*), in partnership with the French Biodiversity Agency, aims to study the potential and suitability of this MPA network for bottlenose dolphin conservation in the French Mediterranean, as well as to propose conservation strategies that support the MPA network. To this end, three lines of research are being investigated: the first line of research aims to identify management units and to define the challenges related to bottlenose dolphin conservation; the second line of research aims to evaluate the efficiency of the MPA network in managing management units and to assess existing and potential tools and resources; the third line of research intends to take the socioeconomic context into consideration in a dynamic way, by using an adaptive management approach. Combining these different lines of research will enable the development of integrated management strategies for each individual MPA, for the MPA network, as well as at the Sea Basin scale. It will also enable the mobilisation of the different stakeholders.

Contacts:
H. Labach (GIS3M/CEFE), hlgis3m@gmail.com,
V. Lauret (CEFE), valentin.lauret@cefe.cnrs.fr
and O. Gimenez (CEFE), olivier.gimenez@cefe.cnrs.fr

* For further information: www.gis3m.org

SUSTAINABLE FISHERIES IN THE NORTH-WESTERN MEDITERRANEAN SUPPORTED BY A NETWORK OF MPAs

The European funded project SafeNet* aims to identify coherent networks of MPAs as well as other area-based fishery management strategies, in order to both help fisheries achieve their maximum sustainable yield and maximize long-term socio-economic benefits for fishermen in the north-western Mediterranean. To this end, researchers and NGOs are working in partnership in order to apply an ecosystem-based approach to fishery management and to elaborate joint solutions in collaboration with stakeholders. Project results will therefore be key to achieve:
1. 'Good ecological status' in the north-western Mediterranean (i.e. the main objective of the European Union's "Marine Environment Strategy" Framework Directive)
2. Environmental, economic and social sustainability of fisheries (as stated by the European Union's Common Fisheries Policy).

The collection and integration of ecological and socio-economic data relating to fisheries, as well as the involvement of stakeholders (fishermen, MPA managers and staff, NGOs, fishery representatives and authorities) will enable the sharing of both traditional marine ecosystem knowledge and management related suggestions. Integrating this information via ecosystem models will make it possible to (1) assess the current benefits of MPAs and other fishery management approaches (for example, fleet-specific fishing management, species-specific quotas, etc.) and (2) simulate the effects of potential alternative MPA network configurations. The project will therefore identify the most appropriate and effective spatial management scenarios in order to safeguard biodiversity conservation, ensure the environmental, social and economic sustainability of fisheries, and provide guidelines for sustainable fisheries in the north-western Mediterranean.

Contact (CRIOBE): J. Claudet, joachim.claudet@cnrs.fr
*** For further information on SafeNet project (Sustainable fisheries in EU Mediterranean waters through a network of MPAs)**:
www.criobe.pf/recherche/safenet

▲ *Survey conducted among fishermen in the Gulf of Lion Marine Park.* © *Giulia Prato*

▲ *Survey conducted at the fish market in Cannes.* © *Rita Sahyoun*

Joint elaboration of MPA governance indicators: when scientists and environmental managers work together

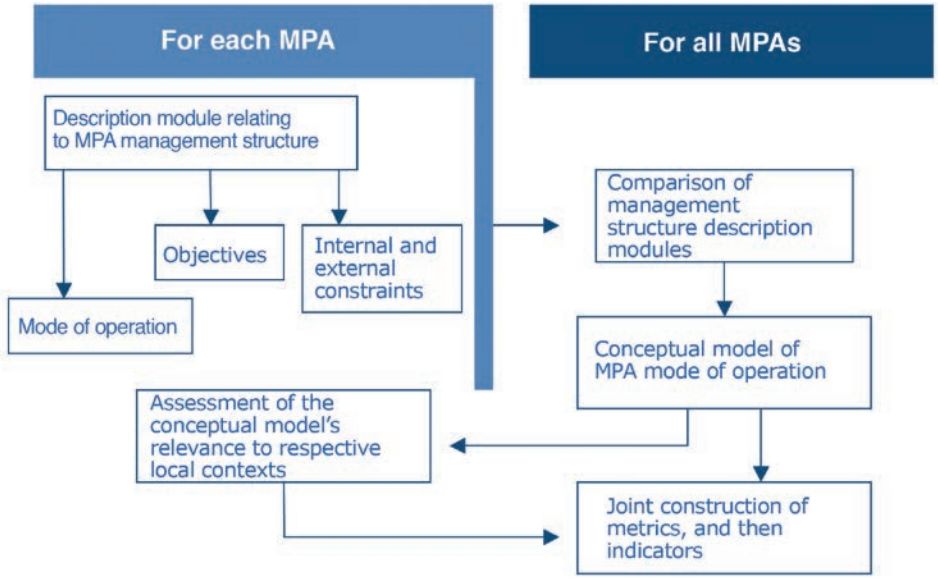
The joint elaboration of MPA governance indicators by managers and scientists can follow one of two different approaches. This was one of the findings of the PAMPA project (funded by the LITEAU programme from 2008 to 2011)*, which covered three Mediterranean MPAs: the Côte Bleue Marine Park, the Bouches de Bonifacio Nature Reserve and Cerbère-Banyuls Marine Reserve.

The first approach—based upon a collective exploration of governance—is used when the concept of governance is poorly understood by its future users. This first approach is articulated around three main stages: a) the description, for each MPA management structure, of its mode of operation and objectives, as well as of the internal or external constraints affecting its functioning; b) the elaboration of a conceptual model for each operational MPA c) the joint development of metrics and indicators (see Fig. 1).

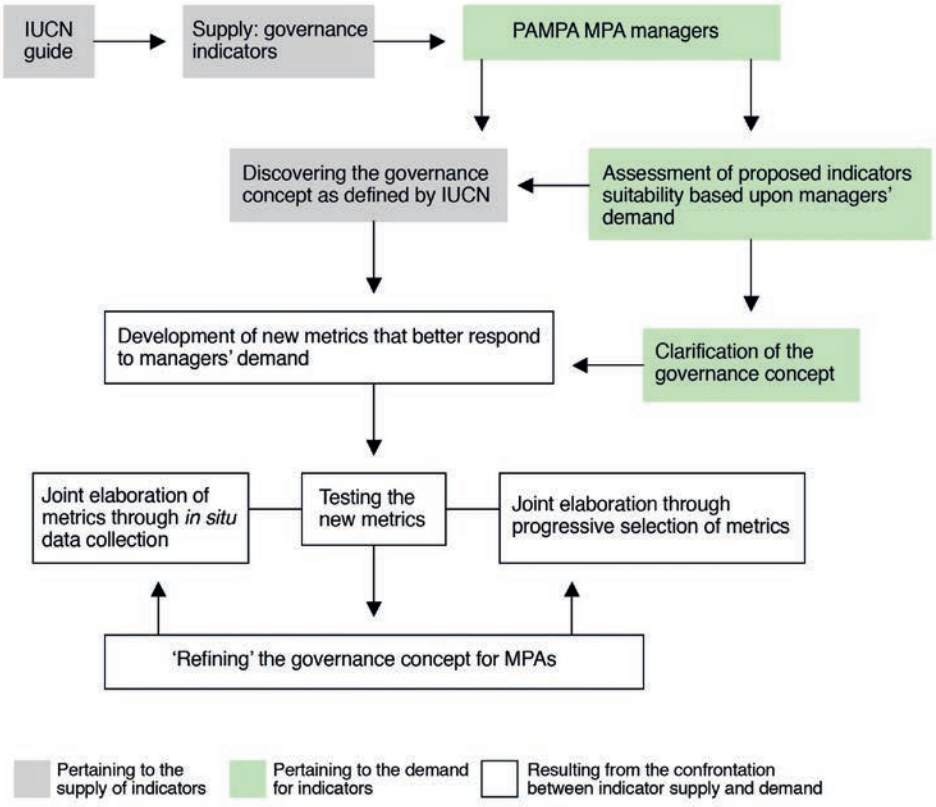
The second approach is based upon a confrontation between supply (MPA governance indicators defined by the International Union for Conservation of Nature (IUCN)) and demand (that of the MPA managers participating in the PAMPA project). Through this approach, MPA managers are able to clarify the concept of governance by first assessing the relevance of the indicators provided to them, and then themselves developing new indicators, considered more adapted to their day-to-day work (see Fig. 2). A total of 66 metrics has been documented and discussed. In order to reduce this number, each manager involved in the PAMPA project was asked to select a set of 10 priority metrics. **This progressive selection process resulted in the selection of 19 metrics, which were integrated into a common indicator dashboard for all MPAs.**

Contact (ESPACE-DEV):
G. David, gilbert.david@ird.fr

* PAMPA project: Indicators of MPA performance for managing coastal ecosystems, resources, and their associated uses.



▲ *Fig. 1. Joint construction of governance indicators through a collective exploration of the governance concept.* © G. David



▲ *Fig. 2. Joint construction of governance indicators through confrontation of indicator supply and demand.* © G. David

Marine energies

Marine energies in the Mediterranean, challenges and prospects

Although the offshore wind and tidal energy sectors are already operational abroad, France has been slow to design and implement marine renewable energy (MRE) projects. Yet, France has a strong development potential for MRE, given the natural assets of its many metropolitan and overseas coasts*.

As of the end of the last century, many studies demonstrated the need for moving from an economy based on cheap and abundant oil, to a sustainable economy based on renewable sources of energy. Since then, two new elements have reinforced this perspective:
- Scientific evidence proving that global warming of the Earth's atmosphere is mainly due to human activities, and that the greenhouse effect is accelerating.
- The recognition that renewable energy technologies, in particular offshore technologies, provide a viable means for making the transition to a low-carbon economy free of pollutant residues.

Although States and international organisations are now, at quite a fast pace, setting ambitious objectives (such as that of increasing the share of renewable energy to at least 20% of total energy consumption by 2020), the inertia of the national—perhaps even global—energy system, low oil and gas prices, and lobbying, continue to hinder the development of renewable energies. In the marine sector, these obstacles are compounded by the lack of mature technology (in all sectors except for the wind energy sector), the additional costs associated with offshore remoteness and natural constraints, as well as the multiple appeals lodged by local residents against such projects. Nevertheless, since the 2000s, a number of stakeholders (businesses, consultancy firms, research institutes, universities) have been investing increasing resources into the renewable energy field, with support from governments and, most importantly, from local authorities interested in these decentralized sources of energy. Many prototypes have been tested, drawing upon diverse and innovative technologies (over 100 prototypes tested to date). In 2010, the French government launched a first call for tenders for offshore wind projects representing a total power of 3 GW. This call for tenders was the first of a series to come. The launch of four pilot floating wind farm projects in 2015 (of which three in the Mediterranean, and two in Occitanie) marks a new step forward.

In the French Mediterranean, offshore wind energy is emerging as the first significant MRE, in particular on floating support structures as water depths, except in coastal areas very close to the shore, are high (50 to 100 m). The Gulf of Lion is an excellent area for wind energy production due to its frequent, strong and steady winds. Indeed, these winds enable offshore wind turbines to operate 50% of the time, which is twice as long as onshore wind turbines. The Occitanie Region, whose ambition is to become a "positive energy region (*région à énergie positive)* by 2050" (i.e. a territory whose energy requirements are met entirely by renewable energies), is favourable to hosting floating offshore wind farms. Major developments are underway, including the extension of Port-la-Nouvelle. In addition, French engineering companies, which are highly innovative in the field of floating structures and anchoring system construction, are exporting their expertise all over the world (80% of this French sector's turnover in 2017). Other Mediterranean sites appear to be suitable for wind energy exploitation, including: the southern coast of Italy, the Aegean Sea off the coast of Greece, and the western coast of Turkey. Some 40 projects worldwide are currently under consideration, while others are underway, most notably in Portugal, but also in the North Sea, in South Korea, in the United States of America, etc.

The French State, under the authority of the Interregional Directorate for the Mediterranean Sea, and within the framework of its Maritime Spatial Planning, has conducted a consultation addressing future areas in which commercial floating wind farms might be established. The consultation process notably took into consideration existing activities in the concerned areas (fishing, etc.) and potential impacts on wildlife. **The consultation resulted in the identification of four macro areas in the Gulf of Lion, covering a total area of 3,300 km²**, in which future commercial wind farms, selected through calls for tenders, will be located. As of 2025, the offshore wind energy sector is proposing to create 4 to 6 wind farms, each with a capacity of 500 MW, within these macro areas. Wind farms generate new ecosystems, associated with the presence of anchor lines, floating structures, etc. Indeed, these infrastructures create new habitats, and are subjected to high levels of biological colonisation. Therefore, the electricity transmission network may host permanent ecosystem observatories (for the measurement of physical and biological parameters), with a specific focus on the observation of ecosystems associated with the presence of offshore wind farms.

Other forms of marine energy are longer term or site-specific. Thus, ocean thermal energy, via the collection of thermal energy accumulated in the sea to supply coastal populations with heat and cooling, represents an interesting form of energy for the Mediterranean. This technology, which has been tested successfully in Polynesia, is not yet widespread, except in Monaco and Marseille. It will probably spread with future urban development projects. The *Pôle Mer Méditerranée* competitiveness cluster has included marine energy as one of its programme's six strategic areas of action.

Contacts: P. Marin (*Pôle Mer Méditerranée*), marin@polemermediterranee.com, G. Herrouin (*Pôle Mer Méditerranée*), herrouin@polemermediterranee.com and D. Lacroix (IFREMER), denis.lacroix@ifremer.fr

* See Paillard M., D. Lacroix and V. Lamblin (coord.), 2009. *Marine renewable energies: prospective foresight study for 2030 (Énergies renouvelables marines: étude prospective à l'horizon 2030)*. Editions QUAE, France. 336 p. French and English versions available.

Floating offshore wind energy is the Mediterranean's unrivalled potential marine energy, but it has yet to be implemented and developed to deliver this potential.

Assessing the potential of our marine energy

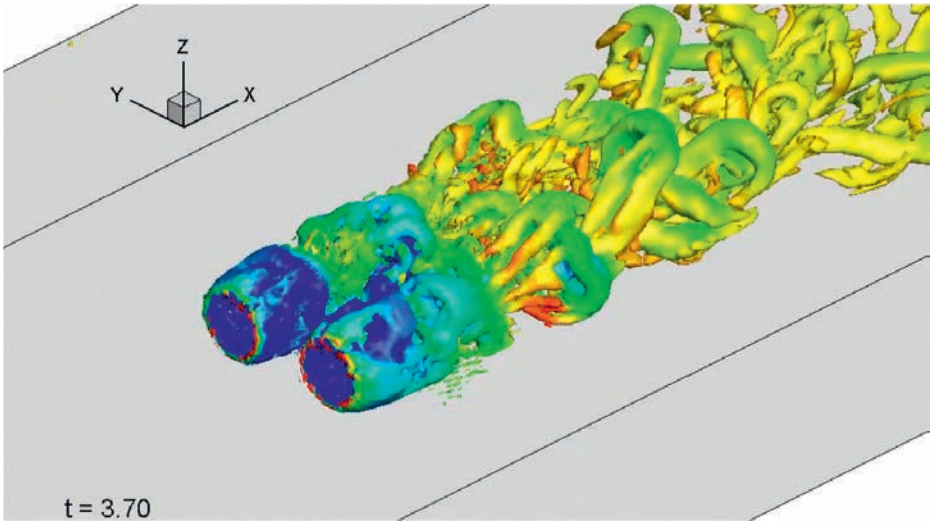
The work of the LEMON (Littoral, Environment: Models and Numerics) team, based in the local Montpellier antenna of the INRIA Sophia Antipolis-Méditerranée research centre (National Institute for Research in Computer Science and Control), enables the assessment of marine energy production potential at different scales. Assessment involves designing high-resolution models for coastal areas, and calculating the interaction between currents and marine current turbines in order to optimize turbine positioning. One of the major difficulties associated with high-resolution models is the coupling of equations modelling diverse physical behaviours. Indeed, while it is indispensable to use very high precision models in the area where turbines will be positioned, it is also necessary (because of computing costs) to use lower precision models (with lower resolution) in areas that are further from the coast. Therefore, it is essential to set up coupling strategies between these offshore and coastal models, whose physical and mathematical characteristics are very different!

In order to understand the interaction of coastal currents with marine current turbines, it is necessary to use models that take into consideration the turbulence generated by turbine blade rotation. **The models developed by the LEMON team and its collaborators** apply a combination of deterministic and random techniques, which make it possible to both quantify production forecasts, and provide ranges for these forecasts through the precise determination of error bars, which are essential in order to guarantee minimum levels of energy production.**

Contact (LEMON team, INRIA):
A. Rousseau, antoine.rousseau@inria.fr

*** For further information:**
- LEMON team (INRIA): http://team.inria.fr/lemon
- Meric: http://meric.cl
- Projet SDM (*Stochastic Downscaling Method*): http://sdm.gforge.inria.fr/

** Collaborators: TOSCA team (Simulating and calibrating stochastic models, INRIA, Sophia Antipolis) and the Catholic University of Santiago (Chile).



▲ *Turbulence produced by blade rotation of two marine current turbines.*
© C. Escauriaza/PUC Santiago & MERIC

TIDEA, IDENTIFICATION OF SUITABLE AREAS FOR TIDAL ENERGY DEVELOPMENT

NOVELTIS has set up an innovative service known as TidEA (Tidal Energy Assessment), which is the first tool in the world to provide tidal data on worldwide coasts. Indeed, TidEA is a new platform aimed at supporting marine renewable energy stakeholders in the identification of suitable areas for the development and installation of tidal energy exploitation structures. The TidEA service is a unique decision-making tool enabling the identification of the most suitable sites for tidal energy development. It also provides detailed information on the tidal energy resources available at each site of interest, through the provision of relevant indicators calculated by NOVELTIS and validated using Copernicus Marine Environment Monitoring Service (CMEMS*) products (altimetry data). TiDEA is a global tool that maps worldwide coastal regions, providing data to bathymetry up to 100 metres depth. For each selected site, the service provides data on maximum current speed, the average energy potential, as well as indicators of speed threshold occurrence.

Contact (NOVELTIS): R. Bru, contact@noveltis.fr

For further information: www.tidea.io/tidal_energy

* www.marine.copernicus.eu

EolMed, pilot project for floating wind turbines in the Mediterranean

EolMed* is a 24.6 MW offshore floating wind power project located on the Languedoc coastline, off the coast of Gruissan (Aude Department), over 18 km away from the shore. This **pilot project provides a level of technological innovation, unique to Europe, through its installation of offshore wind turbines the specificity of which is that they are installed on floating concrete structures.** These wind turbines (scheduled to be operational as of 2021) will enable the production of electricity using the kinetic energy of the wind, a regular and abundant natural resource in the open sea. EolMed is driven by a consortium of four partners: *Quadran Énergies Marines*, responsible for development, exploitation and maintenance, IDEOL and Bouygues TP, responsible for engineering, construction and implantation, and Senvion, responsible for supplying offshore turbines with a power of 6.15MW. In addition, right from the start of the project, *Quadran Énergies Marines* has been mobilizing businesses and research laboratories based in Occitanie. These stakeholders have been engaged in a dialogue that has opened many avenues for action and reflexion, in particular in relation to potential co-uses within concession areas, and to the digitalisation of the project related consultation conducted with local residents, fishermen and all those concerned by the wind farm installation. The **E-Debate research programme aims to create new digital tools to enable the general public to interact with major projects, understand the main issues associated with wind turbine installation, and participate in the project consultation through a website.** Furthermore, a digital platform made available on-line in September 2017, makes it possible to timestamp all exchanges and to track the project evolutions that have taken into consideration the views expressed on the platform. E-Debate is a collaborative research programme (co-funded by the Occitanie Region and the ERDF/European Regional Development Fund) that brings together scientists (UMPV through the CEFE) and private sector stakeholders (Intactile Design and *Quadran Énergies Marines*).

Contact (*Quadran Énergies Marines*):
L. Tokarski, l.tokarski@quadran-marines.com

For further information: www.eolmed.fr/en/
E-Debate Platform: https://eolmed.edebat.fr/

* EolMed is one of the four projects selected within the framework of the 'Pilot Floating Wind Farms' Call for Tenders launched by ADEME in 2015.

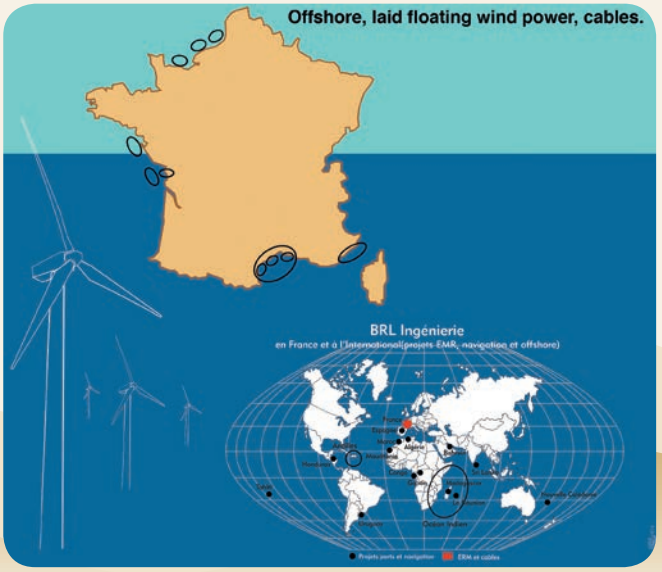
▲ *Representation (synthetic image) of a floating wind turbine installed on a semi-submersible platform.* © *Quadran Énergies Marines*

BRLI SUPPORTS THE "GULF OF LION FLOATING WIND TURBINES" PROJECT

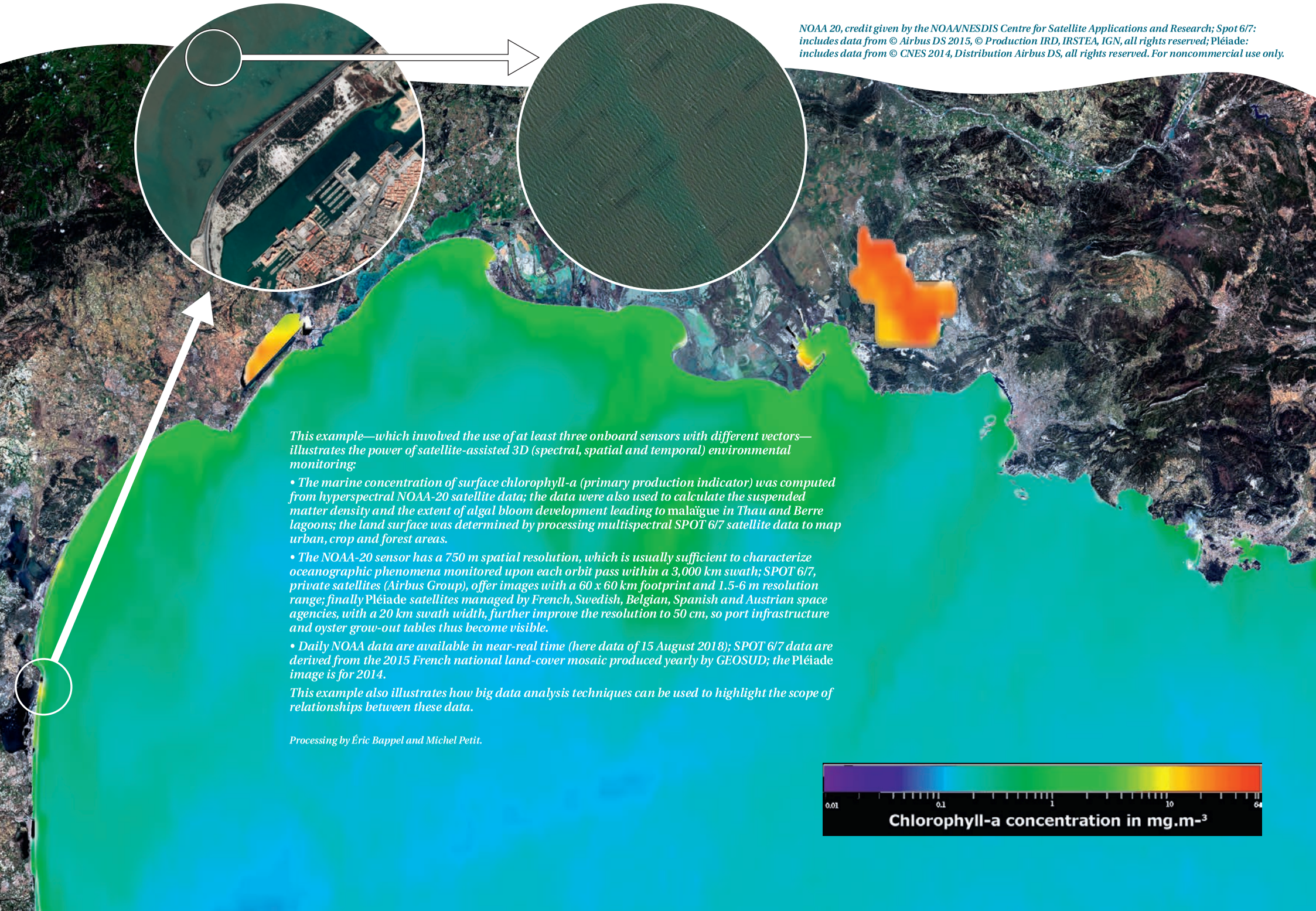
The BRL Group, which is a member of Occitanie Region's *Parlement de la Mer* (see p. 128), specializes in the fields of water, environment and land-use planning. Its subsidiary, BRL Ingénierie (BRLI), a consultancy firm working in France and abroad, and member of the *Pôle Mer Méditerranée* competitiveness cluster, has been involved since the 2000s in the development of renewable marine energy. In Occitanie, BRLI is supporting the "Gulf of Lion Floating Wind Turbines" project led by ENGIE Green, EDP Renewables, the "*Caisse des Dépôts*" Group and RTE (Electricity Transmission Network). Within a short period of time (14 months) and in close collaboration with the main stakeholders of the territory (fishermen, Gulf of Lion Marine Park, government services, etc.), BRLI experts conducted the project's environmental and regulatory studies, including underwater campaigns, observations made by boat and airplane, and social surveys. The pilot farm, installed off the Leucate and Barcarès coast, plans to deploy four 6 MW marine wind turbines installed on steel floating structures and anchored at an average depth of 80 m. In the Mediterranean, BRLI has also supported the Provence Offshore (*Provence Grand Large*) project, off the Gulf of Fos, in the Faraman area (three wind turbines with a capacity of 8 MW each).

These two projects are characterized by significant environmental challenges (Natura 2000 areas, natural reserves), as well as by significant socio-economic uses of natural resources (port areas, coastal areas, professional and leisure fishing, etc.). In response to these complex challenges, BRLI, with its large portfolio of projects in the Channel and the Atlantic Ocean (Fécamp, Dieppe-Le Tréport, Yeu-Noirmoutier, Courseulles-sur-Mer offshore wind farms, etc.), is providing the full breadth of its expertise in coastal, maritime and port project environmental impact studies in order to support the emergence of these ambitious projects.

Contact (BRL Ingénierie): N. Fraysse, dc.brli@brl.fr



© *BRL/GL*



NOAA 20, credit given by the NOAA/NESDIS Centre for Satellite Applications and Research; Spot 6/7: includes data from © Airbus DS 2015, © Production IRD, IRSTEA, IGN, all rights reserved; Pléiade*: includes data from © CNES 2014, Distribution Airbus DS, all rights reserved. For noncommercial use only.*

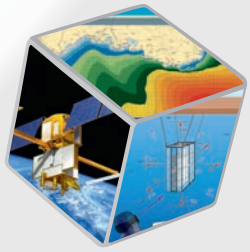
This example—which involved the use of at least three onboard sensors with different vectors—illustrates the power of satellite-assisted 3D (spectral, spatial and temporal) environmental monitoring:

- *The marine concentration of surface chlorophyll-a (primary production indicator) was computed from hyperspectral NOAA-20 satellite data; the data were also used to calculate the suspended matter density and the extent of algal bloom development leading to* malaïgue *in Thau and Berre lagoons; the land surface was determined by processing multispectral SPOT 6/7 satellite data to map urban, crop and forest areas.*
- *The NOAA-20 sensor has a 750 m spatial resolution, which is usually sufficient to characterize oceanographic phenomena monitored upon each orbit pass within a 3,000 km swath; SPOT 6/7, private satellites (Airbus Group), offer images with a 60 x 60 km footprint and 1.5-6 m resolution range; finally* Pléiade *satellites managed by French, Swedish, Belgian, Spanish and Austrian space agencies, with a 20 km swath width, further improve the resolution to 50 cm, so port infrastructure and oyster grow-out tables thus become visible.*
- *Daily NOAA data are available in near-real time (here data of 15 August 2018); SPOT 6/7 data are derived from the 2015 French national land-cover mosaic produced yearly by GEOSUD; the* Pléiade *image is for 2014.*

This example also illustrates how big data analysis techniques can be used to highlight the scope of relationships between these data.

Processing by Éric Bappel and Michel Petit.

Power of long-term observation and synergy of digital integration



20 September 2042. *The weather was dreadful at sea and ashore—it was the third so-called Cévenol storm of the season, and even more severe than the previous ones. "Already the third," said the Lo Lugran fishing captain as he entered the secure seaway. "People are gathering on the VM9...", he thought, looking at the control screens. This reflected the fact that traffic had been increasing steadily for 20 years, with the advent of a new generation of freight and passenger ships, in addition to international offshore and coastal surveillance vessels. Throughout the summer, his company's Overboats had done an excellent job of rounding up pelagic fish schools in the regulatory fishing cages, but within the authorized quota limits of course. The catch was transshipped before being put up for sale at the Permanent Digital Fish Auction. These autonomous robots received the actual or highly probable position of the fish schools, as calculated by an advanced deep learning algorithm based on various environmental data from direct* in situ *observations or spaceborne remote sensing devices. Once they had accumulated enough fish, these units slowly directed the schools towards cages along a route calculated by their onboard system to optimize energy expenditure of the fish while respecting their euphoric living conditions. Quotas were estimated weekly by population dynamics models that had been completely revolutionized following the incorporation of environmental DNA data collected by many gliders and Overboats.*

The visibility was really limited and the seas very rough, but the captain —fully aware of how his job had changed since the outset—was not really worried. All of the ships were now interlinked, in accordance with government agreements. Their navigation and status parameters were exchanged in real time, with each ship having an autonomous system to analyse the situation with regard to both human and ocean-weather environments. This system—a marvel of the latest digital technology—was the real pilot of the Lo Lugran, ensuring that there would be no possibility of a collision. Who could have imagined an unprecedented cyberattack on the systems and its implications?

Everyone can optimistically or pessimistically imagine the end of this futuristic narrative. But the fact is that significant advances in knowledge, associated research tools, descriptive and predictive models and therefore professions are under way in all fields. The major primary driver of this trend is synchronous with the emergence of big data—the new mathematical paradigm. This paradigm, which is the fourth in the history of science according to T. Hey, cannot be efficient without the development of mathematical algorithms, particularly Bayesian statistics (machine learning, etc.), but also topology, probability (Markov chains, etc.), linear algebra (singular value computation, etc.) and analysis (wavelet decomposition) algorithms. They must be independently able to find links in big datasets. Then experts assess their relevance, but on a theoretical basis, which is the novel aspect of this approach.

Parallel computations on a grid of several linked computers (from 10 to more than 100,000)—while awaiting the advent of an efficient quantum computer (currently in the prototype phase)—are needed to come up with solutions to problems at hand within a reasonable amount of time. **In short, the synchronous arrival of such combined algorithmic intelligence/quantum computer technology is the key to this digital revolution, which obviously has an impact on marine science**: oceanology, meteorology, fisheries, marine ecology, coastal geomorphology, physical and human geography, etc. This transition between mainstream and big data models has generated unprecedented opportunities and will likely trigger series of breakthroughs in science, technology, innovation, and also in terms of the profession. This once again quite factual setting is known and, beyond the endless logorrhoea between overestimation and dehumanisation of novelty, the awareness of the absolute necessity to foresee this evolving process is growing among decision makers—those who can anticipate and master it will benefit in science, education, imagination/creation (applications) and innovation.

Data is the resource that experts tap from the big data mine. The initial step is therefore data structuring which—in the area of interest—concerns physical, chemical and biological environment data, as well as human activities. As shown hereafter, the French Occitanie region already hosts internationally renowned structures devoted to the processing, archiving and dissemination of: (1) streamed historical data, and (2) *in situ* data acquired via observatories (OSU and OSH) or remote sensing, particularly from Earth observation satellites (CNES, GEOSUD, etc.). These satellites are fitted with powerful advanced tools (sensors) that can monitor broad maritime areas with the finest spatiotemporal and spectral resolution, and the collected data are used to fuel models for calculating water currents, temperature, salinity, swell, wind, phytoplankton content, as well as pollutant levels, coastal erosion, while generally being effective for detecting changes between two dates. The space oceanography sector in Toulouse has been particularly dynamic for over 25 years and now hosts a range of research laboratories and aerospace industry leaders. This has prompted national and international operators (CNES, ESA, NASA, JAXA, CNSA and ASI) to develop—from the design to the operational phase—a significant number of space-based Earth observation systems (SMOS, SWOT, CFOSAT, AEOLUS, PLEIADE, COSMOSKYMED, etc.). This is complemented by the fact that research structures in the Languedoc-Roussillon area have access to field datasets in addition to the expertise required to validate aerospace sensors, particularly for studies in the Mediterranean Sea and its coastal zone.

One major challenge is now to formalize access to databases and exchanges between public and private stakeholders. The Occitanie Data initiative currently being set up could provide an effective response. Teaching must first be tailored to meet the urgent demand in new professional areas, e.g. data analysts capable of understanding computer systems and smart algorithms so as to be able to fine-tune them to ensure data dialogue, while having genuine expertise in their specialized research field. Already in 2013 the shortfall for this type of occupation in the United States was estimated at more than 2 million jobs by 2020, including a high proportion in our target sector.

Another corporate challenge concerns risk-taking in patenting—it is strange that **47% of patents issued worldwide that are associated with marine genetic sequences are held by a single privately-owned German group***.

In this chapter, public and private research teams have—through tangible examples—sought to highlight the strengths of the Occitanie region in this new and ongoing research setting.

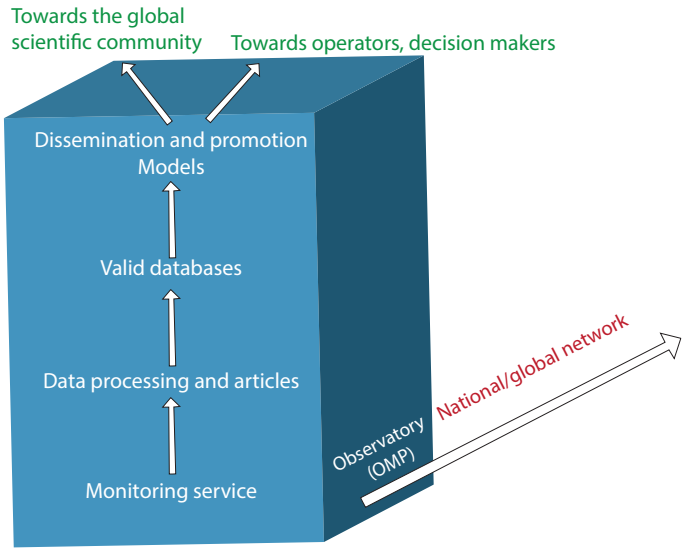
Michel Petit (Agropolis International)

* *Badische Anilin und Soda Fabrik* (BASF)

Observatories and in situ *data*

Observatories for Science of the Universe (OSUs) – specific missions

OSUs were founded by decree in 1985. Pursuant to the statutes, a representative of the National Institute for Earth Sciences and Astronomy (CNRS-INSU) as well as a representative of the region in which the given OSU is located are members of the Board. Most OSUs also serve as in-house schools for their affiliated universities. High-level research is conducted by all OSUs, while they also contribute to training, knowledge dissemination and the development of international cooperation activities. Each OSU has specific responsibilities for the acquisition, archiving and storage of observation data, the development of theoretical tools and models, and dissemination of the results to national and international communities. With the aim of gaining further insight into how the Earth and Universe function, these 'observation services' span the fields of astronomy, geophysics and, more recently, land surfaces and oceanography/aerology. OSUs thus shed fresh light on environmental and societal issues such as climate change and environmental/seismic disasters (see next article).



▲ *Functioning of a certified monitoring service.*
© C. Jeandel and M. Toplis

The Observatory Midi-Pyrénées (OMP) is one of the first USOs which was launched in 1985. Under the guardianship of the University of Toulouse III, CNRS, CNES, the French Research Institute for Development (IRD) and *Météo-France*, OMP has grown steadily since then, with a staff of around 1,200 people currently hosted in a joint service unit (UMS) and six joint research units (UMRs)*.The geographical focus is in the metropolitan Toulouse area, but the OMP is also present elsewhere in the region (Tarbes, Lannemezan, Auch and Foix), in addition to its emblematic location at the Pic du Midi de Bigorre. OMP contributes to 58 INSU-labelled observation services, including 32 as coordinator. These services encompass all INSU disciplines. In addition, OMP is increasingly involved in several 'workshop areas' accredited by the CNRS Institute of Ecology and Environment (INEE), thus complementing its thematic coverage in the environment field and its geographical location in Occitanie region. The observation services for which OMP is responsible are often local offshoots of national or even international initiatives. In this respect, **the observatory handles the collection of data, their scientific validation and promotion, while also providing wide access to the scientific community, operators and decision makers** (see illustration).

Contacts: M. Toplis (OMP), michael.toplis@irap.omp.eu, C. Jeandel (LEGOS), catherine.jeandel@legos.obs-mip.fr and G. Boulet (CESBIO), gilles.boulet@ird.fr

*Including CESBIO, GET, LA and LEGOS joint research units (UMRs).

SNO DYNALIT – AN OBSERVATION NETWORK FOR MONITORING CHANGES IN COASTAL AREAS

National research stakeholders are jointly involved in major monitoring programmes such as the CNRS National Observation Service (SNO) Coastal and Coastline Dynamics (DYNALIT). In Occitanie region, these monitoring activities are carried out by OSU OMP and OSU OREME (see p. 88) and its Coastline Observation System (SO LTC), which pools coastal dynamics research teams of several research structures affiliated with the universities of Toulouse, Perpignan, Montpellier, Aix-Marseille, Toulon and Grenoble.

SNO DYNALIT aims to build a long-term hydromorphological database of findings from 30 workshop sites representative of French coastal environments (sandy coasts, cliffs and estuaries). The approach involves permanently measuring coastline changes using modern techniques while streamlining data acquisition strategies between laboratories from the three French coastal regions (over 120 researchers). More specifically, SNO DYNALIT combines its observational data with meteorological and oceanographic forcing data. Sandy beach dynamics, for instance, are monitored twice yearly by a topographical survey of the beach and coastline before and after each winter period to determine the impact of these energy periods on shoreline variations over the years.

Contacts: R. Certain (CEFREM), certain@univ-perp.fr and R. Almar (LEGOS), rafael.almar@ird.fr

For further information: www.dynalit.fr/dynalit_uk

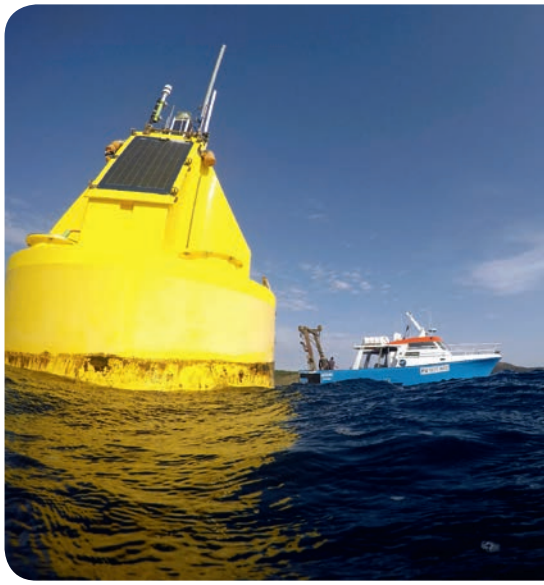
▶ *Beach erosion monitoring by photogrammetry (drone stereoscopic imaging).*
© Rafael Almar

Banyuls-sur-Mer Oceanologic Observatory (OOB) – a long history of research, training and monitoring

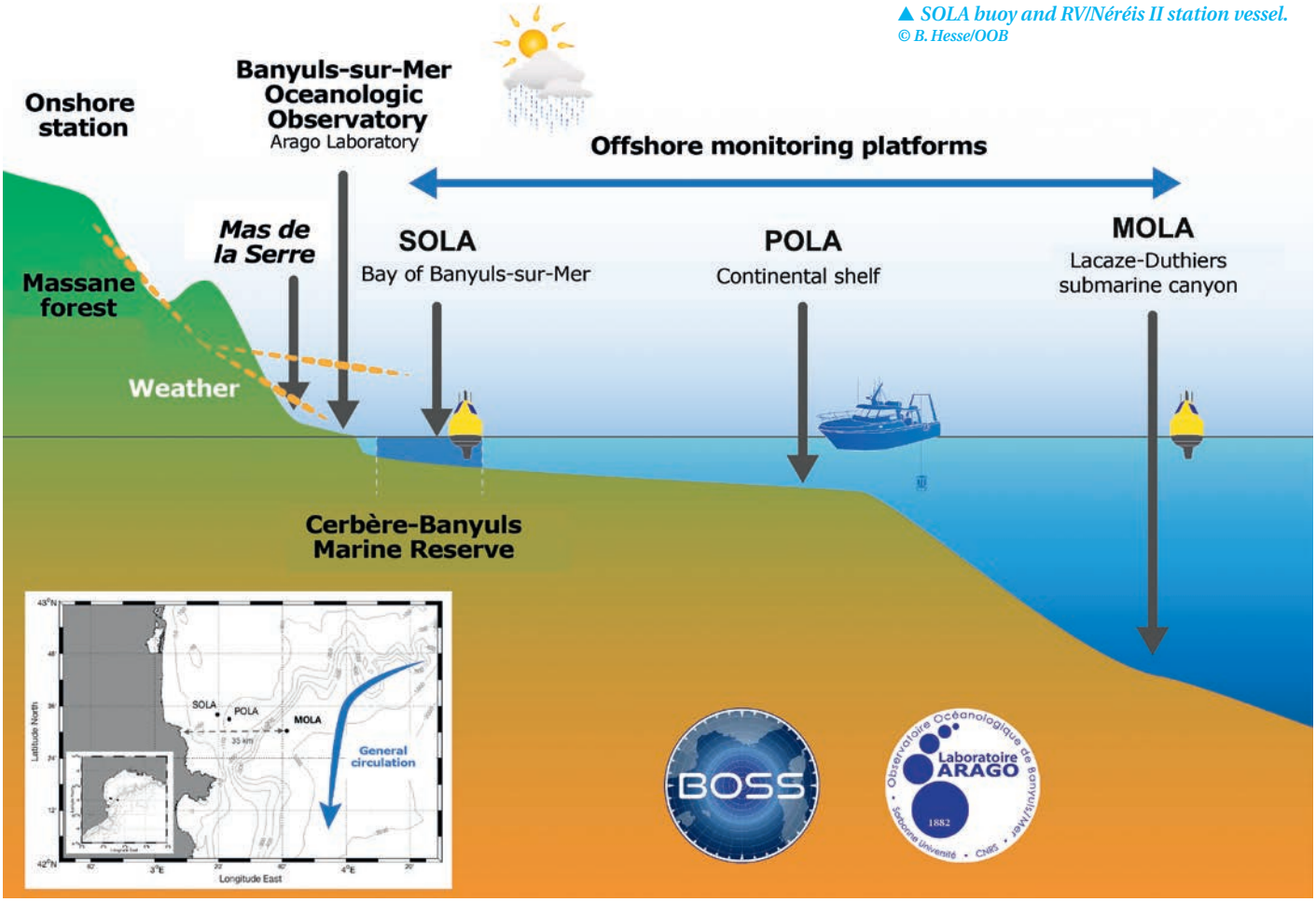
OOB was founded in 1882 and currently brings together four research laboratories and several scientific services and platforms accessible to the scientific community. Researchers conduct integrated oceanography, biotechnology and marine ecology and biology studies, among other in the northwestern Mediterranean area. Since the outset, the Observatory has been steadily monitoring and recording the continental (Albères Mountains) and especially the marine (Gulf of Lion) environment via the Banyuls Observation Sea Service (BOSS), which is responsible for this initiative. **The data series—acquired at a weekly rate for more than 20 years—constitutes one of the most long-term comprehensive databases available for the Mediterranean region. The unique feature is the fact that a single coastal/offshore gradient at the outlet of the Gulf of Lion is sampled under the influence of continental inputs and general circulation** (see figure). BOSS has been developing and deploying multi-instrumented high-frequency measuring buoys for nearly 10 years in the framework of its assessments of the impacts of climate change and meeting new scientific requirements. The marine service package will soon be enhanced with a cabled underwater platform for technological development as part of the REMIMED project (see next page). Earth observation is not to be overlooked as it includes weather monitoring (since 1960), an observatory of 50,000 trees (initiated in 1998) and long-term monitoring of indicators (birds, dragonflies, amphibians, plants, etc.). OOB is also involved in training students from Sorbonne University and other partner universities in France and Europe. Finally, via the Biodiversarium, which includes a Mediterranean garden, a public aquarium and an educational laboratory, OOB offers the general public an opportunity to discover the exceptional biodiversity of the site and the research carried out there (see p. 118).

Contacts: P. Conan (LOMIC), pascal.conan@obs-banyuls.fr, R. Vuillemin, (Service BOSS and Moyens à la Mer/OOB), renaud.vuillemin@obs-banyuls.fr and V. Laudet, (OOB/BIOM), directeur@obs-banyuls.fr

For further information:
BOSS : http://sooob.obs-banyuls.fr/fr/index.html
https://twitter.com/banyulsbaybuoy



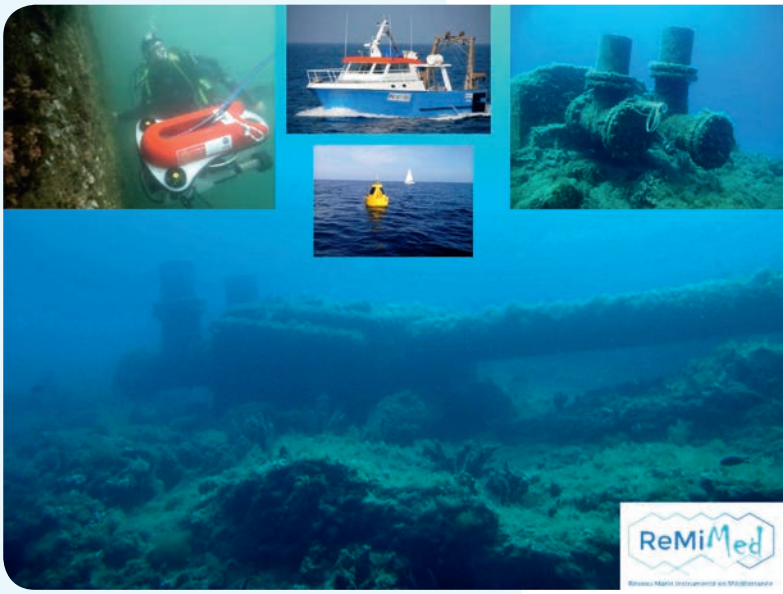
▲ *SOLA buoy and RV/Néréis II station vessel.* © *B. Hesse/OOB*



▲ *Arago Laboratory monitoring sites from the mainland and Massane forest to the instrumented platforms in the Gulf of Lion. The thumbnail map shows the geographical positions of the offshore monitoring platforms: Arago Laboratory Onshore Observatory Site (SOLA), Arago Laboratory Observatory Platform (POLA) and Arago Laboratory Microbial Observatory (MOLA).* © *P. Conan & V. Domien*

REMIMED UNDERWATER OBSERVATION PLATFORM FOR AN ALL-INCLUSIVE MEDITERRANEAN COASTAL SERVICE OFFER

The *Réseau marin instrumenté en Méditerranée* (REMIMED) project aims to develop a pilot cabled underwater observatory in the Bay of Banyuls-sur-Mer at 20-27 m depth at the historical SOLA observatory site (see previous page). The infrastructure will be ideally located in the Gulf of Lion Marine Natural Park in the vicinity of the Cerbère-Banyuls Marine Natural Reserve. The proposed technological platform will include the planned cabled underwater network, the already developed OOB multi-instrumented buoys and the marine facilities available at the station for an all-inclusive service offer on the Mediterranean coastal zone. In addition to its relevance for the observation and operational monitoring of the coastal area, this readily available infrastructure will also serve as a platform at the disposal of scientists, educators and industrial operators wishing to ensure the reliability of their developed instruments through *in situ* tests. Local authorities may also use it for their mediation and communications initiatives. The REMIMED platform aims to equip its infrastructure with new innovative sensors featuring emerging measurement techniques. The platform will be a driving force for industrial development in the field of environmental monitoring, both for R&D companies in the sensor and measurement systems sector and for data processing companies. There is no comparable platform in Occitanie region that has all the resources necessary for working and deploying instruments at sea in addition to automated reception vectors. REMIMED, in keeping with the expertise of OOB on data archiving, management and dissemination, will provide the platform with a real big data technology structure available to a broad-ranging community.



Contacts: R. Vuillemin (OOB), renaud.vuillemin@obs-banyuls.fr, M. Groc (OOB), michel.groc@obs-banyuls.fr and P. Conan (LOMIC), pascal.conan@obs-banyuls.fr

For further information: www.obs-banyuls.fr/remimed

OBSERVATORY FOR RESEARCH ON THE MEDITERRANEAN ENVIRONMENT

The Observatory for Research on the Mediterranean Environment (OREME) is an OSU devoted specifically to assessing unpredictable variations in Mediterranean environments and their vulnerability. OSU OREME—through the resources provided by the *Station Marine de Sète*, with the involvement of the University of Montpellier (UM) and the MEDIterranean platform for Marine Ecosystem Experimental Research (MEDIMEER)—proposes regional, national and international laboratories:

- The opportunity to seamlessly monitor environmental variables (physicochemical and biological) of Languedoc coastal marine environments (Thau lagoon and Sète subtidal zone) in the long term, so as to correlate these different variables with local and global changes or with severe natural events (floods, storms, drought, etc.). Two observation initiatives of OSU OREME (*Suivi-Thau* and *Communautés planctoniques de Thau*, carried out on the Thau lagoon) and the national coastal observation service (SOMLIT-Sète), whose measurement station is located on the continental shelf in the Gulf of Lion off Sète, currently use the technical and logistical facilities (marine facilities, an instrument-park and analytical platform) of the *Station marine de Sète* and the MEDIMEER platform.
- Access to a wide range of experimental devices (including *in situ* and onshore mesocosms*, MEDIMEER platform), with the capability of manipulating and controlling environmental forcings. Such high-volume devices—which are unique in France and the Mediterranean Basin—make it possible to isolate a mass of seawater representative of the coastal ecosystem studied, and to quantify and qualify (under controlled conditions) the impact of natural (global warming) and anthropogenic forcings on the functioning of coastal marine ecosystems (production, diversity, mass flow, resistance and resilience, etc.).

Contact (OREME): S. Mas, sebastien.mas l @umontpellier.fr and E. Servat, eric.servat@umontpellier.fr

*Mesocosm: an experimental apparatus in which species' natural living conditions are emulated, while all environmental parameters are controlled.

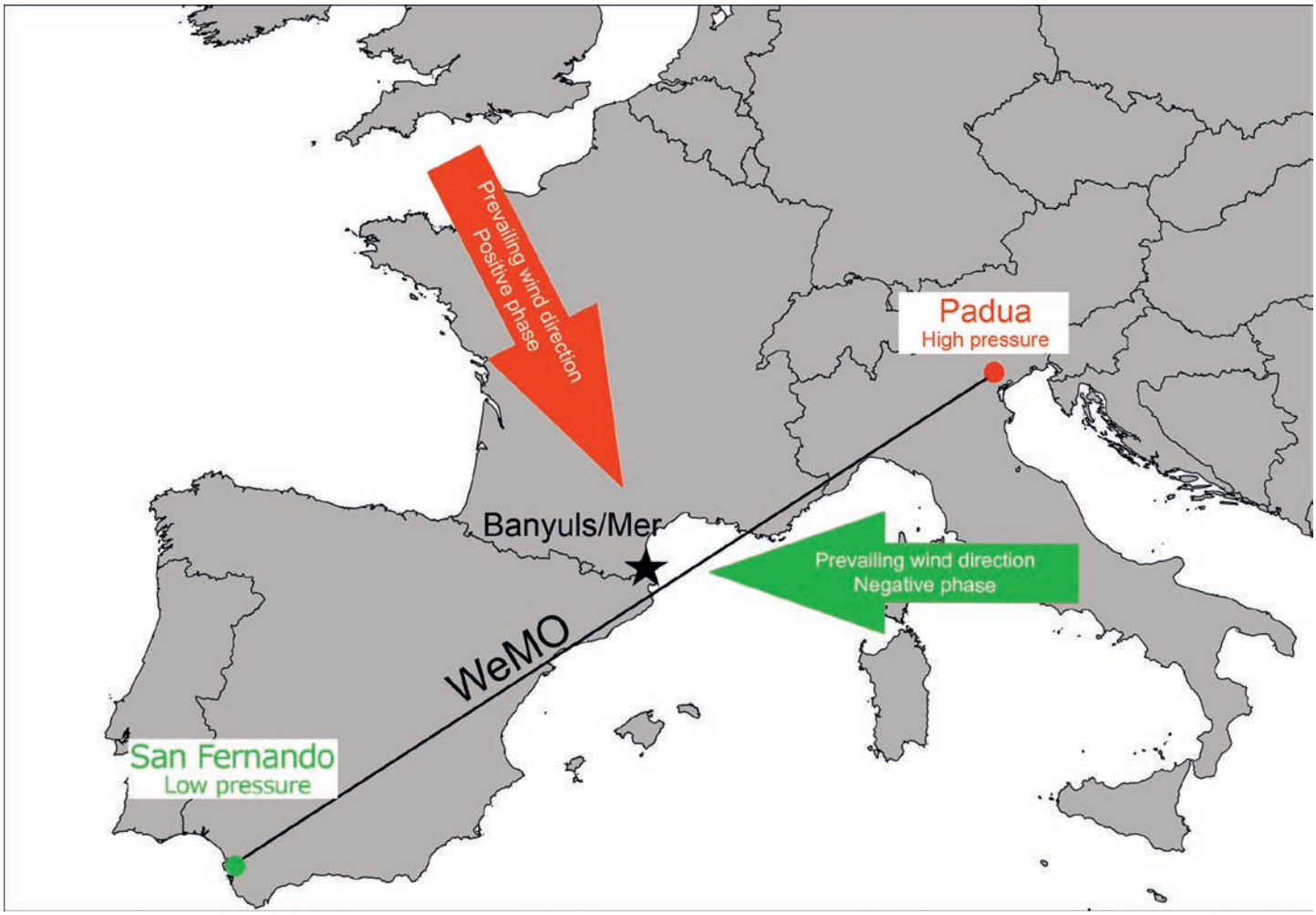
▲ **In situ *mesocosms (volume >1 m³) of the MEDIMEER marine ecology research platform. Each mesocosm is equipped with* in situ *sensors for measuring physicochemical and biological variables of isolated water masses.*** © *Sébastien Mas*

Long-term variations in benthic macrofauna communities in relation to climate change indicators

Benthic macrofauna (fauna over 1 mm closely associated with sediment)—due to its reduced mobility and sensitive life stage—is a good indicator of the impacts of both natural and human-induced environmental changes. The Benthic Ecogeochemistry Laboratory (LECOB) focuses on temporal variations in benthic macrofauna communities in the Bay of Banyuls-sur-Mer by sampling annually four stations since 2004. Relationships between community structure and environmental variables, such as air temperature, atmospheric pressure, wind speed and direction, Rhône river flow, North Atlantic Oscillation (NAO) and Western Mediterranean Oscillation (WeMO) climate indices, have been tested.

The WeMO index measures the difference in atmospheric pressure between San Fernando (Spain) and Padua (Italy), thus serving as a regional proxy that is closely focused on the Gulf of Lion. Northwesterly winds (*Tramontane*) occur when this index is positive whereas marine winds blow when it is negative. The main results of this study (in press) confirmed that benthic communities in the Bay of Banyuls-sur-Mer are undergoing significant temporal changes, while showing that: (i) their dynamics are better correlated with the WeMO index than with the NAO index, and (ii) the Rhône river flow also impacts the structure of these communities. Moreover, the abundance of some species was found to be quite closely correlated with the WeMO index. These results highlight **the relevance of taking natural variations in benthic communities into account when assessing the ecological quality of the environment so as to be able to clearly dissociate the natural and anthropogenic causes of structural changes in these communities.**

Contacts (LECOB):
C. Labrune, labrune@obs-banyuls.fr
and P. Bonifácio, bonif@me.com



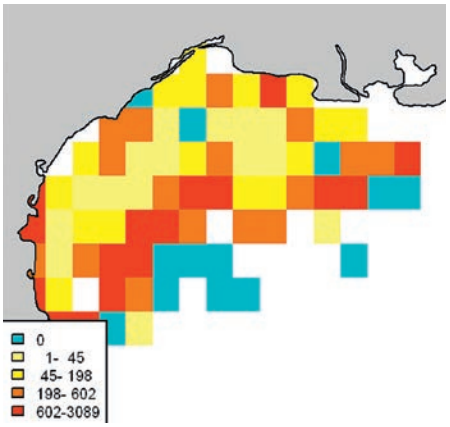
▲ *Prevailing wind direction relative to the WeMO (Western Mediterranean Oscillation) climate index regimes.* © *Paulo Bonifácio. Modified map from: www.ub.edu/gc/2016/06/08/wemo*

Monitoring fish and marine mammal populations in the Gulf of Lion

The main marine fisheries resources harvested in the Gulf of Lion are regularly monitored by scientists (see p. 51). The French Mediterranean MEDITS (*Campagne internationale de chalutage démersal en Méditerranée*) bottom trawl survey assesses demersal fish and invertebrate stocks (hake, anglerfish, red mullet, octopus, *Nephrops*, etc.). This survey, which was initiated in 1994, takes place every year in Corsica and throughout the Gulf of Lion. Collected species are sorted, weighed and counted. Measurements are obtained for 84 species, while key biological parameters (sex, maturity, condition) are recorded for 41 of them. **Information on jellyfish, macro-waste, contaminants and hydrological characteristics of water bodies has also been collected since 2015 in order to get an overall picture of the ecosystem in which these organisms live.**

Small pelagic fish (especially sardines and anchovies) are key species in the ecosystem as well as species of high interest for commercial fisheries. It is therefore necessary to have thorough knowledge of the biology of the target species, as well as independent fisheries data on stock biomass and health, to be able to assess the stocks and propose tailored management methods. Therefore, the *Pélagiques Méditerranée* (PELMED) survey has been conducted every year in the Gulf of Lion since 1993. It consists in a combination of acoustic monitoring along nine transects, perpendicular to the coastline, and trawls to identify species and collect information on other pelagic ecosystem components, ranging from plankton to top predators. Meanwhile, about 10 surveys have been conducted yearly since 2000 (August to October) to estimate the number and size of bluefin tuna schools in the Gulf of Lion and a little further offshore. **A young Mediterranean bluefin tuna abundance index is drawn up based on these data and used to assess overall bluefin tuna stocks.** This survey also involves flights to record observations of marine mammals, such as fin whales, dolphins, sperm whales and some pilot whales.

Contacts (MARBEC):
A. Jadaud, angelique.jadaud@ifremer.fr,
C. Saraux, claire.saraux@ifremer.fr
and T. Rouyer, tristan.rouyer@ifremer.fr



▲ *Maps of* Mullus barbatus *(Linnaeus, 1758) distribution patterns in the Gulf of Lion (MEDITS Campaigns, 1994-2017). A systematic grid was drawn up for each area and then the average density per km² in each cell was calculated based on observation data covering the entire period. For the mapping, cells with average densities corresponding to density quartiles are shown in the same colour:*
Blue: species never observed
Pale yellow: average density [0-25%[
Dark yellow: [25-50%[
Orange: [50-75%[
Red: [75-100%]
Source: www.ifremer.fr/SIH-indices-campagnes

RESPIRE network – monitoring the spatiotemporal dynamics of larval fish colonisation in the French Mediterranean coastal area

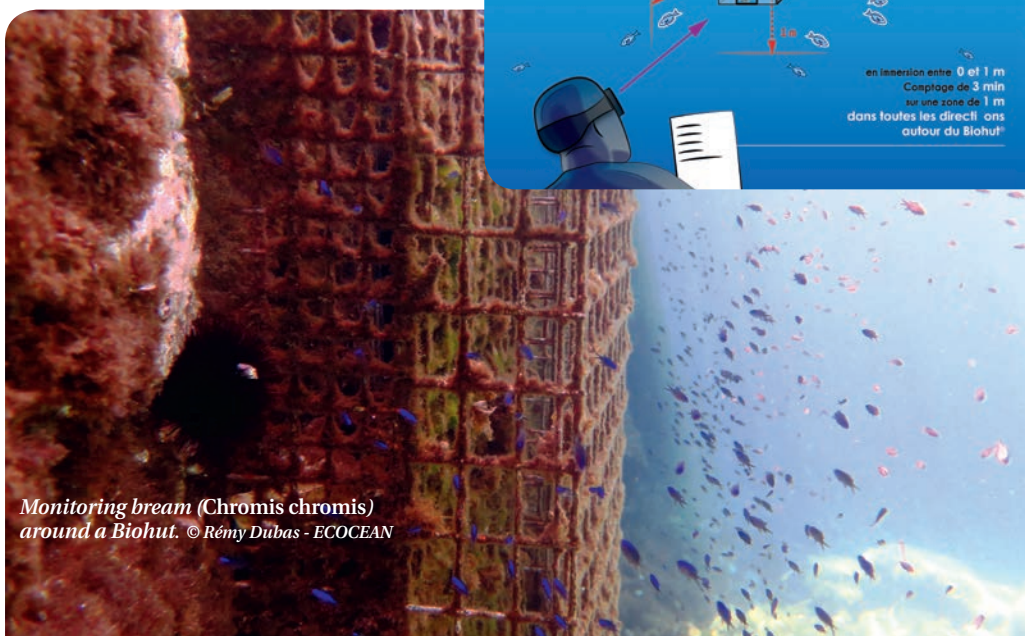
Since March 2015, the *Réseau portuaire de suivi du recrutement* (RESPIRE) monitoring network, financed and implemented by the Rhone Mediterranean and Corsican Water Agency, ECOCEAN and UPVD (CREM/CEFREM)*, has been monitoring spatiotemporal larval fish colonisation patterns in the French Mediterranean coastal area. The counts are carried out three times a year in standard monitoring units (Biohuts, see p. 69) located in 21 yacht harbours. A qualitative and quantitative representation of biological elements enables between-site and/or -year comparisons. A universally accessible reference database (MEDTRIX*) provides knowledge on this crucial stage in the life cycle of young fish with the aim of assessing the ultimate value of restoring the 'nursery' function. **This research highlighted heterogeneity in larval recruitment in the French Mediterranean coastal area, and especially a time lag between the two main French Occitanie and PACA regions. High interannual variability in recruitment was also revealed, in addition to the presence of remarkable biodiversity within the harbours, sometimes with rare and emblematic species such as the brown grouper observed.** The RESPIRE programme aims to gain further insight into these phenomena and this variability.

Contacts: A. Gudefin (ECOCEAN), anais.gudefin@ecocean.fr, A. Fontcuberta (ECOCEAN), amelie.fontcuberta@ecocean.fr, G. Lecaillon (ECOCEAN), gilles.lecaillon@ecocean.fr and P. Lenfant (CEFREM), lenfant@univ-perp.fr

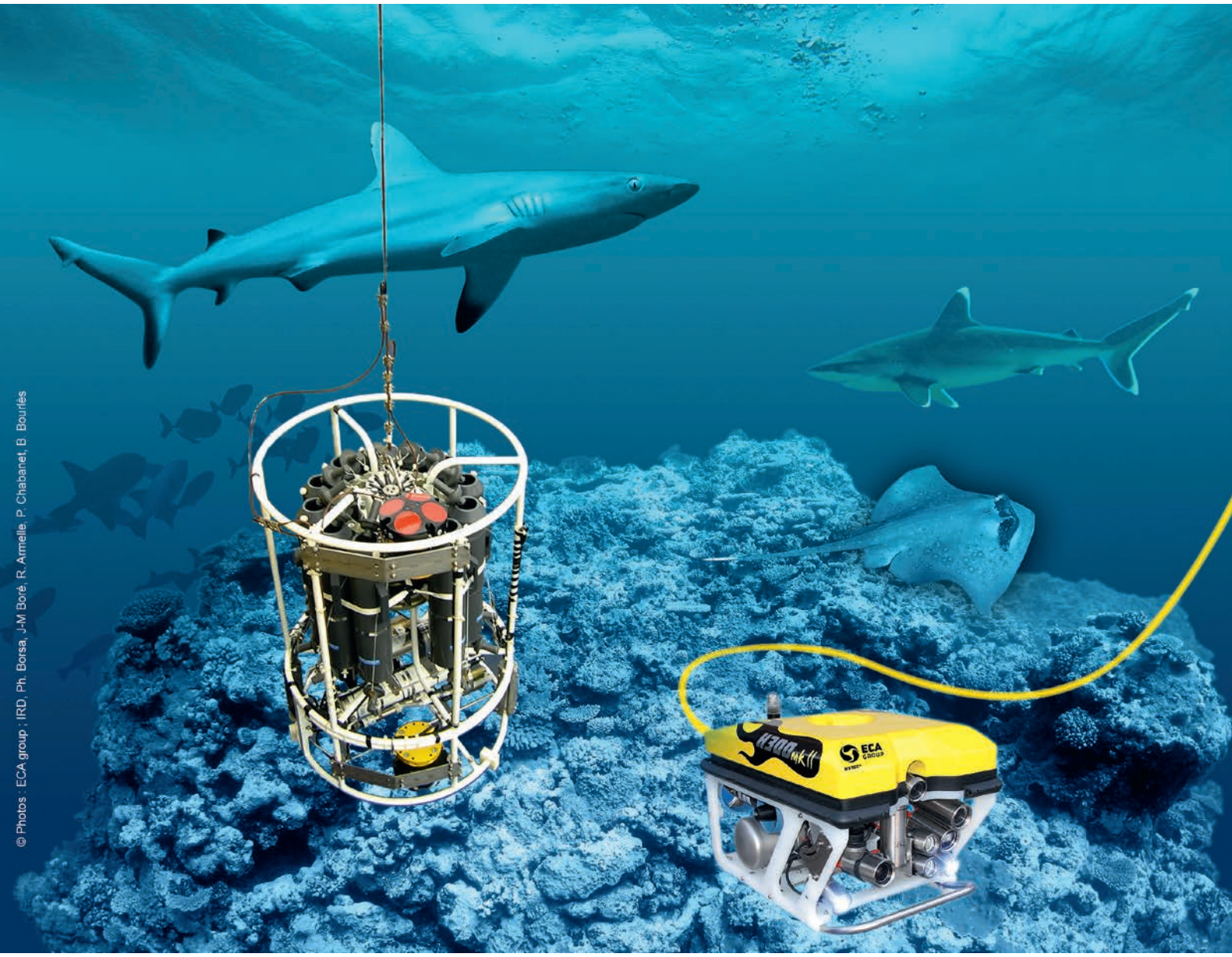
For further information:
www.ecocean.fr/?lang=en
www.medtrix.fr

* Within the framework of the European Marine Strategy Framework Directive which sets out the objectives according to which Member States must act to achieve or maintain a Good Environmental Status in European seas by 2020.

Standard Biohut monitoring method
© ECOCEAN



*Monitoring bream (*Chromis chromis*) around a Biohut. © Rémy Dubas - ECOCEAN*



▲ *Deep marine megafauna detection via environmental DNA.*
© Pierre Lopez

Isolated islands and seamounts – the last refugia for marine megafauna

The oceanographic expeditions (2018-2021) organized by Monaco Explorations aim to study marine megafauna (mainly large bony fish, sharks and mammals) that live near reefs and seamounts in the tropics. Megafauna includes marine species that are highly susceptible to fishing and global warming, and a quarter of these species are endangered. This situation warrants unprecedented conservation efforts which, to be effective, requires more comprehensive knowledge of the geographical distribution of these species. Current data are, however, based mainly on fisheries records and sporadic observations. **Environmental DNA (eDNA)—which is derived from marine organism genetic material filtered from seawater samples—can highlight the species present in a given environment. Monaco Explorations thus offer the unique opportunity to study eDNA in quasi real-time for biodiversity inventories in many areas across the oceans.***

In addition to these technical feats, the expeditions will access isolated sites and deep waters whose megafauna composition is largely unknown. We will also test the hypothesis that the deep ocean (less than 1,000 m depth) represents an unexpected yet poorly protected megafauna refuge. **Deep water samples will thus be filtered to determine the diversity of this megafauna. If the deep ocean stratum turns out to be a biodiversity hotspot, its protection—which is often sidelined in ocean management policies—could then become a priority.**

*MARBEC/EPHE/CEFE/SpyGen/Swiss Federal Institute of Technology in Zurich collaboration.

Contact (MARBEC): D. Mouillot, david.mouillot@umontpellier.fr

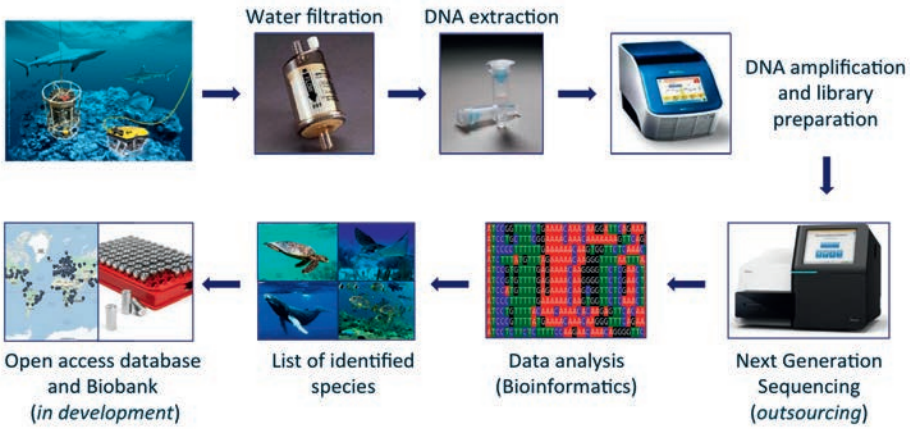
For further information:
http://monacoexplorations.org
https://monacoexplorations.org/david-mouillot-of-cnrs-introduces-his-collaboration-with-monaco-explorations/
https://lejournal.cnrs.fr/articles/un-tour-du-monde-pour-la-megafaune-marine

Marine ecosystem health status indicators based on environmental DNA

Marine protected areas (MPAs) are key conservation and management tools for protecting marine resources. However, knowledge on the health status of marine ecosystems is currently lacking over a human impact gradient ranging from MPAs to the most heavily exploited marine ecosystems. Many species are actually hidden around rocks or under sand (small fish and invertebrates) or are elusive (most mobile predators) and therefore hard to identify by conventional fisheries harvesting or visual census methods. By filtering seawater, the collection of environmental DNA (eDNA)—i.e. DNA fragments released by organisms into their environment via mucus secretion or faeces—may reveal the presence of species in a standard, non-intrusive and non-destructive manner. Based on this method, and in collaboration with CEFE, SpyGen and Andromeda, MARBEC is currently developing **indicators of the health status of marine ecosystems based on the presence of vertebrates and invertebrates harvested by fisheries so as to ultimately infer the levels and types of pressure impacting Mediterranean coastal ecosystems**. For example, recreational fishing does not target the same species as artisanal fishing, so the presence or absence of these species revealed by eDNA will indicate the level of pressure of specific types of fishing on the sampled area. Reference levels for these indicators will then be drawn up for several Mediterranean MPAs.

Contacts: D. Mouillot (MARBEC), david.mouillot@umontpellier.fr and S. Manel (CEFE), stephanie.manel@cefe.cnrs.fr

For further information:
https://reefish.umontpellier.fr
www.spygen.com



▲ *Filtration and environmental DNA analysis procedure developed in collaboration with the French biotechnology company SpyGen.* © *SpyGen*

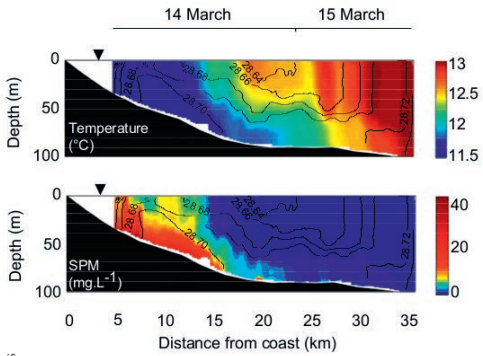
Use of underwater gliders for monitoring coastal dynamics

The coastal area serves as a receptacle for fluvial materials (sediment, organic matter and contaminants), some of which are stored while the rest are released into the deep waters. Water and material fluxes in the land-sea continuum in the Mediterranean Sea, and specifically in the Gulf of Lion, occur mainly during brief intense hydrometeorological events such as floods and storms. It is nevertheless essential to study coastal dynamics on different spatiotemporal scales, which is not possible by the monitoring strategies conventionally used to measure these fluxes. Indeed, instrumented moorings and buoys provide essential measurements of coastal-offshore transfer processes that are not representative on the continental shelf scale. Optical colour satellites only account for the sea surface when there is no cloud cover and at broad spatiotemporal scales. Research-vessel surveys may involve many types of measuring instrument but they are limited by weather conditions. In view of these constraints, autonomous underwater vehicles —or so-called gliders—effectively complement these more conventional monitoring systems. Underwater gliders are already widely used in the offshore sector and have proven effective in monitoring fluxes at coastal interfaces (ANR MATUGLI* programmes recently conducted by CEFREM). These instruments have an autonomy of several months and can be equipped with hydrological, biogeochemical and hydrodynamics sensors, while they are also capable of taking measurements even when sea conditions are impracticable for research vessels.

CEFREM is an international pioneer in the use of underwater gliders on continental shelves to monitor the impact of intense hydrometeorological phenomena on the coastal-offshore transfer of suspended matter. Recent advances have now made it possible to integrate optical and acoustic sensors to enhance characterisation of these suspended particles, with the aim of assessing their fall rate—a key parameter for modelling global sediment flows.

Contact (CEFREM):
F. Bourrin, fbourrin@univ-perp.fr

* ANR ASTRID research programme (DGA/*Direction générale de l'Armement* funding): Autonomous measurements of coastal turbidity recorded by underwater gliders.



▲ *Example of data collected by an underwater glider (temperature and suspended particle concentration) during an eastern storm.*
From Bourrin et al., *2015.* Continental Shelf Research. *109: 135–149. https://doi.org/10.1016/j.csr.2015.08.031*

▼ *Satellite image showing the true water colour with the position of the glider trajectory extending offshore from a coastal buoy.*
© *J. Fabryka/UPVD/MATUGLI, 2017*

POPSTAR – a new generation fish-tagging system for monitoring marine species

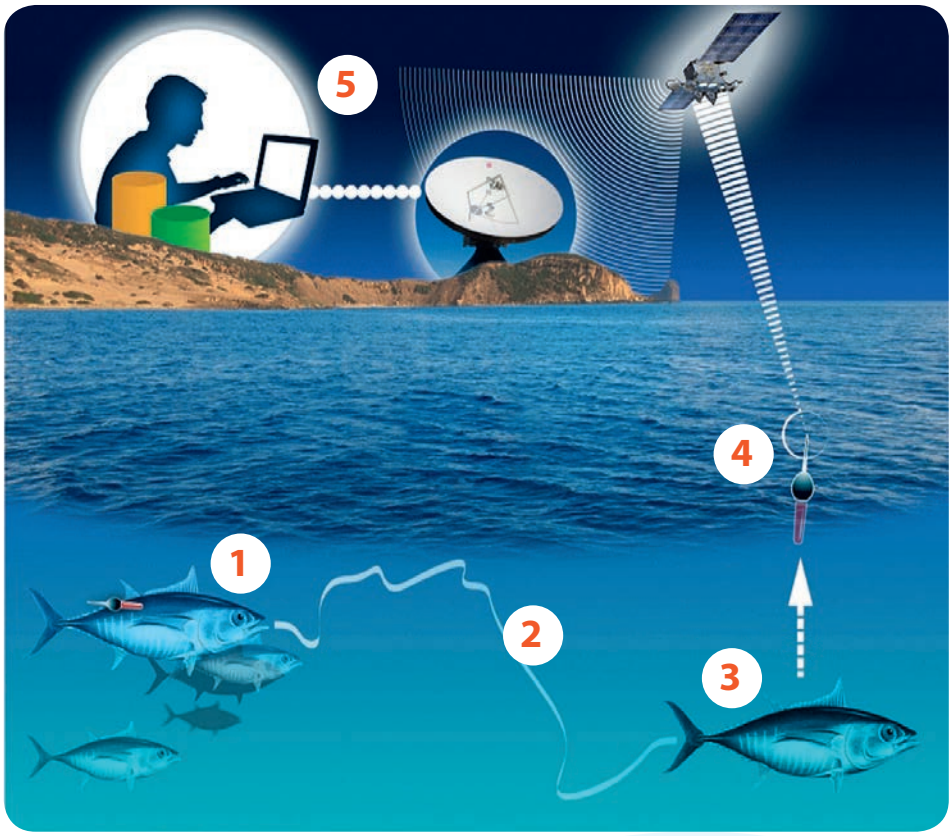
How can the physiological state of large pelagic fish be studied and monitored during their migratory movements? Individual *in situ* physiological measurement data are needed to answer this question. **This calls for the development of a system for measuring physiological parameters that is embedded in the fish and able to log data in the natural environment without any external intervention on the device throughout the tagging time** (typically 1 year). This information is transmitted to a satellite, hence its name 'pop-up satellite archival tags'. The POPSTAR* project aims to develop a more functional and cost-effective tag than other such sensors on the market, with *in situ* logging of data on the physiological state of the fish being the most novel innovation. **For the first time, it will be possible to assess the physiological state of the fish in its natural environment, e.g. by measuring spatiotemporal variations in its fat content!**

The tag must be small enough to avoid hampering the fish's movements. The measuring system has to be particularly energy-efficient since the tag size is directly related to the weight of the built-in battery. Measurements should encompass as many of the biological processes of interest as possible for monitoring the species. Finally, the system must be able to offset internal (e.g. modification of the live fish/electrode interface) and external (e.g. pressure) environmental disturbances, although not all potential disturbances can be identified at this stage. A tiny microchip (a few mm^2) will serve as the measurement system. Alongside the development of this nanoelectronic tag, we have conducted several measurement surveys (more than 2,000 measurements) with a portable prototype. In Occitanie region, these measurements have been carried out in collaboration with professional fishers, fish merchants and IFREMER aquaculture platforms. Preliminary results have demonstrated the effectiveness of the measurement system and the suitability of the tag architecture.

* POPSTAR is a MERLIN project (motto 'Launching new initiatives for our oceans': https://wwz.ifremer.fr/en/Research-Technology/MERLIN-projects-Launching-new-initiatives-for-our-oceans) that was launched by IFREMER in 2016, with the aim of advancing scientific innovation in some promising fields (minimum 3 years funding).

Contacts: S. Bernard (LIRMM), serge.bernard@lirmm.fr, V. Kerzérho (LIRMM), vincent.kerzerho@lirmm.fr, T. Rouyer (MARBEC), tristan.rouyer@ifremer.fr and S. Bonhommeau (IFREMER), sylvain.bonhommeau@ifremer.fr

▶ *Legend:*
1 – Tuna released after tagging
2 – Recording environmental, physiological and geolocation data over 1 year
3 – Tag detaches and floats to the surface
4 – Satellite transmission of logged data
5 – Analysis of logged data



eDNA, underwater gliders, satellite tags – novel *in situ* data sensors for marine biodiversity, resource and environmental monitoring.

Role of Earth observation satellite telemetry

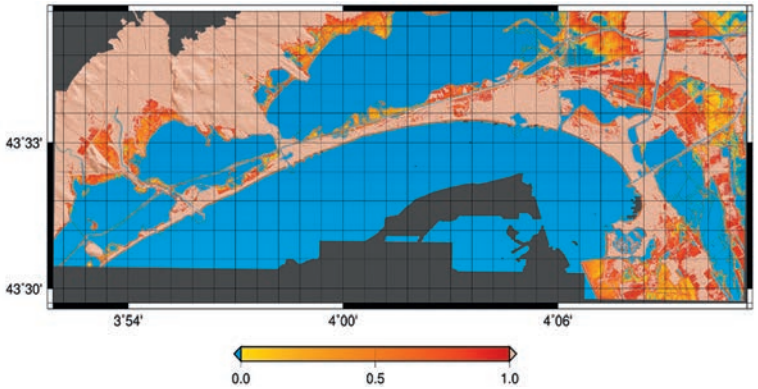
Measuring and understanding climate change impacts on global to local scales

Researchers in Toulouse —based on 25 years of satellite altimetry observations—have highlighted and explained the global sea level rise (~3 mm/year). This climate variable is essential for assessing the impacts of global warming. The reliability of these findings is due to the enormous investment of CNES and researchers to achieve high satellite data quality. These ongoing initiatives have earned our scientists **worldwide recognition for their research, while they are also often called upon for expertise contributions in periodic reports of the Intergovernmental Panel on Climate Change (IPCC).**

The inevitable rise in sea level is accelerating. The combined impact of this factor and other phenomena such as swell, wind, storms and rain makes coastal areas vulnerable, with an ever increasing risk of flooding and shoreline erosion in the short, medium and long term. For preventive reasons, synthetic spatiotemporal monitoring of ongoing phenomena is thus required in exposed regions. **A coastal vulnerability index can be generated by a procedure developed by LEGOS based on a large dataset from several types of satellite (altimetry, *Pléiades* 3D optical imaging and geodesics). This method, which has been applied and validated in the Palavas-les-Flots region (see opposite), can be applied to the entire national or even global coastal zone, depending on the extent of available data.** Global spatialisation of this type of operation is in line with the outlook of the Space Climate Observatory* which—at the initiative and under the responsibility of CNES—is now offering **access to primary datasets on certain pilot areas to demonstrate the potential of satellites to assess the impact of climate change on our societies and habitats**. This exemplary effort will undoubtedly also ultimately benefit from inductive deep learning methods, which are ideal for harnessing the statistical wealth of time-series satellite observation data, including those derived from Sentinel satellites of the Copernicus programme.

Contact (CNES): P. Maisongrande, philippe.maisongrande@cnes.fr

*** For further information:**
http://SpaceClimateObservatory.org

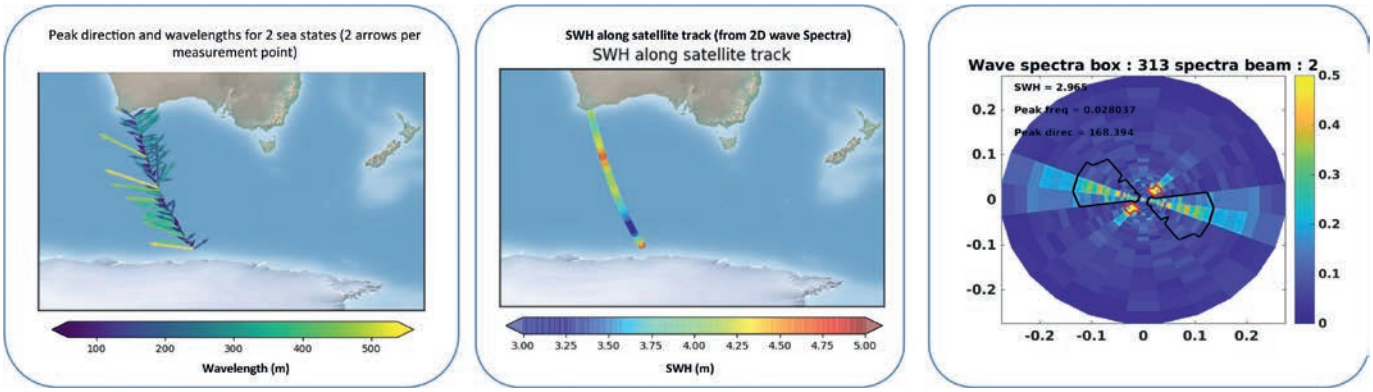


▲ *Simulation of flooding induced by a 1 m sea level rise at Palavas-les-Flots (France). Source: LEGOS/CLS, 2017. Internal study. (Internal ref. CLS: Projections climatiques et vulnérabilité du littoral français, CLS-DOS-16-76).*

Sea-state monitoring via satellite radar sensors

Radar sensors (SAR imagers, scatterometers, altimeters, etc.) are powerful tools for obtaining sea surface information since they are not hindered by cloud cover conditions. Nadir altimeters provide very accurate measurements (cm) of the distance between the host satellite orbit and the sea surface. Powerful models derive different oceanographic parameters from these 'distance' data, such as large-scale currents, tides, bathymetry, with good global coverage through a substantial constellation of missions that are already operational or in preparation (JASON*-2, JASON-3, SARAL*, Sentinel-3*). The significant wave height can also be deduced to generate a preliminary sea state assessment without separating the different wave regimes since only one value is available for each distance measurement.

Synthetic aperture radar imaging systems (e.g. SAR/ENVISAT, Sentinel-1) feature a specific mode that can generate spectral sea state information in the form of ocean surface image mosaics. Wave directions, frequencies and heights can be derived for dominant regimes from these spectral data. Several wave regimes may then be differentiated and mapped for an identified target area, especially when two systems intersect (cross seas and swells). These



▲ *Preliminary level 2 results acquired by the SWIM real-aperture radar instrument on 3/11/2018. As the instrument is not yet calibrated, the measurements cannot yet be used for scientific purposes, but the outputs have already highlighted the instrument's nominal functioning. Processing at levels 1 and 2 is jointly defined by CNES the LATMOS laboratory (CNRS – OVSQ).* © CNES

data are operationally mainstreamed in specific meteorological models (e.g. MF-WAM of *Météo France*). SAR data nevertheless have some limitations with regard to the wave lengths and directions that can be characterized. These sea state measurements must all be complemented by ocean surface wind measurements.

The Radar Algorithms, Processes and Products service of CNES—a world leader in space oceanography for several decades—contributes markedly to developing new concepts for future satellite missions and sensors. For instance, the CFOSAT* mission (launched October 2018) is equipped with a SWIM sensor (a next-generation omnidirectional radar scatterometer) that will complement the wave measurements despite the constraints mentioned above. In addition—a first in space oceanography—CFOSAT will be fitted with both wind and wave scatterometers, which will operate synchronously to facilitate modelling of the ocean surface and help gain further insight into the mechanisms involved. Finally, in the near future, the SKIM* and SEASTAR* missions —both of which are based on radar concepts— will attempt to measure surface currents on a small scale (<1 km).

Contact (CNES): C. Tison, celine.tison@cnes.fr

For further information:
www.aviso.altimetry.fr/en/home.html

* CFOSAT: China France Oceanography SATellite
Sentinel: European Copernicus mission
JASON: French-American altimetry mission
SARAL: French-Indian altimetry mission
SKIM and SEASTAR: European Earth Explorer 9 and 10 missions in preparation

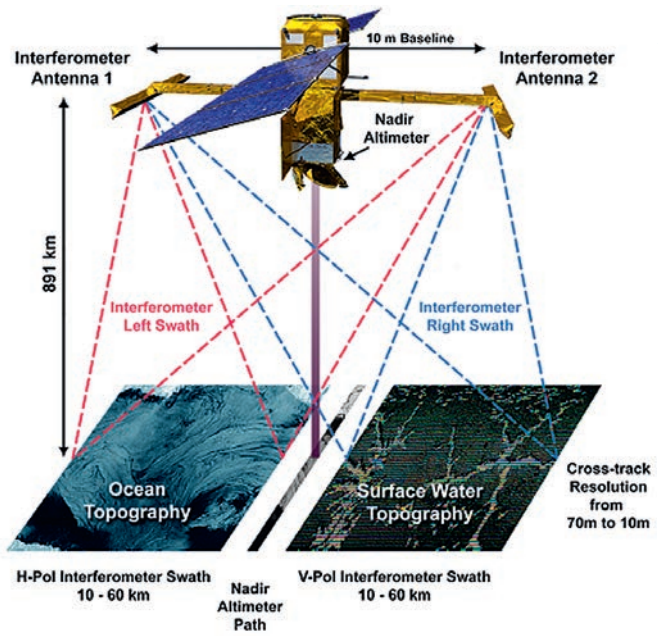
Unprecedented technological innovations to monitor the ocean from space

Thales Alenia Space (TAS) designs and manufactures active and passive instruments for scientific and operational oceanography from its Toulouse and Cannes sites. The Sentinel-3 satellite, developed by TAS on behalf of the European Space Agency, is devoted entirely to ocean observation. Sentinel 3—a real technological masterpiece with a powerhouse of different on-board sensors—enables water colour observation (OLCI* sensors), water surface temperature (SLSTR* sensor) and height measurement (SRAL* radar altimeter), as well as calculation of marine currents, tides, etc. Data from these sensors fuel oceanographic forecasting models, with many operational applications such as marine current forecasting for fisheries and navigation, as well as supporting offshore platform operations, etc.

The SWOT* satellite, currently being built by TAS on behalf of CNES, will produce (and this is a first!) 3D mapping of oceans, lakes and rivers with unprecedented accuracy. It will complement and enhance the family of Jason altimetry satellites previously developed by TAS (bilateral CNES/NASA collaboration). As the space industry is not immune to the digital revolution, future radar altimeters designed and developed in Toulouse by TAS—world leader in radar altimeter development—will incorporate the latest digital technologies to generate more accurate measurements to meet the changing needs in the fields of research, operational oceanography, climate monitoring and freshwater resource management.

Contacts (TAS): L. Phalippou, laurent.phalippou@thalesaleniaspace.com
and S. Mathieu, sandrine.mathieu@thalesaleniaspace.com

* OLCI: Ocean Land Colour Instrument
SRAL: SAR Radar Altimeter
SAR: Synthetic Aperture Processing
SLSTR: Sea and Land Surface Temperature Radiometer
SWOT: Surface Water and Ocean Topography



▲ *SWOT: a French-American mission to study ocean and terrestrial surface water bodies. This broad-swath satellite will be able to observe all of the Earth's lakes, rivers, reservoirs and oceans at least twice every 21 days.* © CNES/Ducros David, 2015

◀ *Dual-swath Ka-band radar interferometer system.* © CNES

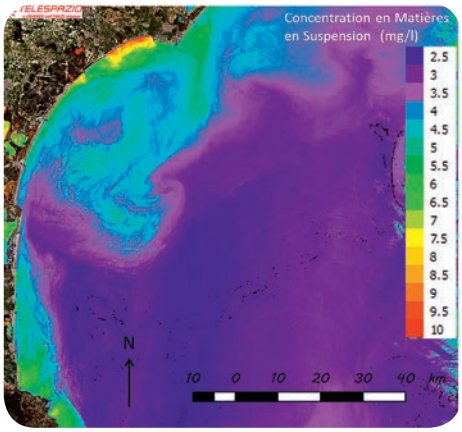
Contribution of spatial imagery to coastal monitoring

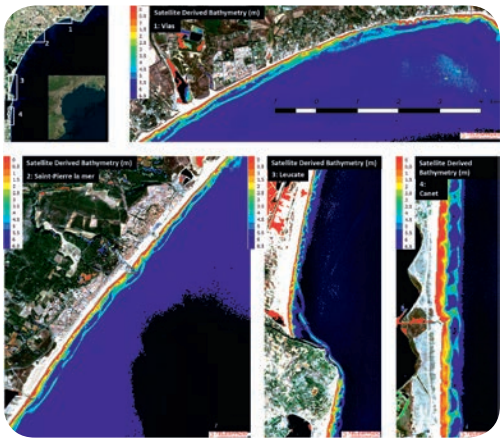
Spatial imagery is used to monitor a range of environmental parameters that are essential for integrated management of coastal areas. It directly and independently delivers different physical variables: water depth (via multispectral optical imaging), ground motion (via interferometric measurements in radar image series), coastline (via radar or optical imaging), suspended solids, water quality (hyperspectral measurements), etc. These variables fuel digital models and ultimately provide users with operational very high spatiotemporal resolution environmental monitoring. Big data techniques have also recently made it possible to process huge datasets while introducing the change detection concept, thereby alerting the expert or manager on a specific event or on the need for a data update. Through artificial intelligence, the alert can also be targeted to suit the user's specific needs.

Through its EarthLab initiative, Telespazio France (a Thales-Leonardo subsidiary) has developed unmatched expertise in France in spatial data processing for coastal applications and now has an arsenal of leading benchmark products (Copernicus, Suez, Mercator Ocean, etc.). Telespazio France —located at three sites (Toulouse, Bordeaux and Montpellier)—is committed to partnership-based innovation, particularly with several public research teams based in Occitanie region (IRT Antoine de Saint-Exupéry, TETIS, LIRMM). The company is collaborating with its partners in the implementation of big data platforms for the analysis of the huge spatial data flows that will be generated by the new Earth observation satellite constellations.

Contact (Telespazio France): F. Marques, francois.marques@telespazio.com

For further information:
www.earthlab-galaxy.com/en/





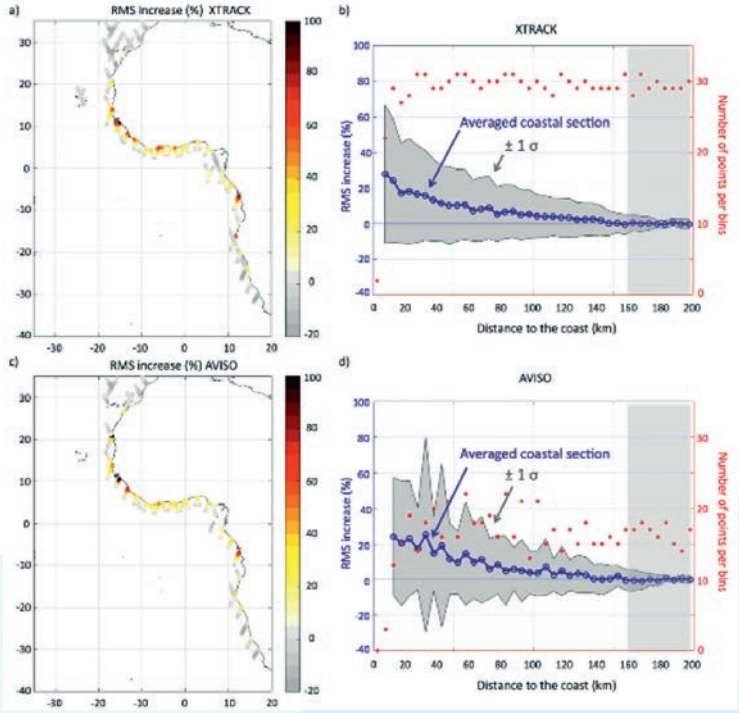
◀ *Left: Suspended solids concentration from Sentinel-2 images, eastern Gulf of Lion zone.*
© Sylvain Capo/Telespazio France

◀ *Right: Water depths determined from Sentinel-2 images, eastern Gulf of Lion zone.*
© Sylvain Capo/Telespazio France

Satellite altimetry – a novel tool for monitoring ocean coastal areas

Satellite altimetry—a technique used to measure sea level variations—is a major unparalleled tool for studying and monitoring the ocean. It has provided estimates on many parameters regularly and continuously for over 25 years (sea level, currents, waves, wind, tide, etc.) with many scientific and operational applications. Yet satellite altimetry is still not widely used in coastal oceanography and missions using this technology missions were initially designed to monitor offshore areas. The measurement resolution is too limited (surface height estimated at a 6-7 km interval along the satellite track, with a 10-day revisit at best) to be able to observe the rapid dynamic processes that occur in ocean nearshore zones. Radar altimetry echoes are biased near land and therefore harder to analyse. Standard altimetry processing and products are thus not tailored for coastal oceanography needs.

With a view to monitoring the sea level in coastal areas in the current climate change setting, research laboratories have been working for over a decade to develop algorithms to streamline the processing of altimetry measurements in coastal areas, and then to reprocess all archival observations. More efficient novel altimeters are also being developed* that generate greater volumes of higher resolution data. CNES and LEGOS



▲ *Study of changes in the amplitude of temporal sea level variations: regional distribution on the left and mean distribution according to the distance to the coast on the right. When tracking African coastal zones using a recent operational altimeter product (AVISO, bottom) and with a research altimeter product developed at LEGOS (X-TRACK, top), very significant variations are noted between points along the coast. With enhanced processing, the number of observations (red dots) is higher and increasingly reliable near-shore information is obtained in areas where* in situ *observations are sparse. The same study is underway on long-term coastal sea level changes.*
From Birol et al., *2017.* Advances in Space Research. *59(4): 936-953. doi:10.1016/j.asr.2016.11.005.*

—forerunners in this field—are developing and distributing new altimetry products** that provide time-series sea level data and tidal component estimates. **Recent studies show that these initiatives now provide access to top quality measurements up to 3 km from the coast, as compared to 50 km 10 years ago. These data are extremely valuable, especially for coastal regions of the world where no *in situ* tide gauge data are available** (see previous page). They are thus used to an increasing extent for applications in ocean coastal areas, either alone or jointly with other types of observations and models of coastal circulation, long-term sea level and tidal trends, changes in coastal marine ecosystems, etc. Feedback from these experiments is crucial to assess future altimetry mission needs.

Contact (LEGOS):
F. Birol, florence.birol@legos.obs-mip.fr

* SARAL/AltiKa in 2013, Sentinel-3A&B in 2016 and 2018, SWOT due in 2021.
** X-TRACK, PEACHI: www.aviso.altimetry.fr/en/data/products

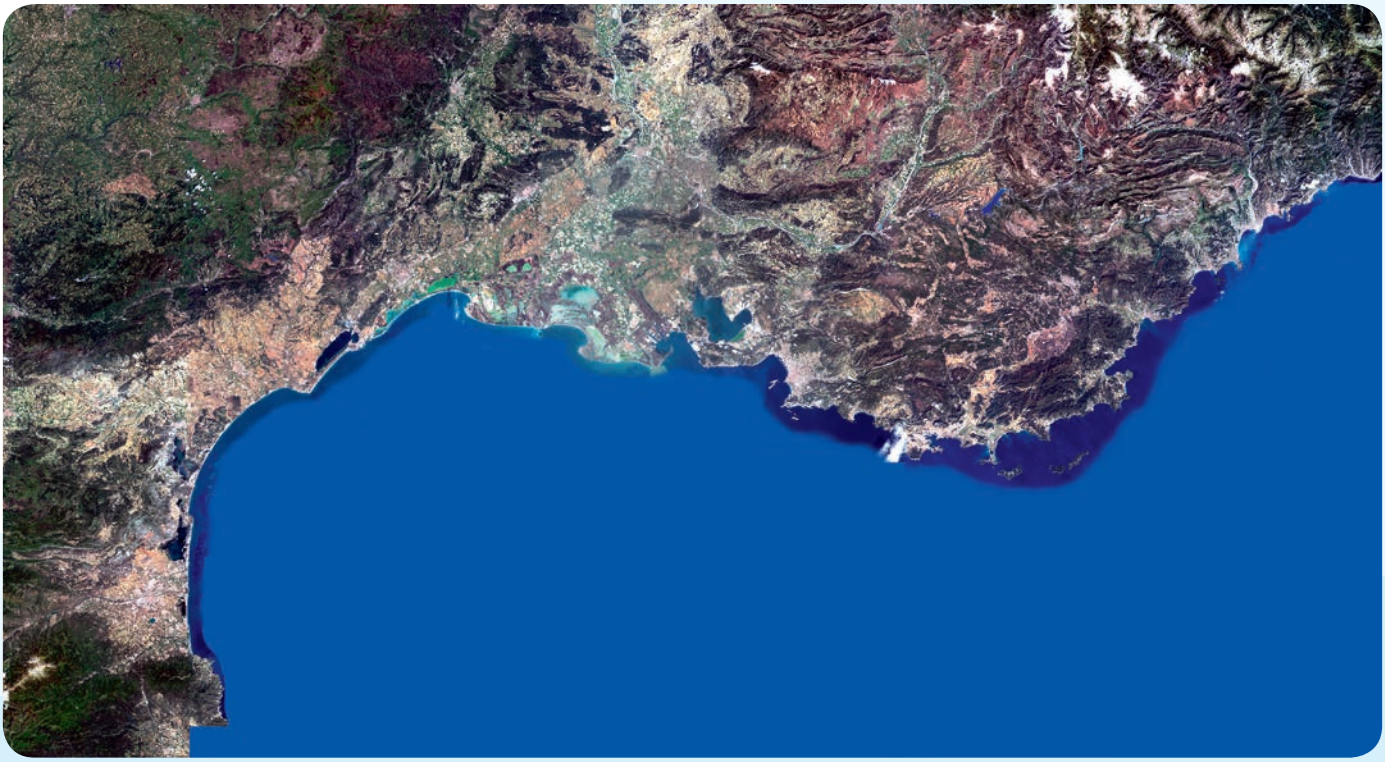
GEOSUD – A MAJOR INSTRUMENT FOR DEMOCRATIZING ACCESS TO SATELLITE IMAGERY

Satellite images provide researchers and public services with valuable data for ocean monitoring and coastal management, as illustrated by the catalogues of the ODATIS and THEIA national data portals, which respectively bring together scientific communities focused on ocean and continental surface observation. For the detailed management of coastal areas, particularly in the Mediterranean Basin, the use of satellite imagery has barely developed despite the fact that these areas have many issues in common. This could be explained by the high cost of very high spatial resolution (<5 m) optical images and the complexity of their processing and implementation. The GEOSUD* project is addressing the challenge of lowering costs and offering services tailored for users. GEOSUD—based on an original and quite unique pooling strategy and equipped with a satellite receiving station since 2014—acquires homogeneous national image coverage yearly (since 2010) as well as images for anywhere in the world upon request. The GEOSUD archive —containing over 13,000 very high resolution images—is available under license to any French public stakeholder (and foreign and private partners). The project will offer online services for digital image processing on high-performance clusters installed at the French National Computing Centre for Higher Education (CINES).

Such images have, for instance, been used by the *Syndicat Mixte du Bassin de Thau*, in collaboration with TETIS research lab, for the development and implementation of SCoT**, SAGE** and Natura 2000 documents on the Mediterranean coastal area: fine mapping and monitoring of land use urban sprawl, natural habitats, ecological continuities and coastline. Research is underway on the spatialisation of several ecosystem services. GEOSUD investments are currently being incorporated into the new Data Terra research infrastructure, which includes four national data centres (including THEIA and ODATIS) and DINAMIS, a unified national satellite imagery access system set up jointly with the French National Space Agency (CNES) and the French National Institute of Geographic and Forest Information (IGN).

Contact (GEOSUD): P. Maurel, pierre.maurel@irstea.fr

* GEOSUD was launched in 2011 through an initiative of partners of the *Maison de la Télédétection* (CIRAD, IRD, IRSTEA, AgroParisTech and, more recently, CNRS) with funding from the State-Region Planning Contract/European Regional Development Fund (CPER/ERDF) and the French Investments for the Future Programme (PIA) in favour of the Equipment of Excellence (EQUIPEX) project.
** SCoT: French Scheme for Coherent Territorial Development – SAGE: French Water Development and Management Scheme.



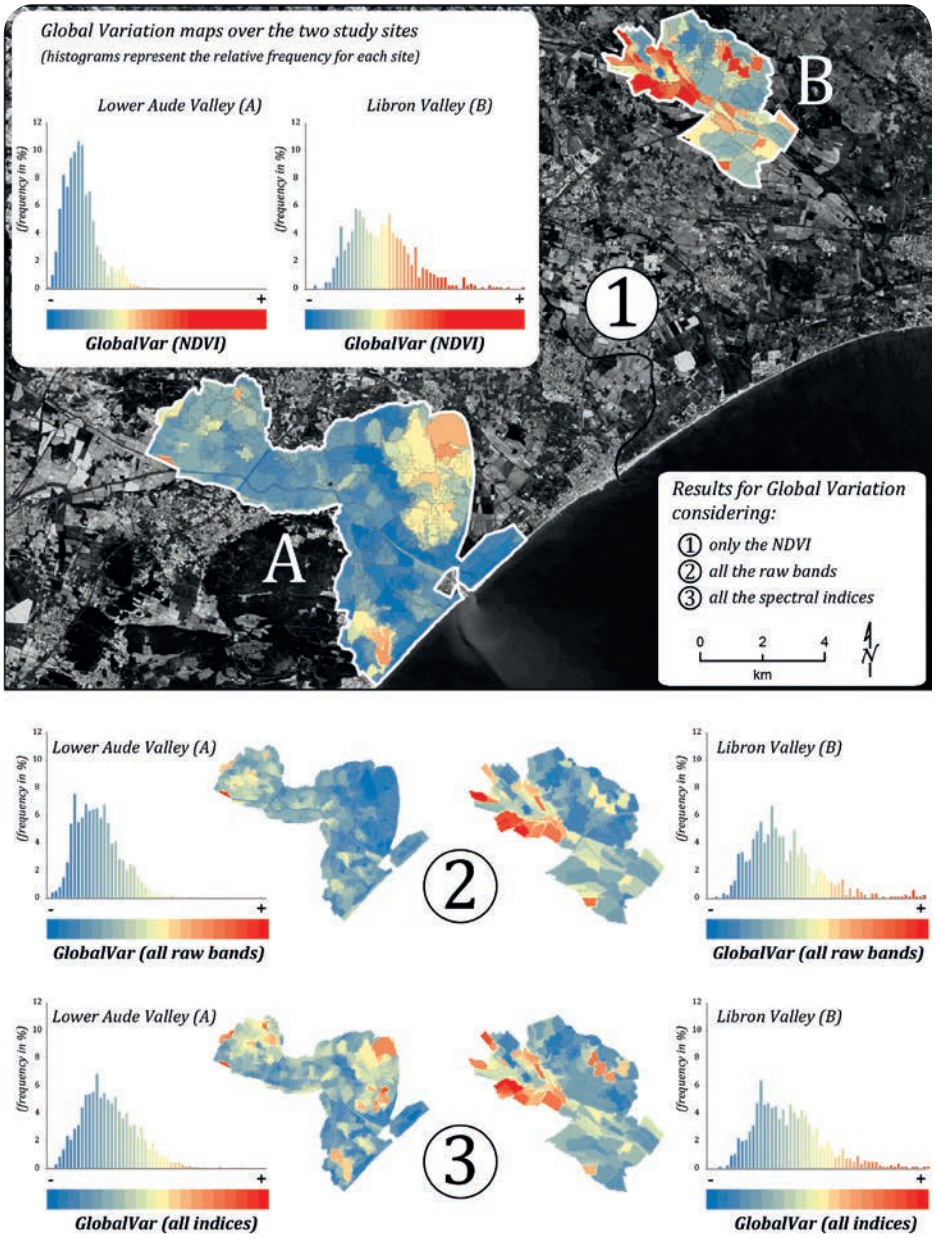
▲ *From a SPOT 6-7 satellite image mosaic of metropolitan France (2016).*

Modelling, simulation and forecasting in the big data age

Contribution of remote sensing and new big data approaches to coastal region monitoring

Mediterranean coastal regions are sensitive ecosystems that are also important from an economic standpoint (tourism, fisheries, aquaculture, leisure). Yet these regions are overexploited and subject to intense environmental and anthropogenic pressures, so their environmental monitoring is crucial. Remote sensing data are essential for monitoring coastal territories, while recurrent satellite observations enable systematic monitoring of changes over time in an area (e.g. coastal changes, growth, land cover change, natural habitat monitoring). When satellite observations can be repeated (the Copernicus programme offers satellite, optical and radar images at a frequency of less than a week), spatiotemporal trends may be detected while deducing their dynamics, while objects of interest may also be detected and categorized. Moreover, remote sensing produces multi-source and -scale information. Different types of sensor are available (optical, radar, multispectral, hyperspectral, LIDAR) and each provides additional information to describe physical phenomena. Acquisitions are also possible at different spatial scales, from very high (0.5 to 1 m) to medium (100 m) spatial resolution.

While remote sensing data represent a wealth of information, recent data science approaches (data mining, machine learning, deep learning) provide techniques and tools to tap these resources and generate value-added products. Data science techniques facilitate automated analysis and classification of large bodies of heterogeneous information. Deep learning techniques, for instance, are tailored for processing and analysing information sourced from images. They offer tools to merge data from different sensors (optical/radar/LIDAR) at various spatiotemporal scales for intelligent subsequent use in decision-making processes. Useful and valuable knowledge may be extracted from remote sensing data using data science techniques. Hence these are key tools for monitoring coastal regions.



▲ *Analysis of scientific time-series satellite image data. The data science method used automatically analyses the target zone and then, based on the spatial and radiometric information input, detects and highlights geographical areas that change more significantly over time.*
From Guttler et al., *2017.* Journal of Photogrammetry and Remote Sensing. *130: 92-107.*

Contact (TETIS): D. Ienco, dino.ienco@irstea.fr

Simulation of extreme processes – spatial quantification of coastal risk during very intense storms

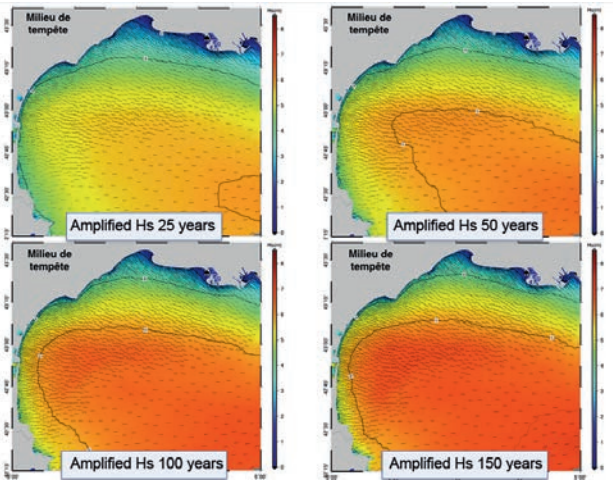
This research addresses an industrial need for physical modelling support, i.e. the linkage of numerical and statistical models. From an industrial perspective, studies are focused on the design and development of a prototype modelling platform with the systematic use of high-performance computing (HPC). With regard to issues related to coastal risk management, the findings highlight and illustrate the contribution of research at the crossroads of these disciplines—geophysics, computer science and mathematics.

The development of tools to model coastal hydromorphodynamics on HPC clusters broadens the scope of academic research to new issues encompassing computer, mathematical, oceanographic and hydraulic aspects. Hydromorphodynamic processes can be accurately modelled and studied via stochastic analysis based on massive computation of spatiotemporal coastal and nearshore parameters. In Mediterranean coastal areas, waves are the main source of the energy that underlies risks and impacts. In order to study the impact of extreme wave-related scenarios —which are rare by nature—it is essential to gain insight into the physical processes involved and to be able to 'replay' them. In this study, a semiparametric method was developed with the aim of producing/simulating extreme spatiotemporal sea state fields*. This method makes it possible to extract extreme events from available data and then to simulate even more extreme events that have not yet occurred. This provides access to an unlimited number of realistic 'disaster scenarios' that can be directly used for risk prediction—**decision makers rely on simulated extreme scenarios to learn how to anticipate them and accelerate their decision-making during crisis situations.**

Contacts: R. Chailan (LIRMM/IMAG/GM/IBM), romain.chailan@gmail.com, F. Bouchette (GM), frederic.bouchette@umontpellier.fr, A. Laurent (LIRMM), anne.laurent@montpellier.fr and G. Toulemonde (IMAG/LEMON-INRIA team), gwladys.toulemonde@umontpellier.fr

For further information:
- GLADYS-littoral: www.gladys-littoral.org
- LEFE/INSU CERISE project (Simulation of scenarios incorporating extreme spatiotemporal fields with possible asymptotic independence for environmental science impact studies): http://cerise.msem.univ-montp2.fr

* Study carried out as part of a Cifre UM/IBM thesis supervised by GM, IMAG and LIRMM. https://tel.archives-ouvertes.fr/tel-01289184 and https://projecteuclid.org/euclid.aoas/1507168834



◀ *Extreme scenarios (corresponding to value ranges expected every 25, 50, 100 or 150 years) of significant wave heights obtained by stochastic simulation.* © *R. Chailan, 2015*

Hyperspectral analysis and LIDAR measurement – pollution detection and precision bathymetry

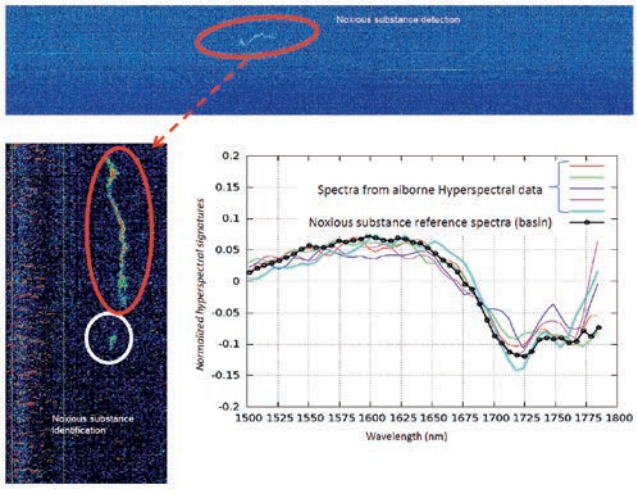
The coastline is a critical area that is highly vulnerable to human activities. ONERA is developing specific optical remote sensing expertise to characterize and monitor changes in human activities. This research is primarily applied in two areas: marine pollution and the development of underwater or airborne techniques to accurately assess bathymetry features in shallow waters and throughout the water column.

ONERA focuses research on detecting chemical pollutants on the water surface. A novel method for identifying and analysing the different types of pollutant has been validated using airborne hyperspectral data (see Fig. 1). **This method could thus be used for the detection of plastic debris in the sea because plastics all have a similar spectral signature (in the 1.0-2.5 µm range).**

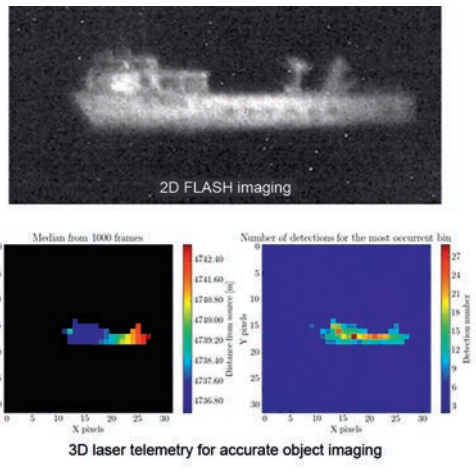
ONERA has developed tools and methods for estimating aerosol and anthropogenic gas emissions at industrial sites that could be applied to effluents discharged by ships. **Technological developments combining laser and camera imaging now also facilitate monitoring of maritime traffic over several dozens of kilometres in very poor visibility conditions (e.g. fog) both during the day and at night** (see Fig. 2).

ONERA has the expertise necessary to characterize shallow and deep waters. Upwelling detection based on surface temperature difference measurement therefore provides useful information for water management. Moreover, ONERA can assess major water column components (phytoplankton, marine sediments and yellow matter) using its submerged or airborne LIDAR equipment resources. Combined hyperspectral imagery and LIDAR telemetry pave the way for accurate mapping of the seabed, even under high turbidity conditions (e.g. application to underwater archaeology).

Contacts (ONERA):
N. Rivière, nicolas.riviere@onera.fr,
P.-Y. Foucher, pierre-yves.foucher@onera.fr
and X. Briottet, xavier.briottet@onera.fr



◀ *Fig. 1 (left). Detection and analysis of chemical pollutants in the sea by airborne hyperspectral remote sensing.* © *ONERA*



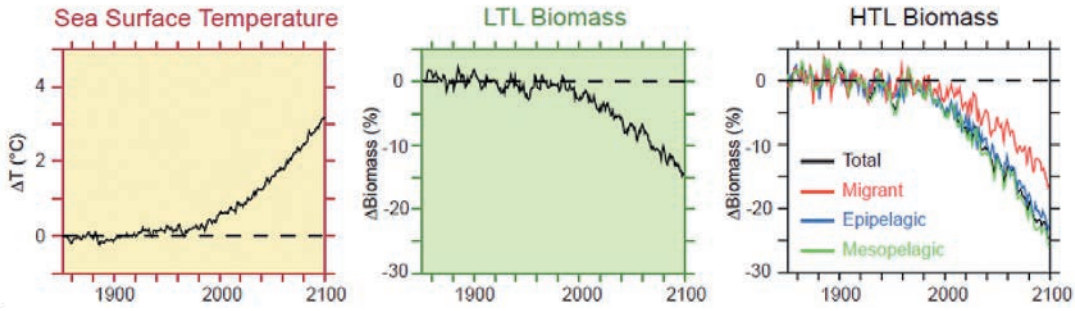
◀ *Fig. 2 (right). Nocturnal detection of a boat at several km range under poor visibility conditions.* © *ONERA*

The ecosystem modelling challenge

Marine ecosystems are rapidly changing due to climate change, fishing and other disruptions (pollution, acidification, eutrophication, habitat destruction). Their evolution is hard to predict due to their high complexity and the non-linear responses to environmental changes and anthropogenic pressures. Mathematical models help gaining insights into ecosystem functioning and anticipating their changes according to climate change scenarios and different human activity governance strategies. These models—which have been developed to represent, study and predict marine ecosystems—have advanced significantly in recent years. Wild populations exploited by fishing were previously represented independently without consideration of the impacts of the environment on their dynamics or of their multiple interactions with other ecosystem components. Ecosystem models now incorporate a growing number of components and processes.

End-to-end ecosystem models specifically account for interactions between physical (temperature, currents), biogeochemical (nutrients, primary production), biological (individuals, populations, communities), ecological (plankton to top predator food webs), fisheries (fishing fleets) and economic (fish markets) systems. Interactions between these many ecosystem components are responsible for nonlinear dynamics that can trigger unexpected changes. It is therefore necessary to represent and link them to the 'Earth system' elements—such as the climate or the global economy—that constrain them. Mathematical formulation, computer implementation, parameter estimation and assessment of such models are conceptually and technically challenging and require synoptic observations (unfortunately often scarce or unsuitable) of the different socioeconomic, ecological, biological, geochemical and physical systems considered. They also require access to high-performance clusters capable of simulating ecosystems at high spatial resolution over large geographical areas and projecting their future evolution to the end of this century.

Contacts (MARBEC):
O. Maury, olivier.maury@ird.fr
and Y. Shin, yunne.shin@ird.fr



◀ *Simulation of global marine ecosystem trends until 2100. Left: mean ocean surface temperature. Middle: mean primary production. Right: biomass of the three main pelagic ocean fish communities.*
From Lefort et al., *2015.* Global Change Biology. *21: 154-164.*

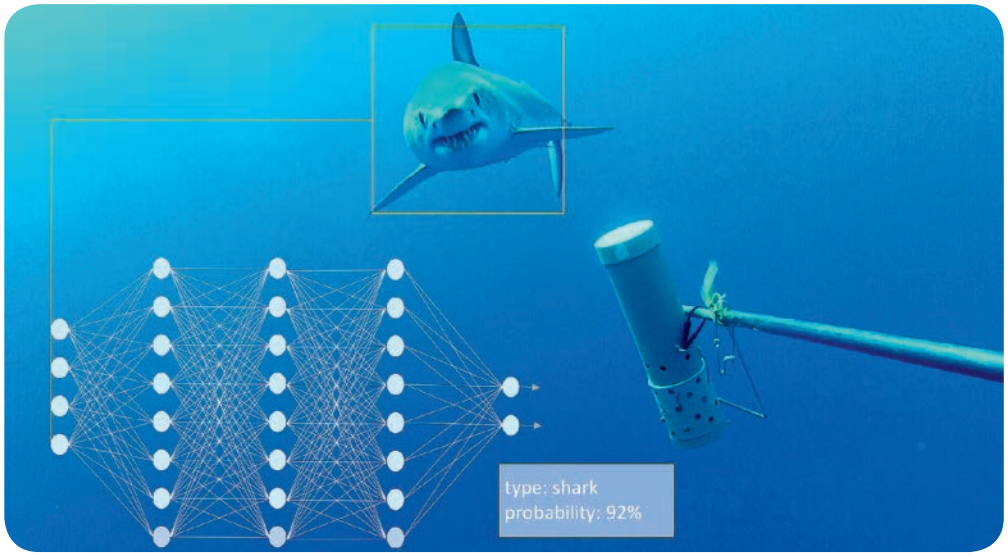
Deep neural networks for automated shark recognition

In situ monitoring of marine biodiversity is crucial for drawing up policies to curb its erosion. To this end, researchers use an observation system consisting of baited cameras, but large-scale application of this tool is hampered by the considerable investment required to manually process thousands of hours of video. **Researchers at UMR ENTROPIE have developed an innovative automatic fish recognition system based on deep neural networks to quickly analyse this large quantity of images at low cost. These deep learning AI algorithms are able to independently learn how to solve a task from a set of examples while exploiting the operating principles of biological neural networks.**

These algorithms were initially applied to sharks, which are among the most vulnerable species in the oceans and several are at risk of extinction. This was done in the Natural Park of the Coral Sea—one of the largest marine protected areas in the world—in the framework of the PRISTINE* and APEX* projects conducted by IRD Nouméa and UM, in partnership with the Total Foundation, the Pew Charitable Trust and the New Caledonian government. The shark results are very promising and researchers are currently extending this innovative approach to other fish species, particularly in the Mediterranean as part of the Monaco Explorations initiative*.

Contacts (ENTROPIE):
L. Mathon, laetitia.mathon@gmail.com,
C. Iovan, corina.iovan@ird.fr
and L. Vigliola, laurent.vigliola@ird.fr

For further information:
- PRISTINE project: http://pristine.ird.nc
- APEX project: http://apex.ird.nc
- Monaco Explorations: http://monacoexplorations.org



▲ *Deep neural networks for automated shark recognition. The network receives an input image and analyses it to generate a shark presence probability in the output image. The network consists of layers of neurons that sequentially analyse the image. Connections between neurons are iteratively modified during learning in order to tailor the network for shark recognition.*
Shark: screenshot of a video acquired by a baited camera as part of the PRISTINE project.
© Laurent Vigliola/IRD/UMR ENTROPIE

Underwater videos for automated fish identification and location

How can we measure underwater biodiversity? How do we observe, identify and locate this biodiversity? To answer these questions, LIRMMM and MARBEC* are developing automated image and video analysis methods to process the large volumes of generated data. The objectives are threefold:

1. develop deep learning algorithms for automated fish recognition based on images and videos
2. apply these advances in a case study to assess biodiversity in Indian Ocean coral reefs (Mayotte and Madagascar) and the benefits of measures implemented for their protection
3. provide the general public with access to an automated fish recognition app.

We are currently developing **algorithms for automated detection and recognition of fish species in HD videos based on deep learning methods**. Preliminary research on a study model trained on 20 Indian Ocean species resulted in **a 94% recognition success rate**. In the medium term, we will set up a web server that will offer the general public the opportunity to send underwater photographs in which fish will be automatically located and identified. In the long term, **this type of algorithm will facilitate monitoring of a large spatial area at very high temporal frequency to, for instance, detect rare or exotic species and measure the impacts of marine protected areas in the Mediterranean Sea**.

Contacts:
M. Chaumont (LIRMM), chaumont@lirmm.fr
and D. Mouillot (MARBEC),
david.mouillot@umontpellier.fr

For further information:
https://reefish.umontpellier.fr

* This interdisciplinary project brings together marine ecology (MARBEC) and image analysis (LIRMM) laboratories in the framework of a thesis funded by the GAIA (Biodiversity, Agriculture, Food, Environment, Land, Water) graduate school and LabEx CeMEB (Mediterranean Centre for Environment and Biodiversity) and partnerships with the UM Naturalist Group and the NGO Wildlife Conservation Society (WCS).

▲ *Fish detection and identification in an image*
© LIRMM/MARBEC, 2018

Big data – data that is so huge in volume that it cannot be comprehended overall or analysed by the human mind, or even by conventional computation approaches.

New digital services to benefit the community and coastal and maritime monitoring platforms

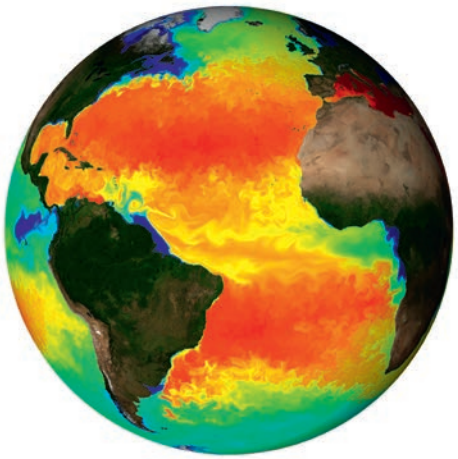
Digital ocean services in support of science and blue growth

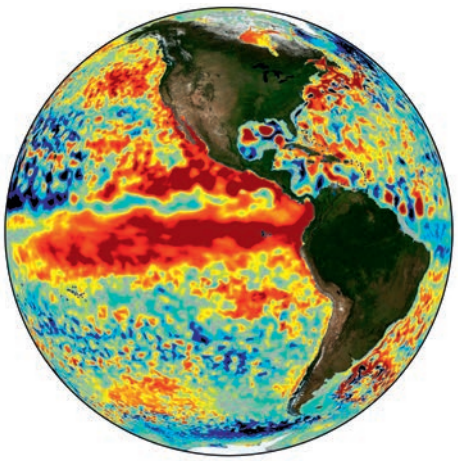
Mercator Ocean International is one of the few global ocean information service operators able to generate digital representations of the world's oceans. The history of the company—which is located in Ramonville-Saint-Agne in the Occitanie region—began more than 20 years ago as a small structure running digital systems geared towards real-time 3D description of ocean states on regional and global scales, within the new ocean-focused sector in Toulouse. In 2010, Mercator Ocean became a public interest structure, and in May 2015 a delegation agreement was signed with the European Commission to set up and operate the EU Copernicus Marine Service.

Copernicus is the EU space-based Earth observation programme while the Copernicus Marine Environment Monitoring Service is devoted to surveillance of oceans worldwide. It offers **free access to a globally unrivalled catalogue of information and expert products describing the physical and biogeochemical features of European seas and the global ocean**. These data pertain to ocean circulation (major currents, waves, eddies, turbulence, sea level, etc.), the thermohaline state (large bodies of water, temperature, salinity, density, etc.), biogeochemical state (chlorophyll, oxygen, primary production, etc.) and the state of frozen bodies of sea water at high latitudes (sea ice cover and movements in the Arctic and Antarctica). They represent key assets for development of the blue economy and research on climate change or marine biodiversity, for example, particularly in Occitanie region, by revitalising specialised downstream sectors (environment, transport, research, defence, etc.). This information also contributes, for example, to the overall understanding of the ocean environment for the future installation of floating wind turbines in the Gulf of Lion* or the optimized routing (fuel economy) of a fleet of container ships** serving Mediterranean ports. Mercator Ocean currently has over 16,000 subscribers worldwide (late 2018).

Contact (Mercator Océan International):
L. Crosnier, laurence.crosnier@mercator-ocean.fr

For further information:
http://marine.copernicus.eu
*http://marine.copernicus.eu/usecases/environmental-monitoring-offshore-wind-farm-offshore-leucate-mediterranean-sea/
** http://marine.copernicus.eu/usecases/ship-routing-save-fuel-reduce-co2-emissions/

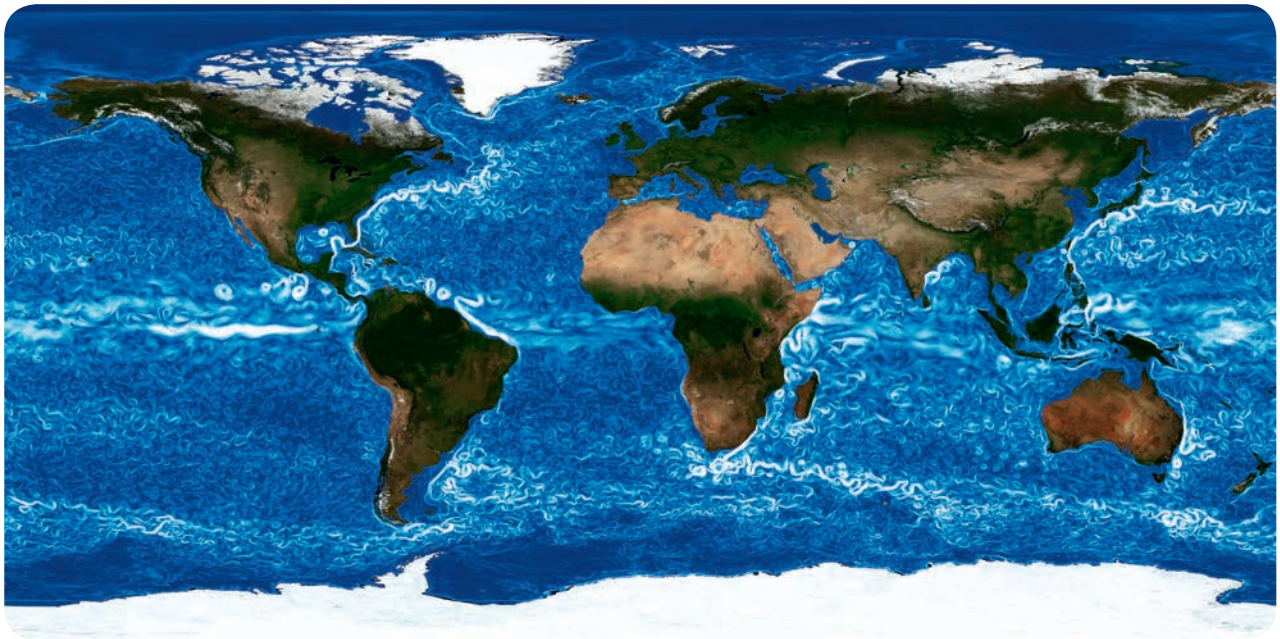




▲ *Surface salinity forecast map for 29 March 2018 based on the global model (1/12°).*
© EU Copernicus Marine Service/Mercator Océan

▶ *Ocean thermal content map calculated for the top 300 m surface layer for 29 September 2015 (with the* El Niño *phenomenon signature), based on the global model (1/12°).*
© Mercator Océan

▼ *Surface current forecast map for 29 March 2018, based on the global model (1/12°).*
© EU Copernicus Marine Service/Mercator Océan



HOMONIM – improved forecasting of coastal flooding along French sea coasts

SHOM in Toulouse focuses on the scientific, technical and operational development of ocean and coastal sea state models in coastal areas. The aim is to design digital tools for the forecast of the physical state of the ocean so as to generate value-added oceanographic products and services that can be used by the armed forces or public maritime and coastal policy makers. In response to the growing social demand for coastal natural risk prevention, the teams were tasked by the French Directorate-General for Risk Prevention and the Directorate-General for Civil Protection and Crisis Management to improve coastal surges forecasting capabilities occurring during storms and hurricanes. These studies also benefit from steady advances in supercomputer performance. Since 2012, as part of the HOMONIM* project, new storm surge and coastal wave models have been developed in compliance with operational forecasting system requirements:

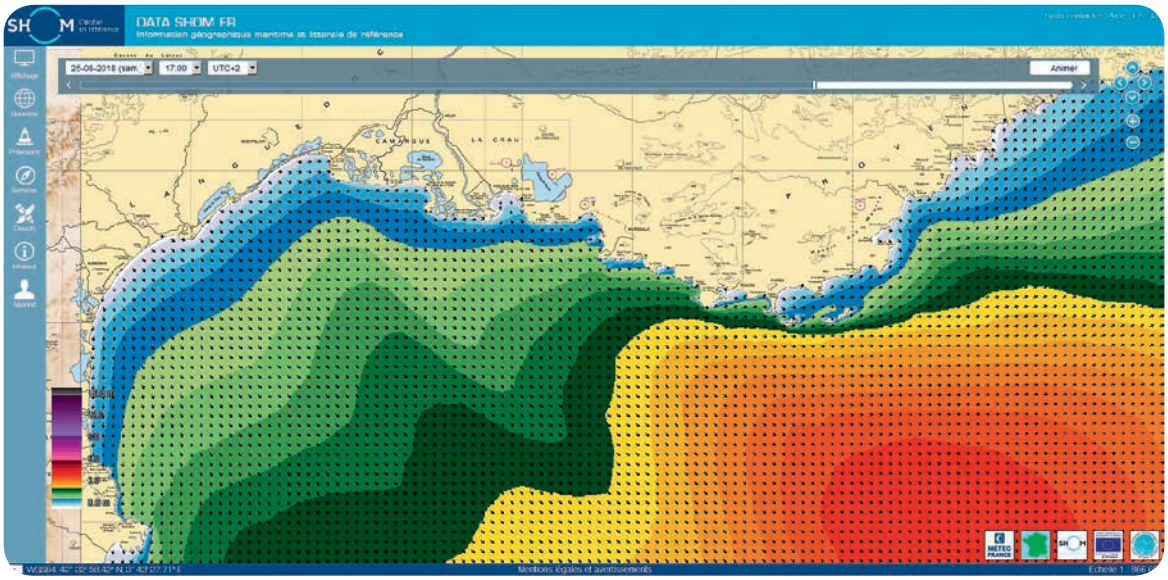
- academically valid models: consideration of physical processes, coupling, numerical resolution method, parametric studies, non-regression tests, etc.
- availability of baseline information on bathymetry and sedimentology features, etc. at modelling-compatible resolution
- availability of real-time observations (tide gauges, buoys, satellites, etc.) for model validation
- a computation cost consistent with real-time operation.

Models are evaluated in terms of their accuracy in simulating water levels and storm surges characteristics observed during past storms. Each new configuration has proven to be more effective in predicting the water levels reached during these extreme benchmark events. The new configurations are regularly incorporated into *Météo-France*'s real-time operational forecasting processes so that forecasters can obtain the information they need several times a day to analyse the risk of flooding along metropolitan and overseas coasts and define the surge and wave flooding vigilance level. The project—carried out in partnership with *Météo-France*—benefits from the many other collaborations that SHOM has with the OMP (LEGOS and LA), the *Institut de Mathématiques de Toulouse* and *Mercator Océan* in the region.

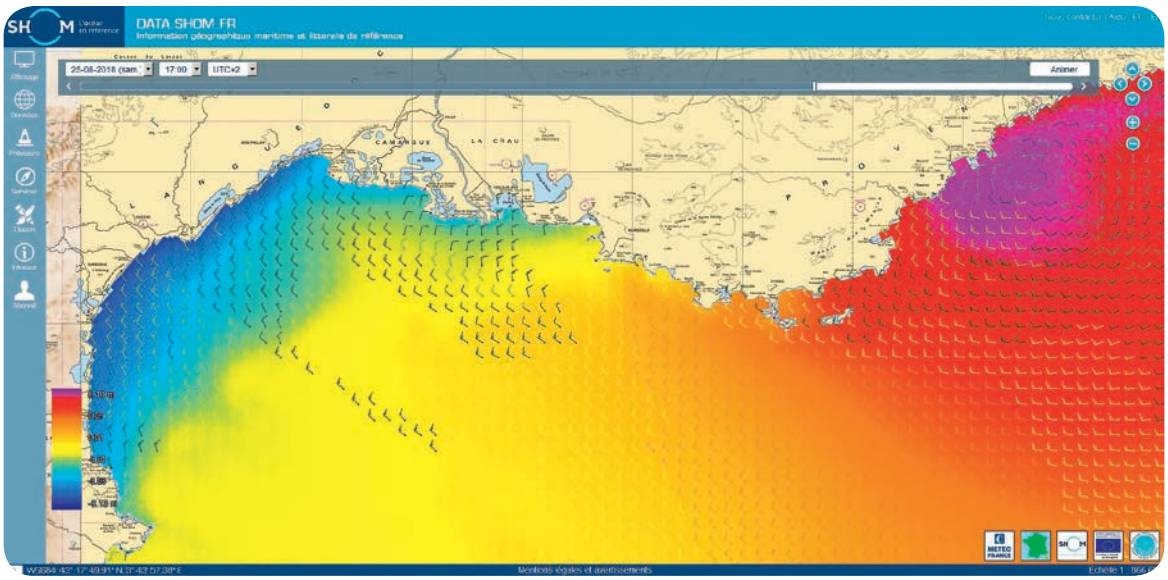
Contacts (SHOM): A. Pasquet, audrey.pasquet@shom.fr, H. Michaud, heloise.michaud@shom.fr and D. Jourdan, didier.jourdan@shom.fr

For further information: https://data.shom.fr

* HOMONIM project: History, observation and modelling of sea levels.



▲ *Example of a significant wave height forecast (m) on Aug. 25 2018 at 15 h GMT. The wave height is low along the coasts (< 10 cm) of the Gulf of Lion, favoured by an offshore prevailing wind and swell. In the SE part of the area, the sea state is fully developed by a steady high wind (60-65 km/h), with wave heights reaching 4.3 m.*
© SHOM and Météo-France *(HOMONIM project results)*



▲ *Example of a positive/negative storm surge forecast (m) on Aug. 25 2018 at 15 h GMT. The values range from -10 to +10 cm along the coasts in strong offshore breeze conditions (*Tramontane *wind 40-45 km/h) over the Gulf of Lion and a slight low pressure system along the* Provençal *coast (1004 hPa and cyclonic winds), conducive to slight water accumulation on the coast (+ 10 cm).*
© SHOM and Météo-France *(HOMONIM project results)*

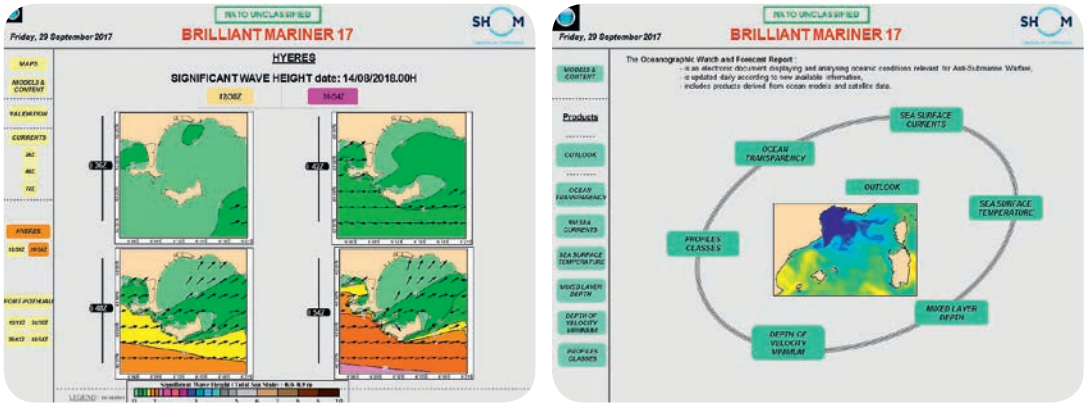
Oceanography support for the French defence sector from a base in Toulouse

The SHOM Operational Forecasts unit (PREVOPS) draws up daily real-time oceanographic and acoustic products for the French Ministry of the Armed Forces. Scientific advances in meteorological forcings and data assimilation techniques, as well as in understanding physical processes and their ever-enhanced numerical modelling, led to recent substantial improvements in operational ocean forecasting. Technological developments have also boosted the computational performance, and allowed a more frequent update of the model outputs, as well as the increase of the number and geographical scope of the forecasts. The oceanographic production of the PREVOPS unit thus currently covers all ocean basins worldwide from SHOM's operational facility in Toulouse. Moreover, the SHOM Data Fusion Centre (CFuD) operates seamlessly year-round to promptly meet the various operational needs of the armed forces.

The PREVOPS unit develops **many value-added products for the French defence users in order to meet the varied needs** (amphibious, anti-submarine and mine warfares, etc.) **of forces deployed over different fields of operation**. The available range includes products dealing with conventional oceanographic parameters (3-day forecasts of sea surface temperatures, horizontal marine currents, etc.) or more elaborate products (bulletin commenting on and qualifying the ocean state for SONAR acoustic applications, etc.). CFuD thus processes data from regional high-resolution 3D forecasting systems developed and managed by SHOM, as well as global oceanographic and meteorological forecasts issued by *Mercator Océan* and *Météo-France*.

Contacts (SHOM):
C. de Nicola, cyrille.de.nicola@shom.fr
and C. Lucion, christel.lucion@shom.fr

For further information: https://data.shom.fr



◀ *Oceanographic and amphibious environment bulletin issued for the 2017 Brilliant Mariner exercise.*
© SHOM

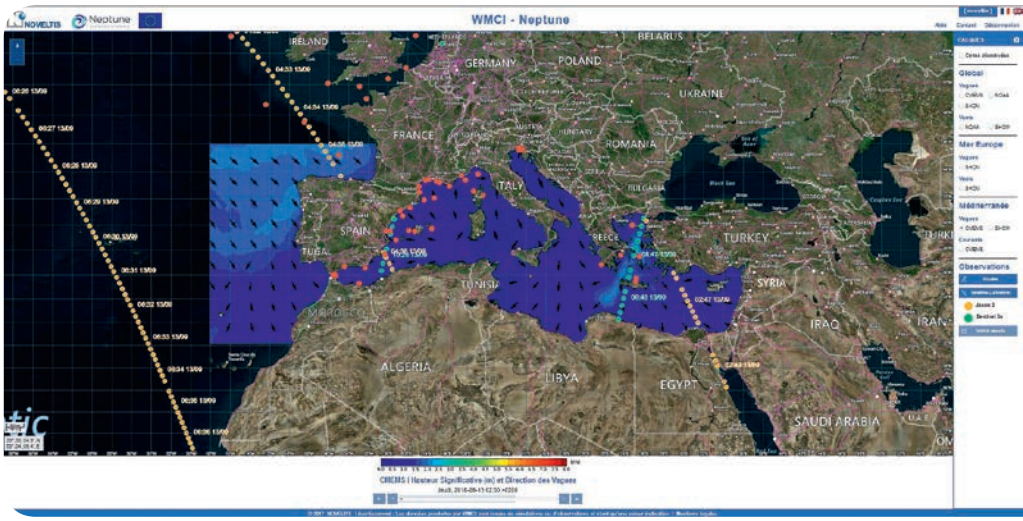
WMCI – a sea state forecast analysis service to streamline shipping routes

How can we determine the accuracy of sea state forecasts so as to be able to decide and plan offshore operations, while reducing technical, human, material and environmental risks? There is presently no simple or holistic answer to this question. Most maritime operators use sea state forecasting models to obtain information on wave heights and sea conditions. They have access to measurements from hundreds of sensors (buoys) managed by leading oceanographic institutes worldwide or to satellite altimetry measurements. There is, however, currently no single online solution that pools all sea state information while also providing a wealth of comprehensive information on wave heights to the entire maritime sector.

The NOVELTIS Wave Model Confidence Index (WMCI) service provides operational support to all stakeholders in the maritime sector for planning and optimising their offshore activities. This service—which is the result of numerous exchanges and discussions between offshore operators and NOVELTIS—offers unique expert integration of all measurement data, thus facilitating their mutual processing and comparison with results from the most widely used wave forecast models. **The WMCI website* is dedicated to offshore sea state and risk forecasting. It enables users to view various ocean-weather parameters from different forecasting models for different areas worldwide and compare them with *in situ* observations (buoys, ship watch reports) and satellite measurements** (see below).

Contact (NOVELTIS):
R. Bru, contact@noveltis.fr

*** For further information**:
https://wmci.noveltis.fr



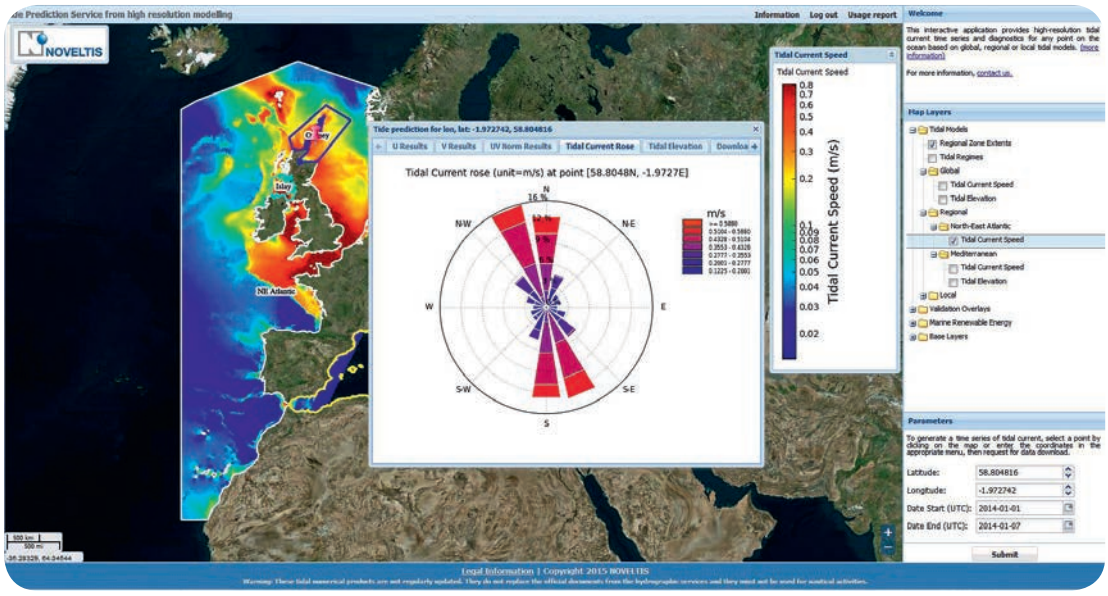
▲ *WMCI interface – Mediterranean sea state forecasting. Red dots indicate the buoy positions, while yellow and green dots indicate satellite tracks (Jason-3 and Sentinel-3A).*
© NOVELTIS

TIPS – an online tide forecasting service

NOVELTIS has been promoting methods for improving altimetry products for monitoring coastal areas for several years using regional tidal models that are more suitable for modelling coastal processes than global models. NOVELTIS has developed several regional atlases, particularly on the French northeastern Atlantic and Mediterranean coasts. These new generation atlases—enhanced by satellite altimetry data correction—are more accurate than currently available international atlases. **Since 2012, NOVELTIS has thus been providing the entire maritime sector with access to its online TIPS service, which supplies tidal current and elevation forecasts and tidal energy assessments for all global seas upon request.** This service is based on the most recent tidal models developed by NOVELTIS and is gradually enriched with other regional or local tidal models. Through this service, NOVELTIS is regularly called upon for its tidal expertise by a range of end users: operators specialized in marine infrastructure, maritime transporters, service companies, developers of marine renewable energy projects, etc.

Contact (NOVELTIS):
R. Bru, contact@noveltis.fr

For further information: http://tips.noveltis.com



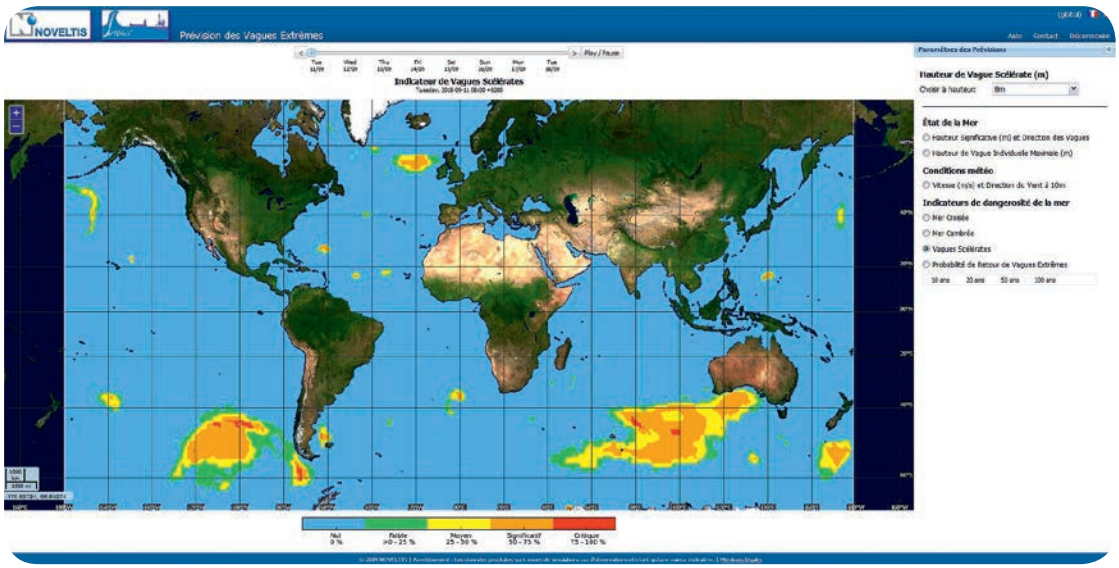
◀ *TIPS web interface.*
© NOVELTIS

SAVaS – the world's first extreme and rogue wave forecasting service for the maritime sector

NOVELTIS SAVaS is the world's first operational service for sea state forecasting and extreme and rogue wave risk warning. This service was developed with the support of the French Directorate General of Armaments and has been validated with the French Navy during several offshore missions. **SAVaS offers continuous and customized protection for all civilian and military stakeholders involved in the marine environment. It provides 7-day forecasts of synthetic indicators while taking the size of ships and offshore platforms into account in order to tailor the risk assessment according to the extent of their vulnerability.** Forecasts are produced at different spatiotemporal scales and updated every 6 h. The information provided by SAVaS is reliable, accurate, fast, easy-to-use and the service is operational worldwide. End users do not need to install any software and may access the service via a variety of electronic devices: a customizable and easy-to-use online mapping interface and daily bulletins prepared by NOVELTIS expert forecasters who transcribe SAVaS indicators. Users pay a fee for access to the online SAVaS sea state and offshore risk prediction service. It allows them to view different ocean-weather parameters as well as indicators of extreme offshore events (crossed seas, steep seas and rogue waves, see below).

Contact (NOVELTIS):
R. Bru, contact@noveltis.fr

*** For further information:** https://savas.noveltis.fr



◀ *SAVaS website – rogue wave occurrence indicator.*
© NOVELTIS

An observatory to gain insight into coastline change patterns

The sandy Catalan coast is a 44 km N-S-oriented hydrosedimentary unit extending from Racou beach (Argelès-sur-Mer) to Cap Leucate and forming the Roussillon plateau coastline. This very developed lowland coastline is highly vulnerable to marine storms and associated coastal erosion and marine flooding hazards. Consequently, *Perpignan Méditerranée Métropole* (whose four coastal municipalities cover 23 km of this linear area), and the municipality of Leucate, have initiated—with the support of the Rhone Mediterranean and Corsican Water Agency and BRGM—a coastal monitoring initiative to gain insight into the changes under way, and ultimately to implement a more sustainable integrated approach to managing this area. The Catalan Sandy Coast Observatory (launched in 2013) thus intends to equip itself with a sandy coast monitoring tool, a solid knowledge base and a decision-making tool to gain greater insight into coastal dynamics and risks related to human activities and interactions between the watershed and the sea. Its missions are: (i) coastal monitoring (data collection), (ii) information sharing (database compilation), (iii) analysis of phenomena and drawing up recommendations (data interpretation), and (iv) communication (widespread data dissemination). On the basis of the monitoring carried out and its understanding of the coastal dynamics, **the observatory thus helps draw up recommendations for the restoration and sustainable management of the coastal environment.**

Contact (BRGM): Y. Balouin, y.balouin@brgm.fr

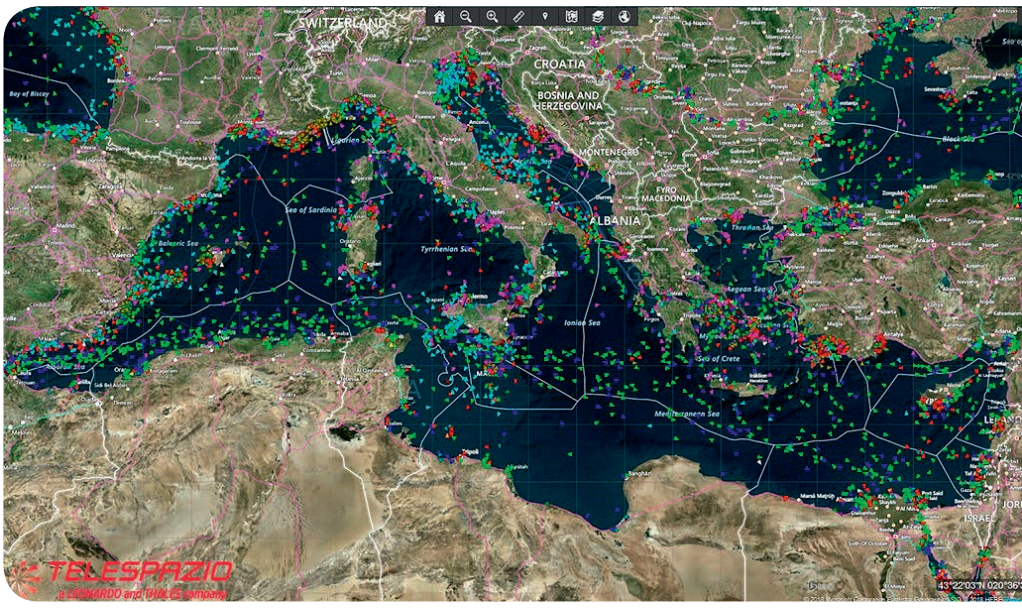
For further information: http://obscat.fr

▼ *Bathymetric monitoring of the mouth of the Agly River in March 2017.* © *ObsCat-BRGM*

From satellite monitoring of maritime areas to the 'sea cloud'

Monitoring of maritime areas is necessary for many operators: the private sector to monitor their economic activities at sea, the public sector for State missions at sea (fisheries control, maritime safety and security, etc.). Satellite imagery usage has rapidly increased over the past decade due to shifting offshore threat patterns (previously mainly confined near the coast) and satellite capabilities that now provide users with high resolution images at minimal cost. In a few years, Telespazio France—a Thales-Leonardo subsidiary—has become the leader in the field in France. Telespazio France was initially an operator for the French Navy, in partnership with Airbus, to monitor the 10 million km² of the French exclusive economic zone (Trimaran service, see next article). For the French Directorate of Maritime Affairs, Telespazio France has also set up the new maritime surveillance service assisted by satellite imagery from Sentinel-1 and 2 satellites. At the request of the French Secretary General for the Sea and in partnership with the French Naval Academy Research Institute (IRENav), Telespazio France is developing a new generation of AI-based algorithms for maritime surveillance combining several data sources with numerous applications: installation and monitoring of wind farms, illegal fishing, monitoring of marine parks, etc.

Many initiatives are now being launched around the 'sea cloud' concept, while leveraging big data and high-throughput computing technologies to enhance knowledge of human activities and their impact on the oceans, and ultimately to address new challenges posed by the intensification of sea trade and the weakening of ecosystems in a proven climate change setting. A number of collaborations focused on this promising topic are being forged, in particular with UM for intensive computing and streamlining of learning algorithms.



▲ *Satellite detection of automatic identification system (AIS) signals from the Mediterranean Sea.* © *Telespazio France*

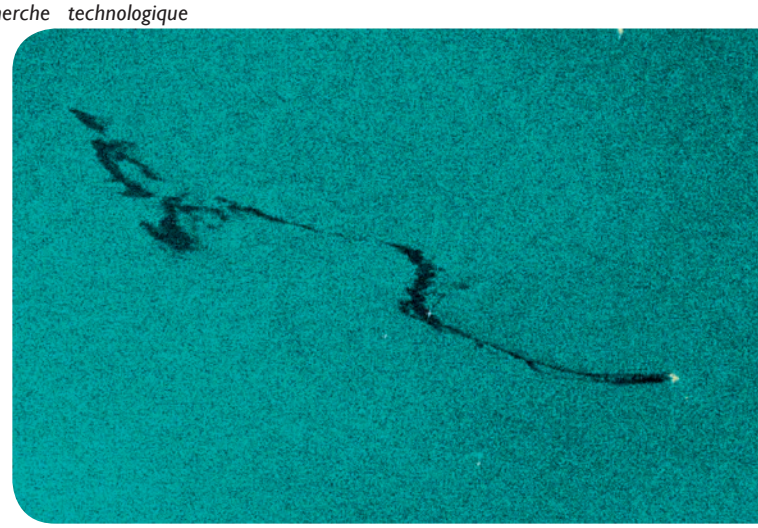
Contact (Telespazio France):
F. Marques, francois.marques@telespazio.com

Oil pollution monitoring

Accidental or deliberate pollution through the discharge of oil or ballast water into the sea continues to be widespread and is very environmentally damaging. Satellite imagery focused on any specific location worldwide can provide a global response. Several currently operational services thus prioritize pollution detection for environmental management purposes. The French Navy's Trimaran service, for instance, is jointly operated by Telespazio France and Airbus DS and, on a European scale, the CleanSeaNet service was set up by the European Maritime Safety Agency and is supported by a network of operators. **Major petroleum companies use this technology to monitor the environment around their offshore platforms, but also to look for natural oil discharges, which are an indicator of the maturity of an oil deposit.**

At the current state of the technology, these services are mainly based on visual analysis of radar images. A detected phenomenon leads to a specular radar signal reflection that appears as a dark spot on the radar image. However, many other phenomena can also cause similar spots. Current automated processing systems do not reliably distinguish between an oil slick and, for example, a windward area, local upwelling or plankton bloom. Telespazio France, in partnership with the *Institut de recherche technologique Saint Exupéry*, is working on **a new generation of processing chains to enhance the reliability of automated detection. This will be based on digital learning methods that can better characterize geometric shapes on a radar image, integrate other data, such as low-resolution multispectral imagery, while also taking contextual data (winds, currents, water colour, etc.) into account**.

Contact (Telespazio France):
F. Marques, francois.marques@telespazio.com



▲ *Offshore collision between a ro-ro vessel and a container ship on 7 October 2018. Sentinel-1 satellite image.* © ESA

Space technologies for fisheries surveillance in the Mediterranean Sea

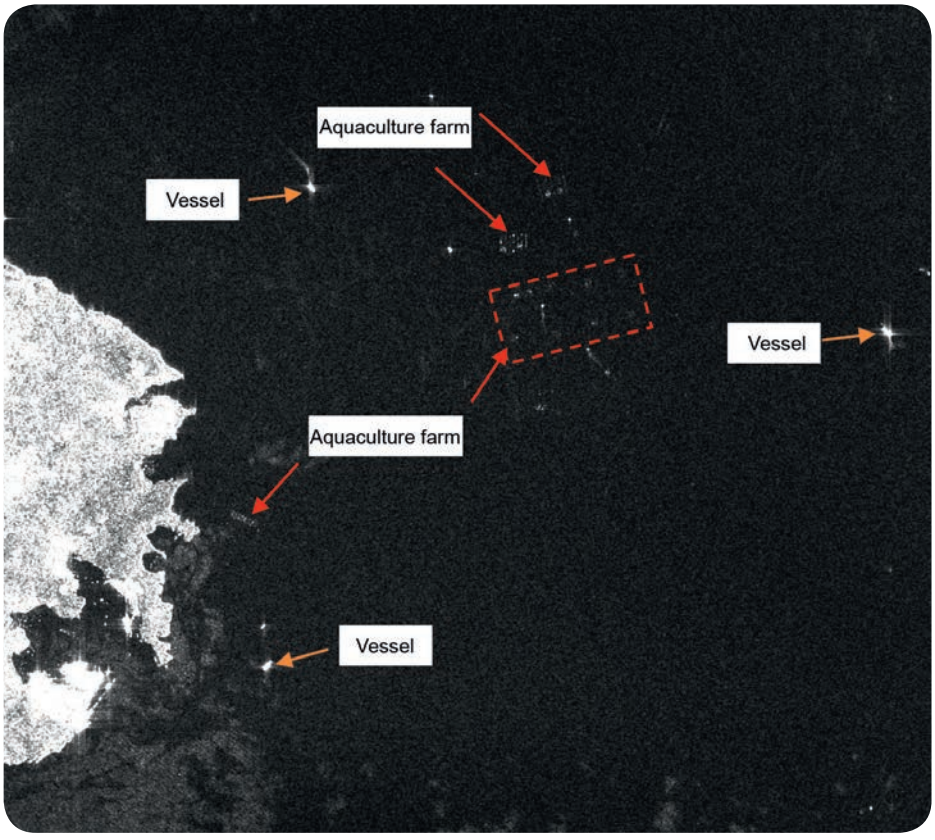
Since 1986, CLS—based near Toulouse and a subsidiary of CNES and IFREMER—has been renowned for operating ARGOS beacons aboard racing yachts, while also being an internationally recognized leader in the fisheries surveillance field. **CLS processes and analyses fishing boat positions and catches recorded by Vessel Monitoring System (VMS) beacons mounted on more than 16,000 vessels around the world. French Mediterranean bluefin tuna fishing vessels are equipped with these beacons. Their fisheries catches are transmitted by satellite and recorded in real time** by the French Maritime Fisheries and Aquaculture Directorate (Ministry of Agriculture and Food).

The entire Mediterranean Basin represents a major challenge for CLS, which serves coastal States, regional fisheries organisations and the European Maritime Safety Agency (EMSA). CLS provides tuna fisheries control software for the International Commission for the Conservation of Atlantic Tunas (ICCAT). This software enables users to display data from more than 50 member countries. CLS is also a partner of the General Fisheries Commission for the Mediterranean (GFCM) and EMSA. In this setting, **CLS is assisting in the detection of illegal fishing activities by combining different sources of satellite information**, including radar images and Automatic Identification System (AIS) positions. Similar tools can be used to monitor offshore aquaculture activities. Based on spatial data, CLS therefore proposes a range of fisheries monitoring tools applicable to the activities of industrial and small-scale fishing fleets. CLS is also developing fisheries stock estimation models (e.g. tuna populations) which, combined with effective control systems, are designed to promote sustainable use of fisheries resources in the Mediterranean Sea.

Contact (CLS):
J.-P. Cauzac, jcauzac@groupcls.com

For further information:
https://fisheries.groupcls.com

▼ *Sentinel-1 radar satellites of the Copernicus programme cover the Mediterranean Sea with images at 10 m resolution. In this image taken on 25 June 2018, the east coast of Malta (left of image), several tuna cages (brighter geometric shapes in the centre of the image) and many vessels of various sizes (very bright spots) can be seen.*
Source: Copernicus Sentinel data modified and processed by CLS.



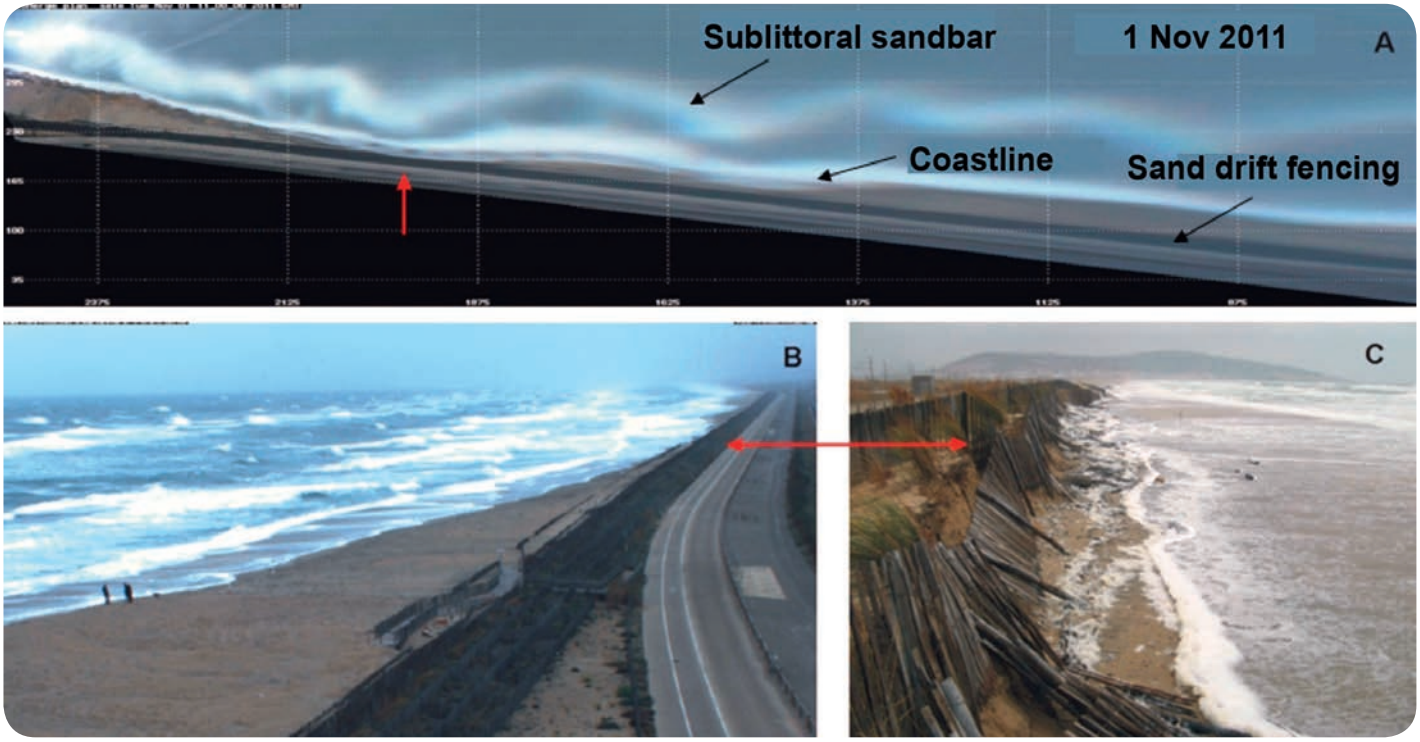
Innovative technology and tools

Development of innovative coastline monitoring tools

Access to *in situ* data is currently a major obstacle on the pathway to understanding and modelling coastal hazards, particularly during storm events when instrument deployment is difficult and risky. New measurement techniques have enhanced the overall understanding of coastal dynamics in recent years. Video sensors now facilitate the characterisation and quantification of optical signatures of coastal morphologies and hydrodynamics, regardless of marine weather conditions. These new tools may be used to reconstruct the morphology (topography, bathymetry) and turbulence conditions (swell, currents, waves) and to acquire novel data on hydrosedimentary processes. **In Occitanie region, two stationary systems have been continuously acquiring information for several years on the Sète barrier beach and Barcarès beach. These systems focus specifically on the hydrosedimentary mechanisms generated by new coastal protection structures such as submerged breakwaters** (see below). The current challenges being addressed include the assimilation of these data into digital models and the ongoing development of these new techniques via mobile sensors (drones).

Contact (BRGM): Y. Balouin, y.balouin@brgm.fr

For further information:
www.brgm.fr/projet/suivi-video-numerique-experimentation-techniques-protection-littoral-lido-sete-marseillan



▲ *Video monitoring of the Sète barrier beach at Marseillan during the storm of November 2011.* © BRGM
A. Orthorectified image.
B. Same raw image.
C. Landscape photo.

Designing practical, straightforward and immediately operational tools for marine and coastal managers.

Breakwaters to combat beach erosion

The protection of the barrier beach from Sète to Marseillan via geotube breakwaters showcases the effectiveness of the innovative solutions proposed by *BRL Ingénierie* (BRLI). In 50 years, marine erosion has led to the loss of nearly 50 ha of this 11 km long and 1-2 km wide sandy strip. A first experimental development project was launched in 2013 to restore the beach near Sète. Geotubes—sand-filled geotextile tubes—were submerged 350 m from the shoreline over a distance of around 1 km. **The beach had recovered about 12 m in width 3 years later.** The innovation—managed by BRLI with the support of UM and CNRS—is threefold:

- invention of the 'breakwater' principle, which reduces the energy generated by storms by mimicking the natural efficiency of sandbars. This soft, sustainable and (if necessary) reversible solution overcomes erosion issues, without shifting them elsewhere
- geotube dimensioning based on shape optimisation calculations (COPTER R&D project*)
- use of huge geotubes (6 x 3 x 30 m W/H/L) to replace conventional rockfill breakwaters.

In the wake of the success of this operation, the second phase of the project was entrusted to BRLI in 2018 by *Sète Agglopôle Méditerranée*. BRLI is also implementing this technique to protect a tourist beach in Tel Aviv (ongoing). BRLI is the subsidiary of the BRL Group, which in turn is a member of Occitanie region's *Parlement de la Mer*, specialised in dealing with water, environment and development issues. BRLI is a consulting company operating in France and abroad while also being a member of the *Mer Méditerranée* competitiveness cluster. It applies its expertise to coastal issues such as the development, protection and sustainable management of coastlines.

Contact (BRLI): N. Fraysse, dc.brli@brl.fr

* ANR COPTER project: Design and shape optimisation against coastal erosion.

▲ *Geotube breakwater for beach protection in Sète (France).* © BRL/GL

Video-enhanced coastal risk management

Coastal managers, who need to know the ecological and economic cost for each coastal development decision, must have a thorough understanding of the environmental dynamics. Scientists can now use images collected with a simple video camera to monitor beach sediment resources through the continuous collection of various data: shoreline changes, topography and bathymetry, and wave parameters. This measurement system benefits from the baseline features of the data collection method—**the video technology enables continuous remote monitoring of shoreline changes, which is an essential factor in this highly dynamic environment. This provides users with knowledge on the state of the beach at a given time while also enabling monitoring of long-term trends or extreme events, ultimately shedding light on sediment dynamics at the local level**.

This technology provides insight of erosion phenomena by forecasting critical thresholds in terms of sediment resources or by assessing trends regarding the natural recovery of beaches after a storm. Video measurement is also effective for managing storm surge and flood risks. This technology provides users with local information, at high frequency, on sea states and peak sea levels, and could ultimately also benefit forecasters or warning systems. Finally, the association of images with scientific measurements can be of primary importance for raising awareness and for communication campaigns on coastal risks.

Contacts (Waves'n See): A. Berger Sabbatel, amandine.berger@wavesnsee.com and Y. Soufflet, yves.soufflet@wavesnsee.com

▼ *Example of automated shoreline detection for a post-storm assessment, Gruissan beach (France), November 2014.* © Waves'n See (SCOP Rivages)

Photogrammetry – an innovative observation method for studying and preserving the marine environment

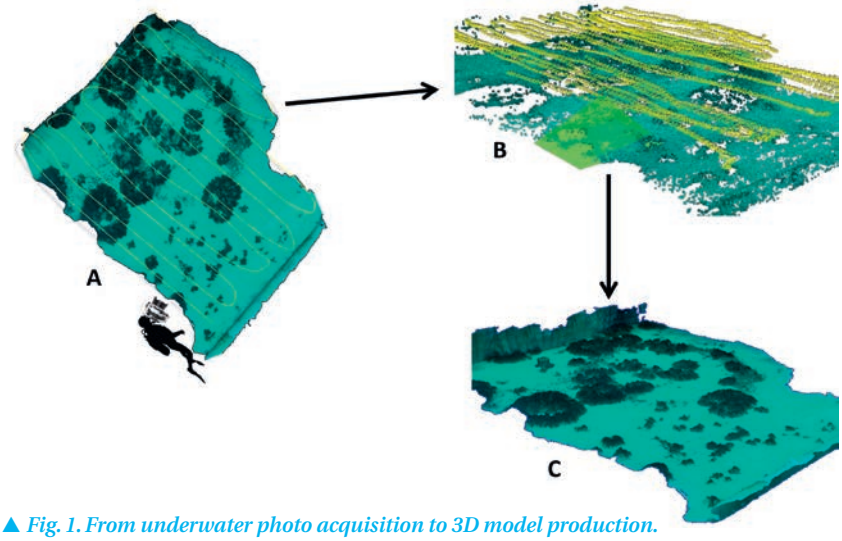
Contacts: G. Marre (*Andromède Océanologie*/TETIS/ISEM), guilhem.marre@andromede-ocean.com, J. Deter (*Andromède Océanologie*/ISEM/LabCom InToSea), julie.deter@umontpellier.fr and F. Holon (*Andromède Océanologie*), florian.holon@andromede-ocean.com

For further information: www.andromede-ocean.com/photogrammetrie.html

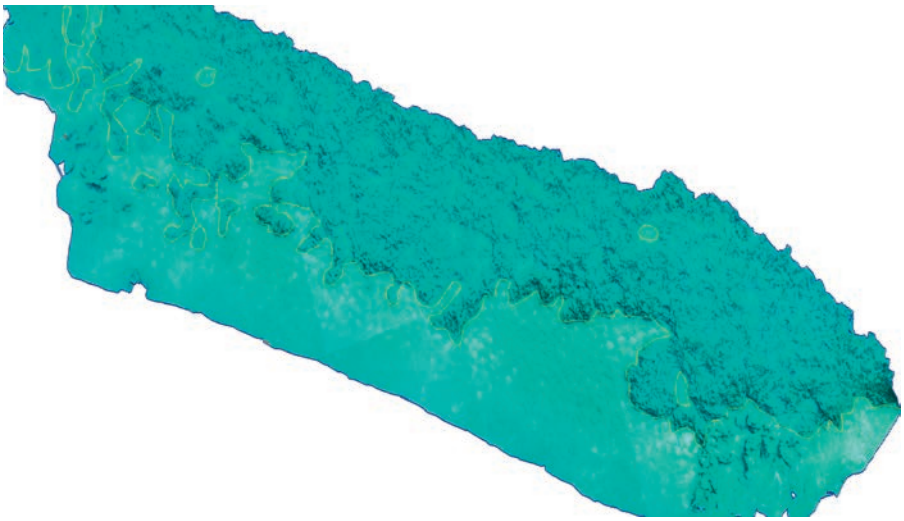
Since 2010, *Andromède Océanologie*, based in Carnon (France), in partnership with the French Water Agency (*Agence de l'Eau Rhône Méditerranée Corse*), has been developing networks to monitor the richest coastal ecosystems in the Mediterranean Sea in compliance with the EU Marine Strategy Framework Directive. To improve its observation methods, *Andromède Océanologie* has launched an R&D project on underwater photogrammetry*—**an innovative technique capable of reconstructing an object or landscape in 3D from 2D photos taken from different angles**. This approach is still not widely used for ecological studies of the marine environment.

Our research is geared towards developing: (i) indicators based on 3D models, and (ii) integrated methods for automated monitoring of changes in marine habitats and their biodiversity, from data acquisition to the assessment of their health status. A first methodological phase involved quantifying and streamlining the accuracy of the method as a function of the data acquisition (see Fig. 1). We are currently working on automated mapping of *Posidonia* meadows—a fragile habitat whose variation patterns have already been monitored by acoustic telemetry since 2010 (see Fig. 2). Meanwhile, we are also studying correlations between indicators of the structural complexity of coralligenous and coral reefs and ecological quality indicators with a view to developing methods for automated measurements of the reef health status directly from 3D models (see Fig. 3). Finally, all 3D models and indicators will be posted online on the Medtrix mapping platform (www.medtrix.fr) for the benefit of the entire scientific community.

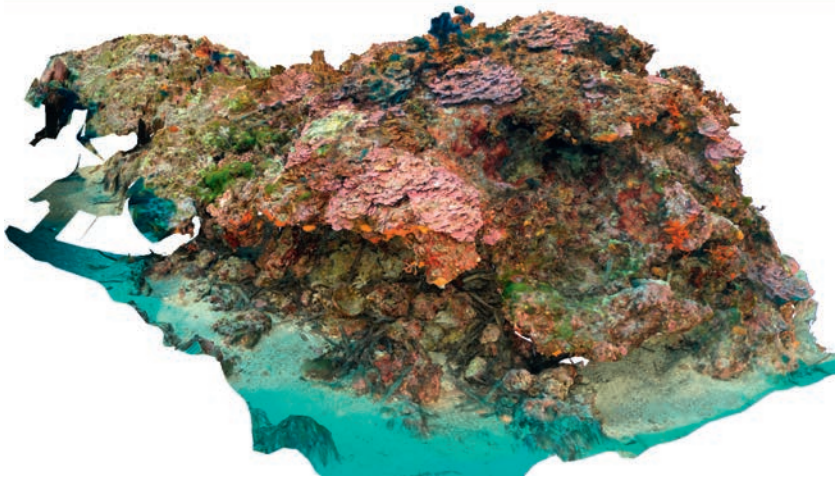
* Studies carried out as part of a CIFRE phD thesis (TETIS/ISEM/LabCom InToSea/LIRMM collaboration).



▲ *Fig. 1. From underwater photo acquisition to 3D model production.* © *Andromède Océanologie*
A. Photo acquisition via underwater transects.
B. Spatial image alignment.
C. 3D textured model production.



▲ *Fig. 2. 3D model of a* Posidonia *meadow and mapping of its lower margin (sea lion, PACA region).* © *Andromède Océanologie*



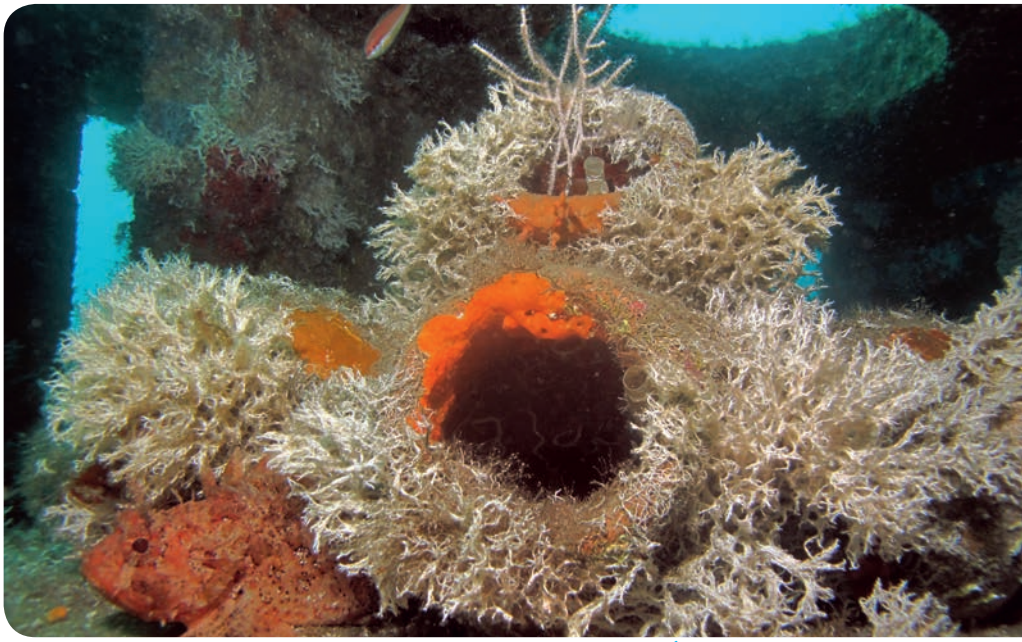
▲ *Fig. 3. 3D model of a coralligenous reef (Bormes, PACA region).* © *Andromède Océanologie*

Smart fish villages

BRL Ingénierie (BRLI)—a subsidiary of the BRL Group which has supported numerous artificial reef development programmes in Occitanie region—was the lead contractor for the *Récifs Prado* operation launched by the City of Marseille to repopulate the seabed in the area. This project spans an area of over 220 ha and is the largest in Europe and the Mediterranean Basin. **In 2014, the project was awarded the *Grand Prix du Génie Ecologique* by the French Ministry of Ecology. BRLI has designed a series of innovative structures adapted to various species to foster broad-ranging biodiversity. Nearly 400 modules of various shapes were submerged in six 'villages' located in Prado Bay.**

The project led to extensive preliminary discussions (elected officials and city services, representatives of the State, fisheries trades, tourism professionals, scientists, divers, etc.) which generated the support of the various stakeholders. The scientific monitoring—carried out by GIS *Posidonie* (a scientific interest group that brings together researchers and partners from laboratories in the French Sud, Occitanie and Corse regions)—highlighted the success of the operation. **The reefs are now fully colonized, while the number of fish species has tripled and biodiversity has increased by more than 30% (number of species).** BRLI provided the complete project management: site selection, consultation phase, reef design, regulatory and environmental studies, and project management. Its experts also assisted the City of Marseille in organizing the first international symposium of reef managers, which brought together more than 17 countries in 2013.

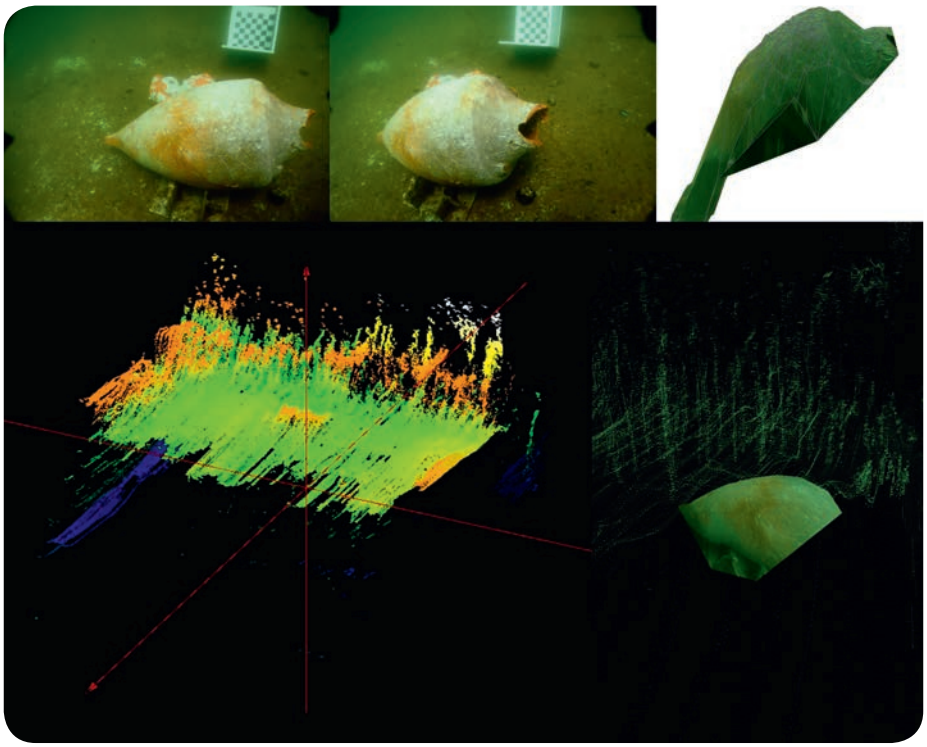
Contact (BRLI): S. Fillon, dc.brli@brl.fr



▲ *Artificial reefs of Prado Bay, Marseille (France).* Grand Prix du Génie Écologique *2014.*
© Sandrine Ruitton

Multimodal image fusion for underwater archaeology mapping

The Explore team of LIRMM's Robotics Department offers many applied programmes devoted to environmental research. Marine and underwater robotics research, in association with marine biologists, hydrogeologists and archaeologists, is a major feature. This research is geared towards analysing natural underwater scenes and especially 3D mapping of underwater environments. Many techniques are available to achieve this goal. The fact that we are able to **fuse two maps obtained with sensors of different resolutions is a unique feature of our work.** An autonomous device (or boat) first scans the seabed with a multibeam sonar and creates a preliminary overall map of the area. This map is then fragmented into small cells representing a mosaic of the seabed. A second analysis is then focused on specific cells using a second higher resolution sensor, thus generating a detailed 3D map of the cell. This acquisition is achieved by an autonomous underwater robot, or a diver equipped with a stereoscopic vision system.



This two-part project concerns the 3D reconstruction of underwater scenes in a confined environment using paired stereoscopic images, in addition to multimodal aspects. We are striving to use this method to obtain **precise reconstructions of archaeological objects of interest (statues, amphorae, etc.) detected in the overall map**. We have thus created a multimodal underwater 3D map using 3D 'video' models and a comprehensive acoustic map.

Contact (LIRMM):
J. Triboulet, jean.triboulet@lirmm.fr

◀ *Top: Paired stereoscopic images of an amphora (left) and a 3D model of the amphora (right).*
Bottom: sonar map of the site (left) and 3D/sonar overlay (right).
© J. Triboulet/LIRMM

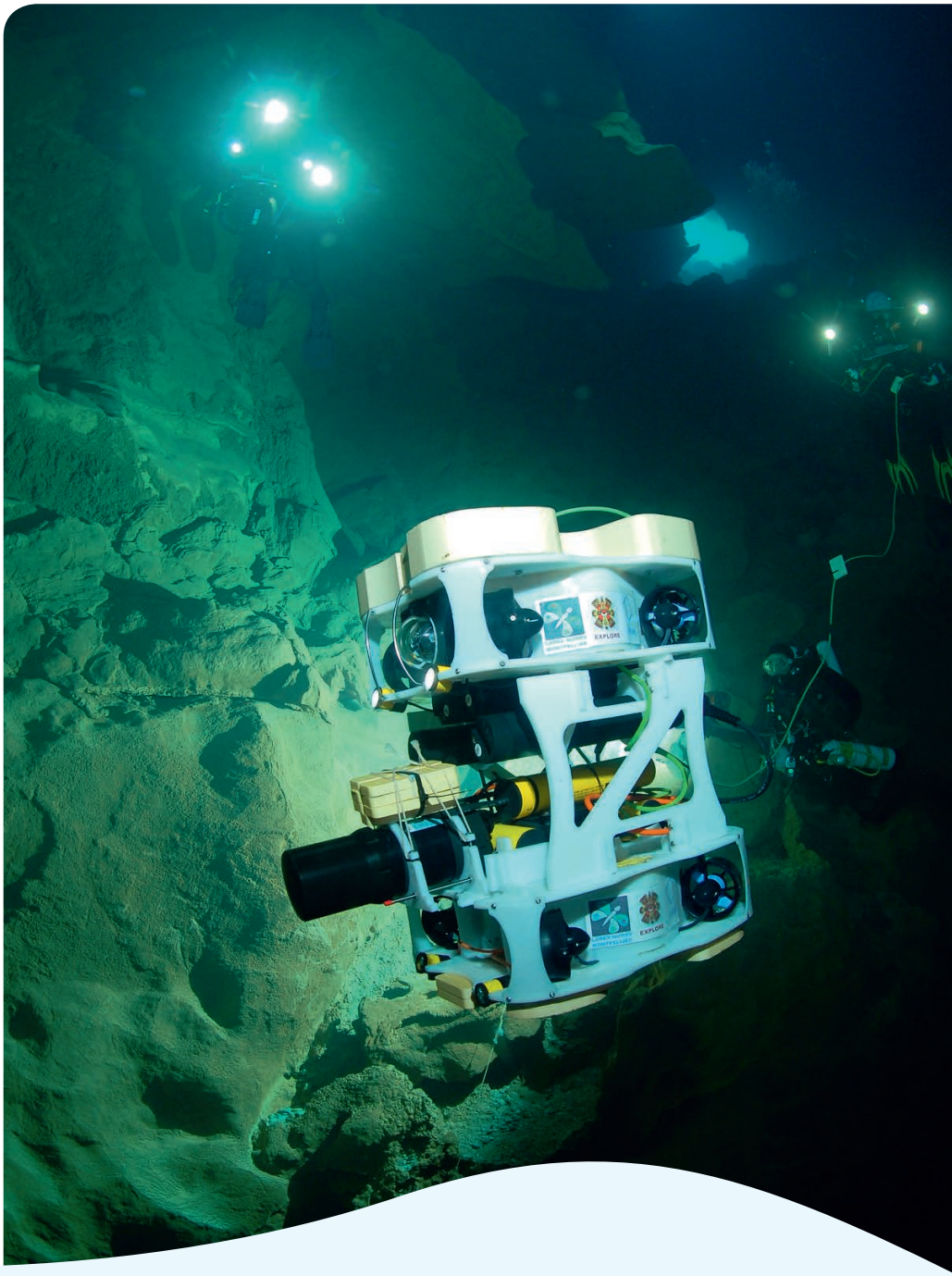
Underwater robotics for environmental assessment and sampling

Contacts (LIRMM): V. Creuze, vincent.creuze@lirmm.fr, K. Godary-Dejean, karen.godary-dejean@lirmm.fr and L. Lapierre, lapierre@lirmm.fr

In the underwater robotics field, LIRMM develops methods to assist users in piloting and navigation, or to make the robotics system completely autonomous during certain mission phases. In both cases, a computer processes the sensor data (pressure, heading, orientation, speed, sonar, Doppler Velocity Log, cameras, etc.) to partially or fully automate the robot control. The ability to accurately localize the robot is essential for its autonomy, but also for geolocalisation of the collected data. LIRMM therefore proposes innovative acoustic and computer vision methods for application both in offshore and highly constrained environments.

LIRMM's research also focuses on the control of robots (control architecture and control laws), with the mutual aim of providing users guarantee of performance, thus ensuring the safety of the vehicle and the accuracy of the reconstructed models during both the autonomous and the remotely operated phases. Finally, these works also focus on underwater sampling and manipulation using specific grippers or robotic hands. The research results are regularly applied during test missions in karst networks in Occitanie Region (production of 3D models of the network), on Mediterranean deep sea archaeological sites (object sampling and 3D modelling, see previous page) or in other oceans, like the Mayotte Lagoon (fish counts or biological sampling). LIRMM researchers base their robotic research on the specific features of each application in close collaboration with users (hydrologists, biologists and archaeologists). All experiments are carried out under the supervision of specialists or the relevant authorities and in strict compliance with regulations (biology, archaeology).

▼ *Ulysses underwater robot exploring a karst network.*
Lighting: Mehdi Dighouth, Manu Dugrenot. Photo: Frank Vasseur.

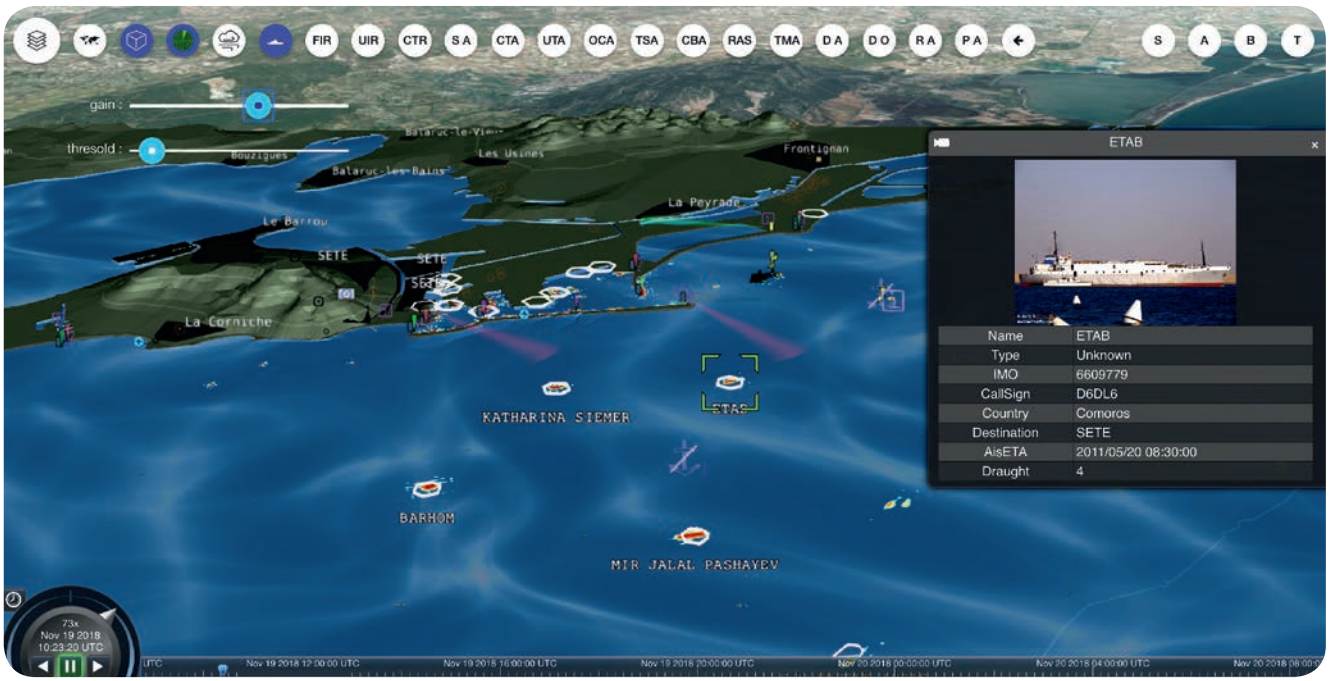


Geospatial data for harbour management

GEOMATYS has been developing solutions for the management, processing and distribution of geospatial data for more than a decade. Highly influenced by the maritime world and concomitant information system needs, we have gradually developed **a unique technological environment capable of handling most multidimensional formats specific to the oceanographic environment and more broadly the maritime world**. On the strength of this expertise and in the light of the current trend towards a constant increase in scientific data volumes in this discipline, we have managed to build up a package of big data processing tools that are now used by major concerned stakeholders in France and abroad. Our intervention range thus spans various areas, such as remote sensing, model implementation, real-time and historical data management and processing, data science and complex data display.

GEOMATYS—with our broad range of expertise, combined with the development of a highly advanced technical environment—is particularly active in the fields of the environment and biodiversity, the development of observatories for nature conservation, the installation of oceanographic information systems, while also being involved in the development of solutions for harbours and in the creation of mission management systems for the naval sector. The company uses all of its above-mentioned technical skills to develop harbour management and supervision solutions. It combines real-time exploitation of coastal radar data, cross-referencing with automatic identification system (AIS) data, while also making effective use of meteorological and oceanographic real-time and forecast data. **The aim is to mainstream all this information into a virtual reality tool to facilitate the interpretation of phenomena, thereby promoting faster and more reliable decision making.**

Contact (GEOMATYS): V. Heurteaux, vincent.heurteaux@geomatys.com



▲ *Screenshot of the RADAR signal coupling software with AIS tracking in Sète harbour (France).* © GEOMATYS

Digital revolution for the benefit of maritime transport and the sea

Boat designs are now impacted by the digital revolution. The technology underlying dynamically positioned vessels—which was a breakthrough just a few years ago—is now available for most commercial vessels. The unmanned boat trend is gaining momentum, with the first container carriers being planned for short commercial lines. Driverless cars are able to manage multiple hazards that occur on roads, but the challenges facing unmanned ships are not any greater, on the contrary.

The next step will certainly involve 'flying' boats, i.e. automatically regulated foil boats. Reinvented by Eric Tabarly in 1980 and adopted by the America's Cup in 2013, **foils are underwater wings whose lift forces the boat hull out of the water and has the advantage of considerably reducing the boat's resistance to advancing, thus making it possible to go just as fast while using less energy.** Foils are currently used in all water sports, but they must be simple, accessible and safe if they are to be included in the design of sailboats and motorboats. With the advances achieved in digital sciences, the next boats will be equipped with so-called second generation foils which—like on a pilotless aircraft—are regulated in real time, thus giving perfect stability for flight just above the water surface. On the boat, motion sensors for the heading, height, speed, acceleration, etc., send information that is processed in real time by a powerful algorithm capable of controlling the foil lift to a central unit via electric actuators. Controlling a boat equipped with four regulated foils is thus very close to the procedure used to control aircraft wing flaps from takeoff to landing. This advanced digital technology significantly reduces the energy required for advancement, to the extent that electric propulsion boats could now be taken into serious consideration. Having boats that consume less fossil fuel and are much quieter underwater would indeed be a real benefit for the marine environment.

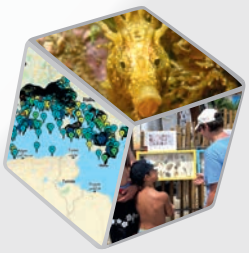
Contact (NEOCEAN): V. Dufour, vincent.dufour@umontpellier.fr

▲ *View of an Overboat – the first electric boat with regulated foils for the general public. It is the size of a jet ski while being perfectly silent, stable and very energy-efficient.* © NEOCEAN

▲ © *Joachim Hocine*

"What becomes of democracy if scientific culture is not disseminated? [...] The 'science and society' debate is an essential debate for the future." (Louis Malassis, Founder of Agropolis International, in a 2002 interview)

Innovative scientific mediation and citizen science



Today, mankind's impact upon marine and terrestrial biodiversity is widely recognized… Species are disappearing, continents of plastic emerging, ecosystems declining… How can we reverse these trends? We must first change a number of our habits and behaviours, in particular those that shape our everyday lives. Here, research plays a key role in increasing knowledge and understanding of these issues, finding solutions and, ultimately, eliciting more intelligent behaviour… However, change will be difficult if this knowledge is not shared with citizens! Herein lies the challenge of scientific mediation.

Scientific mediation (re)connects science to the larger society by disseminating knowledge, ideas, scientific results, recommendations and know-how. Over the ages, this 'science-citizen gateway' has taken on many forms—ranging from the 16th and 17th century's cabinets of curiosities to 21st century's social media (You Tube, Facebook etc.), and, along the way, including thematic workshops, exhibitions, videos, plays, etc.—, all of which give the general public an opportunity to take stock of their knowledge and behaviours while taking ownership of existing solutions! Thus, scientific mediation involves a wide range of stakeholders—museums, non-profit organisations, research laboratories, etc. In Occitanie, there are a number of scientific mediation actor networks,—such as the GRAINE Occitanie network and the *Science Animation* group—which set up and lead actions to support scientific, technical and industrial culture in the region, and support stakeholders in this endeavour.

Without providing an exhaustive list, the first part of this chapter presents a few examples of scientific mediation endeavours in the shape of different exhibitions targeted at the general public. Some of these exhibitions—such as the MARBEC's exhibition "Eelgrass, Meadows Under the Sea" *(Zostères, des prairies sous la mer)*—are coordinated by researchers. Others are coordinated by mediation professionals (always in coordination with scientists) such as the exhibition "Planet Sea" *(Planète Mer)* created by the Science Animation group and the Quai des savoirs. Designed and run by scientists from all disciplines, the Climate Train is a unique and original form of scientific mediation in France, combining a scientific exhibition and travelling participatory conferences on climate change related issues. Some public research laboratories also devote specific venues to scientific mediation, as in the case of the Banyuls-sur-Mer Oceanologic Observatory and its Biodiversarium (OOB). As for the Kimiyo association, it develops approaches to ecotourism that raise holidaymakers' awareness of the environmental issues affecting their holiday destinations, thereby working towards sustainable and environmentally friendly tourism. The Seaquarium, one of Occitanie's major tourist attractions, even created its own Marine Institute in order to share scientific knowledge with aquarium visitors, as well as develop scientific projects involving citizens…

Indeed, scientific mediation cannot be dissociated from citizen science, which is addressed in the second part of this chapter. It is now widely recognized that everyone—experts or novices with a passion for nature, students or maritime professionals—can contribute to scientific knowledge. Indeed, any citizen can voluntarily participate in the collection of large amounts of data, repeatedly, and in accordance with simple protocols answering scientific questions—data that researchers cannot obtain alone!—and help the scientific community in its research activities. Such citizen science programmes are particularly useful for monitoring the natural environment on large geographical scales and/or over long periods of time, in order to, for example, monitor marine biodiversity or the impact of climate change on the environment. Ultimately, the new knowledge acquired can help local authorities and natural area managers develop sustainable management plans and/or resource conservation and environmental protection strategies. Moreover, encouraging citizens to follow specific protocols raises their awareness and makes them curious about environmental change.

The citizen science programmes presented in this second section are conducted by observer-citizen and research laboratory partnerships. In the maritime and coastal domain, the Sentinels of the Sea Occitanie network, coordinated by the Thau Lagoon Permanent Centre for Environmental Initiatives (CPIE), brings together the leaders of the region's citizen science programmes, several of which are described below. For example, "Cybelle Mediterranean" is one of the few programmes that involves both boaters and experienced naturalists in the monitoring of offshore marine animals. "Devil fish" *(Diable de mer)* is another programme that records observations of devil fish species throughout the Mediterranean Basin, thanks to a network of amateur observers and maritime professionals. The "Seahorse Survey" *(EnQuête d'Hippocampes)* programme collects information and conducts ecological field studies on two seahorse species with the participation of divers, fishermen and amateur naturalists. "Species that matter" *(Des espèces qui comptent)* is a programme that brings together divers, freedivers and volunteer underwater fishermen, to perform censuses of three emblematic Mediterranean species (grouper, brown meagre and mother-of-pearl). In addition, several entities whose primary mission is to preserve the marine environment—such as the Gulf of Lion Marine Park or the Cerbère-Banyuls Marine Reserve—are also promoting citizen science involving both scientists and volunteer citizens in the monitoring of populations of blue sharks (a 'critically endangered species' in the Mediterranean according to the IUCN), for example, or the environmental surveillance of invasive species. Finally, this chapter ends with the story of 'Louise' the turtle, another example of coordinated multi-stakeholder action, bringing together maritime professionals, non-profit organisations working towards the conservation of protected species, and public research institutions…

John Bandelier (Kimiyo)

Marine environment scientific mediation

Science Animation, a multifaceted stakeholder

For over 30 years, in collaboration with its scientific, educational and industrial partners, *Science Animation* has been developing and promoting venues, events, online communities and projects to make science, technology and innovation accessible to all. Since 2017, ***Science Animation* has been coordinating a consortium of non-profit organisations*, commissioned by the Occitanie Region to promote and implement actions that will support the development of a scientific, technical and industrial culture (CSTI) in Occitanie, and to support stakeholders in this endeavour**. These non-profit organisations are collectively developing mobile resources, setting up projects and conducting actions in the entire region. For the last several years, *Science Animation* has been experimenting with new scientific and technical mediation formats, drawing in particular upon new technologies, co-creation, participatory approaches and even entertainment culture. In 2017, *Science Animation*, together with *Quai des Savoirs*, organized a major oceanography exhibition: *Planète Mer** (see next page). In 2018, as part of the series of researcher video portraits "Who seeks…seeks" *("Qui cherche… cherche")* directed by Jacques Mitsch, *Science Animation* produced the portrait of Julie Deter, a marine ecology researcher at ISEM*.

Contact (Science Animation): J. Langot, contact@science-animation.org

*** For further information**: www.science-animation.org
Planète Mer Exhibition: www.science-animation.org/fr/actus-et-coulisses/2180-toulouse-figee-dans-les-glaces
Portrait of J. Deter: https://youtu.be/-dM9k-J6JWg

GRAINE Occitanie: creating a networking dynamic

For approximately the last fifteen years, GRAINE has been propelling a regional 'Sea and Coast Education' networking dynamic. The main objective is the exchange and pooling of skills, programmes, tools, information and resources, in order to increase different audiences' awareness of the sea and coast. Other objectives are the creation of a collective culture on these issues and the fostering of partnerships. **This network gathers all stakeholders able to inform, raise awareness, train and/or educate different audiences about the sea and the coast (non-profit organisations, scientists, local authorities…).** This translates into discussion and discovery events, alternating field visits, experts' conferences, good practice exchange workshops, and also enables the creation of pedagogical tools designed, built and shared in a networking dynamic.

How can we talk to the general public about marine ecosystems fragility or coastal erosion? How can we address lagoon pollution and question traditional practices? How can we talk about the *Limicolae* and *Laridae* nesting and the impact of human activities on beaches? How can we introduce young people to marine ecosystems? All these questions are addressed by GRAINE's projects and pedagogical tools in order to put territorial issues into perspective, and promote environmental awareness. In this way, various tools have been created by the Sea and the Coast network, including:
- *Gibbule*: an educational kit for Occitanie environmental educator working on the topic of the coast
- *Aucèl*: an educational van, which is open to the public and proposes activities related to the coast (as part of the Life+ Lag'Nature project)
- *Laromobile*: a cart that raises awareness of coastal birds (as part of the Life+ ENVOLL project)
- *La mer sur un plateau:* a tool for discovering marine environments, marine biodiversity and human activities in the Mediterranean (supported by the French Biodiversity Agency and the Occitanie Region).

Contact (GRAINE Occitanie):
E. Launay, emilie.launay@graine-occitanie.org

For further information:
www.graine-occitanie.org

Echosciences Occitanie: a regional social media dedicated to science and innovation

Articles, general public calendar, online communities, map of cultural and scientific locations worth visiting... This platform, made by and for people passionate about science, invites people to discover what is happening in the region, contribute to CSTI dissemination by posting articles and events, and get in touch with other members of *Echosciences Occitanie*.

For further information:
www.echosciences-sud.fr
Discover OOB articles, e.g. "How does the sea cool down in autumn?" ("Comment la mer se refroidit-elle en automne?"):
www.echosciences-sud.fr/articles/boss-comment-la-mer-se-refroidit-elle-en-automne

▼ *Aucèl educational van, Peyrefite beach (Gardes-barrières, Pyrénées-Orientales, France).* © *J.F. Planque*

The new Climate Train: from national to regional

In October 2015, a train with a climate exhibition on board, travelled throughout France, stopping in 19 cities, and meeting over 23,000 visitors, including 3,500 schoolchildren and 1 100 decision-makers. This innovative venture was initiated, developed and conducted by a small team of three researchers from Toulouse, with the support of an engineer specialized in scientific culture mediation. Travelling on board was **an interdisciplinary working group of scientists from some thirty research institutions and/or laboratories, known as the 'Climate Messengers'.** With their combined expertise in fields ranging from basic sciences to human and social sciences, these Climate Messengers aimed to exchange knowledge and scientific enquiries about climate change, in the broadest possible sense. Of all the COP21 labelled events, the Climate Train proved to be the only one with national breadth extending beyond the Île-de-France Region, and covering such a large part of the country. Open to all, and accessible in the city centres, the Climate Train created a new space for the scientific community and the general public to meet and share knowledge about climate change.

Building on the success of this first train, a new project was designed to meet the many requests from cities that had not been visited in 2015. A new partnership was forged between the Climate Messengers and the French national railway company, SNCF in order to reach further into the territories. The exhibition has evolved, with a greater orientation towards potential solutions to climate change. It is installed on a regional train (TER), which has been specially converted for this purpose, and which will tour those regions of France that volunteer to welcome and support it. In 2020, the Climate Train will make stops in several cities in the Nouvelle-Aquitaine Region and will reach the Occitanie Region in early 2020. **A large part of the exhibition will be dedicated to the impacts of climate change on the marine environment and the coast—with a specific focus upon rising sea levels—as well as the adaptations required**.

Contacts: C. Jeandel (LEGOS), catherine.jeandel@legos.obs-mip.fr, C. Alazard (*Train du Climat*), caroline.alazard@trainduclimat.fr, C. Cassou (CERFACS), christophe.cassou@cerfacs.fr and S. Planton (CNRM), serge.planton@meteo.fr

For further information: https://trainduclimat.fr

© *Train du Climat*

Exhibition: observe and understand Planet Sea (*Planète Mer*), lead the investigation!

2180... Toulouse... The roads are out of service, airplanes are immobilised, the Garonne and the Canal du Midi are completely frozen... This is how the first words of the exhibition's disaster scenario resound. After taking stock of the overall situation in the entrance hall, which presents climate change challenges, oceanography and this discipline's international dimension, visitors embark into the exhibition in order to investigate the following question: why and how could the climate have been disrupted so dramatically? In their quest, they learn about spatial oceanography, travel deep into the ocean thanks to a virtual reality helmet, integrate a sea campaign, inquire into the *El Niño* phenomenon, and go to the laboratory to analyse their samples. A *bona fide* science fiction scenario, but **a real dive** nonetheless **into the daily life of an ocean scientist, reminding visitors of the essential relationship between the climate and the oceans.**

Co-organized in 2017 by *Quai des Savoirs* and *Science Animation*, the Planet Sea exhibition's objective was to introduce people to oceanography and its challenges, as well as raise their awareness about climate issues. Major issues were illustrated by the presentation of objects, experiments, pictures, films… as well as by poetic and stirring artistic pieces. Javiera Tejerina-Risso's "To Record Water during days", a monumental metallic installation connected to seven *in situ* and operational ocean buoys, moved in sync with the live rhythms of ocean swells from around the world, illustrating oceanography's planetary dimension. The Proyectarium aquarium, a digital art piece created for the exhibition, gave visitors an interactive immersion into an imaginary aquarium whose acidity and temperature conditions evolved over the course of the exhibit, impacting the aquarium's biodiversity as a result… This innovative exhibition, based upon an investigation game, brought together the National Centre for Space Studies (CNES), Météo-France, Mercator Ocean International, the National Centre for Scientific Research (CNRS) and Toulouse University. The following two other initiatives were also dedicated to oceans and climate change: the 2017 edition of the *Lumières sur le Quai* festival and the *El Niño-La Niña* interactive exhibition, designed in partnership with Toulouse *Cité de l'espace*, and Medellin *Parque Explora* Museum (Colombia).

Contacts: M. Leonard (*Quai des Savoirs*), marina.leonard@toulouse-metropole.fr and J. Poirier (*Science Animation*), julie.poirier@science-animation.org

For further information:
www.quaidessavoirs.fr
www.science-animation.org

The "Eelgrass, Meadows Under the Sea" (*Zostères, des prairies sous la mer*) exhibition: immersion into the depths and laboratory life

This project began in 2015 at MARBEC laboratory under the impetus of two researchers: Francesca Rossi who works on eelgrass beds diversity, functioning and conservation, and Frédérique Carcaillet who focuses on the transfer of research knowledge to the general public, and the training of students on scientific mediation and scientific museography. These two researchers combined their skills and knowledge, and made the following proposition to the *Fondation de France*: **the creation of a travelling exhibition to raise awareness among citizens and decision-makers about the crucial role that eelgrass ecosystems and their biodiversity play in the functioning of aquatic environments and related activities** (fishing, shellfish farming, tourism…). Indeed, eelgrass beds are threatened all over the world, and this exhibition's objective is therefore to raise awareness and generate the behavioural changes necessary in order to strengthen the last few years' seagrass beds conservation initiatives.

The exhibition design was entrusted to several students* under Frédérique Carcaillet's supervision. The students contributed their skills in ecology, science popularisation, exhibition design, and computer graphics, in partnership with the Thau Lagoon Museum in Bouzigues. Together with the exhibition, the students also created a pedagogical booklet for primary school teachers and schoolchildren, complete with activities to be carried out before, during, and after the visit, a game booklet for children and animated films to be viewed during the exhibition and on a You Tube channel. In June 2017, the Regional Directorate of Cultural Affairs (DRAC Occitanie) financed a certain number of activities on the beach of Bouzigues in connection with the exhibition then being hosted by the Thau Lagoon Museum. First installed in Bouzigues in May 2017, the exhibition was then displayed on the shores of the lagoons of Salses-Leucate (Port-Leucate), Berre (Marignane, Saint Mitre-les-remparts, Miramas), and Thau (Sea Museum, Sète), as well as on the shores of the Arcachon Basin (*Domaine de Certes-Graveyron*). From January 2019 onwards, the exhibition will be hosted by the *Maison départementale de l'environnement* (*Domaine de Restinclières*, Hérault).

Contact (MARBEC): F. Carcaillet, frederique.carcaillet@umontpellier.fr

For further information:
www.facebook.com/herbierszosteres
Workshops - Animated scientific films:
www.youtube.com/watch?v=Uztvp74OhPA&t=31s&index=10&list=UUdMXIvXqFZxiSFtsnFUQiZg

* IEGB Masters (Ecological Engineering and Biodiversity Management Engineering) and ACCES Masters (Facilitation, Communication, Culture, Science Education)

© *Frédérique Carcaillet*

The Biodiversarium: science in a Mediterranean aquarium and garden

The Biodiversarium, OOB's scientific mediation service, combines an aquarium and a scientific Mediterranean garden. Its objectives are to **present the Pyrénées-Orientales Department's terrestrial and marine biodiversity to the general public and to schoolchildren by providing an insight into the research conducted by OOB (see p. 87) and its partners.** Each horizontal strata of this territory's remarkable biodiversity finds its place within an exceptional land-sea continuum, and many of the ecosystems that are represented within the Biodiversarium, fall within the area's protected sites (*Forêt de la Massane* National Nature Reserve, Cerbère-Banyuls Marine Reserve, the Gulf of Lion Marine Park, etc.). The Biodiversarium maintains close links with these protected sites in order to strengthen appreciation of the treasures that they hold.

The public aquarium is located in a building that also hosts research aquariums, a technological platform dedicated to marine biotechnology, a pedagogical laboratory, a remote learning room and research laboratories. The various activities conducted in the building are partially visible to the public. The garden includes several outdoor areas dedicated to presentation of the local terrestrial flora and fauna, as well as museographic areas that complete the visit and enrich visitor experience (exhibitions, interactive models, pedagogical laboratories, etc.). **The Biodiversarium —in particular the aquarium—is a unique scientific mediation tool in Europe. Thanks to the many interfaces created with the on-site research laboratories, visitors can closely observe scientific activity** (research aquariums, technological platforms, laboratories, etc.). The educational rooms, equipped as real research laboratories, welcome close to 4,000 schoolchildren each year, giving them the opportunity to participate in scientific or naturalist workshops. The Biodiversarium's facilitators also engage remotely with schools using information and communication technology. The Biodiversarium is therefore an innovative and modern tool, whose mission is at the heart of the science-society debate, thanks to its dual naturalist and scientific configuration.

Contact (Biodiversarium/OOB):
P. Romans, pascal.romans@obs-banyuls.fr

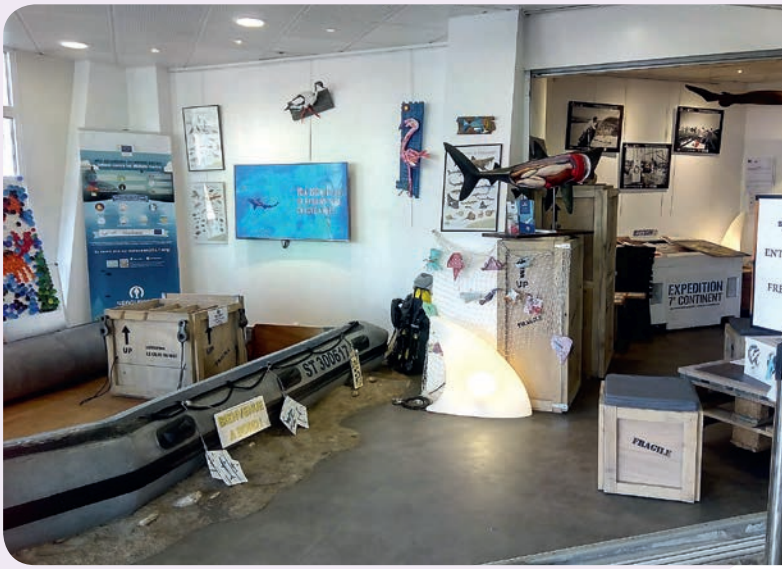
For further information: www.biodiversarium.fr

Posidonia meadows, one of the underwater biotopes reproduced in the aquarium. © *Pascal Romans*

AN AQUARIUM'S COMMITMENT TO POPULAR SCIENCE

For several years, Seaquarium (Grau du Roi's aquarium) biologists and animal care staff have been involved in a number of marine world protection research programmes. With over 320,000 visitors annually, the Seaquarium is also a major tourist attraction in Occitanie. How can these two universes be brought together? How can science be shared with citizens? How can citizens be committed to marine ecosystem protection? To answer these questions, the Seaquarium, together with all of its staff, devised its *Institut Marin*: a public venue providing resources and sharing scientific knowledge. It is a place to imagine and build new projects to preserve the Mediterranean's marine environments, open to all: researchers, non-profit organisations, citizens passionate about nature, responsible citizens etc. Thus, the 'Marine Institute for Mediterranean Ecosystems' non-profit organisation was created in December 2016, to support the Seaquarium, and Seaquarium's Marine Institute opened its doors in June 2017.

Overlooking the aquarium hall, a 25m^2 area has been designed to stir the curiosity of visitors. "Come board a zodiac for a scientific mission at sea", "Here, fishermen are tackling waste, you can make a difference too", etc. Visitors are drawn in so that they may share in scientific knowledge and become more aware about which behaviours to adopt in order to preserve marine environments. These issues are sometimes addressed further in the aquarium. Given that the Institute also acts as an ambassador for the Sentinels of the Sea Occitanie network (see next page), citizen science programmes are also explained, relayed and promoted here, and new research projects and innovations developed.



▲ *The marine institute's public entrance hall.* © *Seaquarium Marine Institute*

Contact (Marine Institute for Mediterranean Ecosystems): J.-M. Groul, institutmarin@gmail.com

For further information: www.seaquarium.fr/en/marine-institute

Ecotourism and scientific heritage: discovering the Thau Lagoon

Based in the Thau basin, Kimiyo is a non-profit organisation focusing on the dissemination of scientific culture, which fosters exchange and cross-fertilisation between different disciplines in order to share knowledge from all fields with the general public. How can scientific culture be made relevant to the tourism sector? One of Kimiyo's initiatives is to introduce holidaymakers to an emblematic marine research venue—Montpellier University's (UM) marine station in Sète—as well as to the unique biodiversity of the Thau Lagoon where the marine station is located. Since its creation in 1879, this station has been supporting research, observation and teaching in the field of marine biology. In partnership with Thau Basin's CPIE, every summer Kimiyo also organises fishing from the shore for holidaymakers in the marine station's surroundings, so that they can discover the lagoon's fauna and flora, as well as the marine station's history and its research activities. Thus, tourists take on the role of the 19th century naturalists who used to fish, identify and classify species. **This form of ecotourism helps the public to consider their holiday destination with a new perspective, to become aware of the surrounding biodiversity, and, *in fine*, to participate in the development of sustainable and environmentally friendly tourism.**

Contact (Kimiyo): J. Bandelier, john@kimiyo.fr

For further information: http://kimiyo.fr

© *Kimiyo*

A few examples of research-supporting citizen observation programmes

Sentinels of the Sea Occitanie, an *in situ* marine, lagoon and coastal citizen science network

Sentinels of the Sea Occitanie —coordinated by the Thau Basin CPIE since 2015—is **a network that brings together leaders of *in situ* marine and coastal citizen science programmes in Occitanie**. The network invites citizens to contribute to science and environmental conservation by participating in 16 programmes* out at sea, on lagoons and along the coast. After having coordinated and promoted various citizen science programmes (Hippo-THAU-see p. 122, MedObs Sub**, BioLit**) within its territory, and in response to the public's enthusiasm for this type of initiatives, Thau Basin's CPIE brought together various stakeholders involved in marine environment protection (scientists, natural areas managers, local authorities, programmes leaders, environmental education organisations) in order to create a federating network and promote marine and coastal citizen science.

All citizens can contribute to one or more of these programmes during their activities on the water, underwater, or along the coast. In this way, Sentinels of the Sea Occitanie federates a true community of regional observers while disseminating good practices for the natural environment. As a result of the development of citizen knowledge of the territory's biodiversity, environmental awareness is one of network's pillars. In addition to environmental awareness and education, **Sentinels of the Sea Occitanie contributes to the management of natural areas and the study of ecological challenges**. Indeed, collected data can be used by researchers, local authorities and/or natural areas managers in order to improve collective knowledge and implement management plans for specific protected species (e.g. groupers, pen shells (*pinna nobilis*), sea turtles) or remarkable sites. The involvement of managers and scientists in this network enables more effectively targeted field actions to be conducted for the protection and respect of the species.

BioLit citizen science field trip organized by Thau Basin's CPIE© CPIE Bassin de Thau

** MedObs Sub: Mechanism to monitor the marine environment's state of health, installed by the Water Agency Rhone Mediterranean Corsica, on the French Mediterranean coast.
BioLit: a national citizen science programme on coastline biodiversity led by Planet Sea.

Contact (CPIE Thau Basin): E. Emmanuelli, e.emmanuelli@cpiebassindethau.fr

*** For further information on these 16 programmes:** www.sentinellesdelamer-occitanie.fr

CYBELLE MEDITERRANEAN: COLLECTING AND SHARING OF MARINE FAUNA DATA

Cybelle Mediterranean is a citizen science programme that brings together boaters, maritime professionals and experienced naturalists to improve knowledge of offshore marine fauna (cetaceans, fish, sea turtles, rays, sharks, birds and macroplankton). Run since 2009 by the *Cybelle Planète* organisation, this programme enables amateurs to easily report their observations of pelagic species at sea. Data is collected by boaters and by members of the sea expeditions organized each year by the organisation. Since 2009, close to 1 600 boaters have enrolled in the programme and 1,500 people have taken part in expeditions. As a result, over 15,000 observations have been reported throughout the Mediterranean Basin.

Drawing upon this experience, in 2016-2017 *Cybelle Planète* partnered with Cotentin's Cetaceans Study Group to co-create a set of digital tools for collecting data at sea: OBSenMER. A mobile application that enables easy observations reporting at sea, with entries into three levels of expertise: opportunistic observations and sighting effort observations (for the general public), and expert observations following a scientific protocol (for experienced naturalists only). A common database brings together the collected observations. Depending on the programme, this database may be public (open sharing) or private. Finally, a collaborative web platform*, makes it possible to consult, manage and share data, and to access to a cetacean photo-identification catalogue. The entire set of OBSenMER tools is shared freely with other organisations collecting and/or using data. The OBSenMER network is divided and administered by geographical area. *Cybelle Planète* administrates the Mediterranean Sea area, with the participation of twenty-three naturalist and/or sailing organisations, institutions, research laboratories, etc., and the sharing of long-term and large-scale homogeneous, standardized data.

Contact (*Cybelle Planète*): C. Arnal, celine.arnal@cybelle-planete.org

For further information: www.cybelle-planete.org/en

* www.obsenmer.org

▼ *Map of the observations reported in the Mediterranean Sea with OBSenMER.*
© Cybelle Planète

IMPROVED UNDERSTANDING OF THE CERBÈRE-BANYULS MARINE RESERVE FOR IMPROVED PROTECTION

Created in 1974, the Cerbère-Banyuls Marine Reserve is located at the heart of the Vermeille Coast. Covering an area of 650 hectares, it stretches along 6.5 kilometres of coastline, between the Banyuls-sur-Mer and Cerbère municipalities. The Reserve has adopted a management plan, in order to plan actions over a 5-year period, with a significant focus upon natural heritage conservation.

Improved understanding leads to improved protection. Scientific monitoring improves knowledge of the marine environment. To this end, the Reserve manager has established a network of partners whose objective is to gather information on the marine environment. Thus, diving observers collect data in compliance with a defined protocol. This monitoring, with the involvement of scientists and volunteer citizens, helps the Reserve manager take all the measures required to maintain this fragile ecosystem in a perfect state of conservation. Permanent environmental surveillance of invasive species such as filamentous algae, *Caulerpa taxifolia* and *racemosa* is ensured in collaboration with the sentinel divers. This surveillance is a true priority for the Reserve and provides valuable information to the manager. Involving users give them the opportunity to take responsibility for their territory and participate in its protection. Management orientations can then be jointly defined, making this site a place where managers and users take joint action with a common objective.

Contact (Cerbère-Banyuls marine reserve):
F. Cadene, frederic.cadene@cd66.fr

For further information:
www.ledepartement66.fr/62-la-reserve-marine-de-cerbere-banyuls.htm

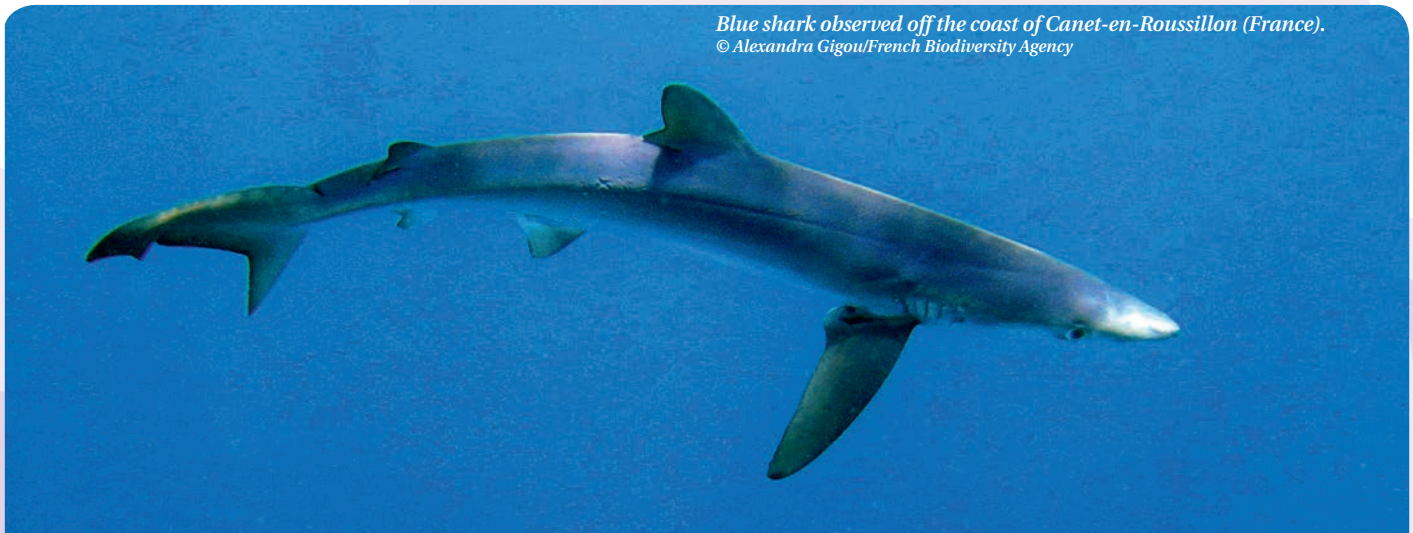
▲ *Sampling of filamentous algae for purposes of analysis.*
© Didier Fioramonti

GULF OF LION MARINE PARK: IMPROVING KNOWLEDGE OF THE BLUE SHARK

The Gulf of Lion Marine Park is a marine protected area covering over 4,000 km² off the coast of the Pyrénées-Orientales and Aude Departments. Dedicated to the marine area's integrated management, the park's ambition is to respond to three interrelated objectives: knowledge of the marine environment, protection of the marine environment, in particular of its marine habitats and species, and sustainable development of maritime activities. The park is also involved in citizen science actions that contribute to meeting these objectives. Thus, since 2016, in partnership with volunteers from the *Ailerons* organisation and recreational fishermen members of the National Boating and Sea Fishing Federation, the park organizes a day at sea to meet blue sharks (*Prionace glauca*). The crews participating in the event collect information on sharks that are caught and then released: size, sex, and samples for genetic analysis. This citizen science initiative improves knowledge of this species. The blue shark is medium in size, usually between 1.80 and 2.40 meters. It has a slender and supple body, and is known as the 'blue shark' because of its dark blue back and bright blue flanks. It is an oceanic shark, which can be observed off the coasts of the marine park from May through to September. It feeds mainly on small pelagic fish, such as anchovies, herrings and sardines, and can have up to 135 pups per litter, measuring 35 to 52 cm at birth. Although it is extremely threatened, the blue shark is not yet protected in the Mediterranean, and continues to be hunted and traded. The first eco-responsible step is to stop consuming its meat. The Gulf of Lion Marine Park belongs to the French Biodiversity Agency, a public institution created in January 2017, attached to the Ministry of Ecological and Solidarity Transition.

Contact (Gulf of Lion Marine Park):
A. Gigou, alexandra.gigou@afbiodiversite.fr

For further information:
www.parc-marin-golfe-lion.fr
www.facebook.com/parc.naturel.marin.golfedulion



Blue shark observed off the coast of Canet-en-Roussillon (France).
© Alexandra Gigou/French Biodiversity Agency

Understanding seahorses and their vulnerability

Created in 1995, the *Peau-Bleue* organisation (based in Agde) aims to better understand and increase awareness about marine life. In 2005, in response to the lack of knowledge about seahorse ecology in France, and in particular of their vulnerability to anthropogenic impacts, *Peau-Bleue* launched the **Seahorse Quest programme *(EnQuête d'Hippocampes)* in order to collect information and conduct ecological field studies of seahorses**. This programme studies the long-snouted seahorse (*Hippocampus guttulatus*) and the short-snouted seahorse (*H. hippocampus*), as well as other species from the Syngnathidae family (pipefish). **It combines participatory surveys in which marine environment users are solicited (project Hippo-ATLAS), and *in situ* studies and monitoring, again with a citizen science approach, notably through strong involvement of amateur divers:**

- Implemented since 2005, in partnership with the Thau Basin's CPIE (Permanent Centre of Initiative for the Environment), the Hippo-THAU pilot-project has been able to further understanding of the ecology of seahorses and pipefish in the Thau Lagoon thanks to strong societal mobilisation (divers, shellfish farmers, fishermen, schoolchildren etc.). Findings have shed light on **their habitat preferences, and shown important population fluctuations, which seem to reflect the natural variability of the lagoon environment**. Unprecedented observations have been made of seahorse juvenile ecology and development.
- Since 2016, the Thau seahorse singularity project has been documenting the **morphological differences between two genetic lineages of long-snouted seahorses** (the Thau lagoon type and Mediterranean marine type) **using a photo-morphometric approach.** Implemented in partnership with Thau Basin's CPIE and ISEM*, this project builds upon the compilation of seahorse images from underwater photographers.
- Since 2012, in partnership with the Seaquarium's Marine Institute and with the support of many volunteer divers, a regular monitoring operation has been underway to track the Espiguette sandbank short-snouted seahorses. **The monitoring programme's results have convinced local authorities and project leaders that sand-dredging operations in the area should not be permitted to impact this vulnerable species**.

Today, the *Peau-Bleue* organisation is the main French centre of expertise on seahorses and Syngnathidae. This scientific expertise is also citizen expertise, as it has been built with the whole of civil society.

Contact (*Peau-Bleue*):
P. Louisy, patrick.louisy@wanadoo.fr

For further information: www.peaubleue.org

* ISEM teams 'Speciation, Evolution and Adaptation in the Marine Environment' and 'Macroevolution and Development' with the support of the Total Foundation.


Hippocampus hippocampus. © *P. Louisy*


Hippocampus guttulatus. © *P. Louisy*

"Devil fish", a citizen science project in service to an endangered species

The devil ray (*Mobula mobular*) is an endemic Mediterranean ray, which can sometimes measure up to 5.20m in size. Often confused with the tropical and equatorial water manta ray, the devil fish is only present in the Mediterranean, both along the coast and offshore, and feeds on plankton and small fish. Unfortunately, the devil ray is also an endangered species, falling prey to accidental catches, including unintentional by-catches in drift nets, and therefore recognized as 'in danger of extinction' by the IUCN. Its protection is made more complicated by the fact that it is rarely observed, and remains relatively unknown (biology, behaviour, population size, etc.).

In response to this situation, in 2010*, the Ailerons organisation, which is based in Montpellier and works to protect sharks and rays in the Mediterranean, launched the "Devil ray" citizen science project in order to improve scientific knowledge of this species. The project's objective is to **create and coordinate a network of observers, including the general public and maritime professionals from across the Mediterranean Basin, in order to record observations of this species. Since 2014, collected data has been transmitted to the National Museum of Natural History and integrated into the Natural Heritage's National Inventory to help improve conservation strategies. Thanks to this project and the involvement of the network of observers, the largest database ever compiled on this species has been created. Data has notably demonstrated the disturbing conservation status of the species, which is now identified as a target species in several marine protected areas including the Gulf of Lion Marine Park.**


Devil fish. © *P. Trelut*

Contacts (*Ailerons*):
W. Travers and M. Lapinski, contact@asso-ailerons.fr

For further information: http://asso-ailerons.fr

* This project is still on-going in 2018.

Recreational divers in search of the Calanques Park's emblematic species

Since 2003, over 1,800 divers from the French Federation for Underwater Studies and Sports (FFESSM) have participated in 15 successive grouper, brown meagre and mother-of-pearl species observation campaigns and census operations both in the Calanques National Park and elsewhere in the Mediterranean (over 35 sites surveyed). Indeed, this is **the largest citizen science operation in the French Mediterranean in terms of numbers of participants and continuity.** It is the objective of these census operations to quantify local populations of these three previously over-exploited flagship species, in order to monitor their evolution. Many clubs from the Gard Department, divers from the Gard and Hérault Departments, as well as diving facilities from the Vaucluse, Var and Bouches-du-Rhône Departments, participate in this gathering every year.

▲ *Species that matter gathering, Marseille 2018.*
© Frédéric Fedorowsky

The inventory principle adopted in the grouper study Group (GEM) campaigns enables greater efficiency in the coverage of areas to be surveyed. Divers explore each site in detail, following parallel pathways, adapted to topography and visibility conditions, thereby enabling each observer to maintain eye contact with the others, in order to avoid duplication and ensure mutual safety. For each individual fish observed, several parameters are recorded: size, immersion time, depth, behaviour and habitat characteristics. These observations enable reliable information to be obtained thanks to a protocol that is easily reproduced on other sites. **The censuses conducted by amateur divers and scientists provide additional information to marine protected area managers. The strength and value of these inventories is that they bring together stakeholders from very diverse backgrounds (institutional representatives, managers, non-profit organisations, recreational users, scientists), raise awareness, and rally all participants (divers, freedivers, volunteer underwater fishermen) around a common unifying and eco-citizen operation targeted towards highly symbolic heritage species.**

Contact (Occitanie Committee/Calanques Park/GEM):
J. Cabaret, jean.cabaret@wanadoo.fr

LOUISE THE TURTLE OBSERVATION, CENSUS AND RESCUE ALERT

On Sunday 20 August 2017, a Thau Lagoon fisherman discovered a large living loggerhead sea turtle (*Caretta caretta*) in his nets. From the oyster spat on its shell, it was clear that the turtle had been in the Lagoon a long time. Immediately alerted, the *Société Herpétologique de France* (RTMMF-SHF)'s French Mediterranean Marine Turtles Network identified the species, collected information relating to the circumstances of the event, and then proceeded to direct the animal to the Centre for Research and Conservation of Mediterranean Sea Turtles (CestMed) care centre. During a brief observation period, biological samples were taken from the turtle, named Louise, and later analysed by the CEFE. Louise's release during the Thau Lagoon CPIE's "Sentinels of the Sea" *(Sentinelles de la Mer)* festival in Sète provided an opportunity to communicate with the general public and enabled Sète IFREMER to monitor the turtle's behaviour using a satellite beacon.

Indeed, Louise, like all her congeners visiting the French coast, contributes to improving our understanding of marine turtle biology, and also acts as an indicator of the marine environment's ecological state, monitored in the context of the European Union Marine Strategy Framework Directive. Louise's rescue is a good example of a concerted multi-stakeholder operation, bringing together professionals, non-profit organisations dedicated to protected species conservation and public research institutions. This type of operation falls under a national marine turtle conservation programme and is supported by the French Biodiversity Agency.

Contacts: J. Sacchi (RTMMF), rtmmf@lash.org, J.-B. Sénégas (CestMed) contact@cestmed.org and F. Poisson (MARBEC), francois.poisson@ifremer.fr

For further information:
RTMMF-SHF: http://lashf.org/rtmmf_info
CestMed: www.cestmed.org/language/en/
MARBEC: www.umr-marbec.fr

Loggerhead sea turtle upon release equipped with an Argos beacon.
© CestMed

Topics covered by the research teams *(January 2019)*

The main research entities mentioned in this *Dossier*, are listed in the following charts. A **dark colour** indicates a topic focused on by the research entity, while a **light colour** indicates a secondary topic, in which the entity is only involved on an *ad hoc* basis. The ratio 'number of scientists involved in the Sea and Coast thematics/total number of scientists' is also indicated for each research entity.

Chapter 1
Impacts of natural and anthropogenic forcing on Mediterranean marine dynamics

1.1. The ocean – a multiscale climate forcing agent
1.2. Formation and acidification of deep Mediterranean waters – the role of the Gulf of Lion
1.3. Combined impacts of meteorological/oceanographic factors – the case of *Cévennes* floods

Chapter 2
Biodiversity and dynamics of marine biological communities

2.1. Structure, dynamics and functioning of marine communities
2.2. Marine organisms: biological models and experimental platforms

Chapter 3
Scientific evidence of ocean vulnerability

3.1. Sea level variations and impact on the shoreline
3.2. Effects of continental inputs on coasts
3.3. Consequences of industrial and anthropogenic activities on the sea and on coastal areas
3.4. Endangered resources

Chapter 4
The basics of sustainable development of the 'sea system'

4.1. Ecosystemic management of fisheries and aquaculture
4.2. Maritime traffic, industrial and port activities
4.3. Biotechnologies, marine bio-engineering and ecological restoration of environments
4.4. Coastal risk management and adaptation to climate change
4.5. Marine Protected Areas and biodiversity conservation strategies
4.6. Marine energies

Chapter 5
Power of long-term observation and synergy of digital integration

5.1. Observatories and *in situ* data
5.2. Role of Earth observation satellite telemetry
5.3. Modelling, simulation and forecasting in the big data age
5.4. New digital services to benefit the community and coastal and maritime monitoring platforms
5.5. Innovative technology and tools

Chapter 6
Innovative scientific mediation and citizen science

6.1. Marine environment scientific mediation
6.2. A few examples of research-supporting citizen observation programmes

Public research teams and units	Number of scientists involved/ Total number of scientists	Chap. 1			Chap. 2		Chap. 3				Chap. 4						Chap. 5					Chap. 6	
		1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	5.4	5.5	6.1	6.2
ART-Dev (UMR) • ***Actors, Resources and Territories in Development (CNRS/UPVM/CIRAD/UM/UPVD)*** Director: David Giband, giband@univ-perp.fr http://art-dev.cnrs.fr	3/70						■			■		■		■									
BIOM (UMR) • ***Integrative Biology of Marine Organisms (Sorbonne University/CNRS)*** Director: Hector Escriva, hector.escriva@obs-banyuls.fr http://biom.obs-banyuls.fr/en	15/15				■	■		■	■														
BRGM • **Bureau de Recherches Géologiques et Minières *(Occitanie Regional Direction)*** Director: Ariane Blum, a.blum@brgm.fr www.brgm.eu	4/40			■			■	■	■					■		■	■	■	■	■	■		■
C2MA • **Centre des Matériaux des Mines d'Alès *(IMT Mines Alès)*** Director: José-Marie Lopez-Cuesta, jose-marie.lopez-cuesta@mines-ales.fr http://c2ma.mines-ales.fr	4/33											■	■	■		■							
CEE-M (UMR) • ***Centre for Environmental Economics - Montpellier (CNRS/INRA/Montpellier SupAgro/UM)*** Director: Brice Magdalou, brice.magdalou@umontpellier.fr www.cee-m.fr	8/31										■		■	■	■			■				■	
CEFE (UMR) • ***Centre for Functional and Evolutionary Ecology (CNRS/UM/UPVM/IRD/Montpellier Supagro/INRA/EPHE)*** Director: Richard Joffre, direction@cefe.cnrs.fr www.cefe.cnrs.fr/en	20/119				■	■				■	■	■	■	■	■	■	■		■		■	■	■

Public research teams and units	Number of scientists involved/ Total number of scientists	Chap. 1			Chap. 2		Chap. 3				Chap. 4						Chap. 5					Chap. 6	
		1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	5.4	5.5	6.1	6.2
CEFREM (UMR) • *Centre of Education and Research on Mediterranean Environments (UPVD/CNRS)* Director: Wolfgang Ludwig, ludwig@univ-perp.fr http://cefrem.univ-perp.fr	21/21																						
CNES (Toulouse Space Centre) • *National Centre for Space Studies* Director: Geneviève Campan, genevieve.campan@cnes.fr https://cnes.fr/en	10/150																						
CNRM (UMR) • *National Centre for Meteorological Research (Météo-France/CNRS)* Director: Marc Pontaud, marc.pontaud@meteo.fr www.umr-cnrm.fr/?lang=en	9/169																						
CRIOBE (USR) • *Centre for Island Research and Environmental Observatory (Paris PSL University: EPHE/CNRS/UPVD)* Director: Annaïg Le Guen, annaig.leguen@cnrs.fr www.criobe.pf/eng	35/35																						
ENTROPIE (UMR) • **Ecologie Marine Tropicale des Océans Pacifique et Indien** *(IRD/CNRS/Univ. of Reunion Island)* Director: Claude Payri, claude.payri@ird.fr http://umr-entropie.ird.nc	35/35																						
ESPACE-DEV (UMR) • *Space for Development (IRD/UM/Univ. de Guyane/Univ. of the French Antilles/ Univ. of Reunion Island)* Director: Frédérique Seyler, espace-dev@ird.fr www.espace-dev.fr	11/67																						
GET (UMR) • *Laboratoire Géosciences Environnement Toulouse (IRD/CNRS/UT3)* Director: Etienne Ruellan, etienne.ruellan@get.omp.eu www.get.obs-mip.fr	23/165																						
GM (UMR) • *Geosciences Montpellier (CNRS/UM/Univ. of the French Antilles)* Director: Benoît Ildefonse, dirgm@gm.univ-montp2.fr, benoit.ildefonse@umontpellier.fr www.gm.univ-montp2.fr/?lang=en	2/85																						
GRED (UMR) • *Governance, Risks, Environment, Development (IRD/UPVM)* Director: Bernard Moizo, bernard.moizo@ird.fr www.gred.ird.fr	8/53																						
HSM (UMR) • *HydroSciences Montpellier (CNRS/IRD/UM)* Director: Patrick Seyler, hsm-direction@umontpellier.fr www.hydrosciences.org/?lang=en	10/77																						
IHPE (UMR) • *Interactions Hosts-Pathogens-Environments (CNRS/UPVD/UM/IFREMER)* Director: Guillaume Mitta, mitta@univ-perp.fr http://ihpe.univ-perp.fr/en	16/25																						
IMAG (UMR) • **Institut Montpelliérain Alexander Grothendieck** *(CNRS/UM)* Director: Jean-Michel Marin, imag-direction@umontpellier.fr http://imag.edu.umontpellier.fr	9/98																						
INRIA-LEMON • *Project team "Littoral Environment: Models and Numerics" (INRIA)* Leader: Antoine Rousseau, antoine.rousseau@inria.fr www.inria.fr/en/teams/lemon	5/5																						
ISE-M (UMR) • *Institute of Evolution Sciences of Montpellier (CIRAD/CNRS/IRD/UM/EPHE)* Director: Agnès Mignot, isem-direction@umontpellier.fr www.isem.univ-montp2.fr/en	5/120																						
LA (UMR) • **Laboratoire d'Aérologie** *(CNRS/UT3)* Director: Céline Mari, celine.mari@aero.obs-mip.fr www.aero.obs-mip.fr	5/52																						
LBBM (USR) • *Laboratory of Microbial Biodiversity and Biotechnology (Sorbonne University/CNRS)* Director: Marcelino Suzuki, marcelino.suzuki@obs-banyuls.fr http://usr3579.obs-banyuls.fr/en	25/25																						
LECOB (UMR) • *Benthic Ecogeochemistry Laboratory (Sorbonne University/CNRS)* Director: Katell Guizien, guizien@obs-banyuls.fr http://lecob.obs-banyuls.fr/en	14/14																						
LEGOS (UMR) • **Laboratoire d'Études en Géophysique et Océanographie Spatiales** *(CNES/IRD/CNRS/UT3)* Director: Alexandre Ganachaud, alexandre.ganachaud@ird.fr www.legos.obs-mip.fr	63/72																						

Public research teams and units	Number of scientists involved/ Total number of scientists	Chap. 1			Chap. 2		Chap. 3				Chap. 4						Chap. 5					Chap. 6	
		1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	5.4	5.5	6.1	6.2
LGEI • **Laboratoire de Génie de l'Environnement Industriel (IMT Mines Alès)** Director: Anne Johannet, anne.johannet@mines-ales.fr http://lgei.mines-ales.fr	6/28																						
LIRMM (UMR) • ***Laboratory of Computer Science, Robotics and Microelectronics of Montpellier (CNRS/UM)*** Director: Philippe Poignet, philippe.poignet@lirmm.fr www.lirmm.fr/lirmm_eng	15/200																						
LOMIC (UMR) • ***Laboratory of Microbial Oceanography (Sorbonne University/CNRS)*** Director: Fabien Joux, joux@obs-banyuls.fr http://lomic.obs-banyuls.fr	35/35																						
MARBEC (UMR) • ***MARine Biodiversity, Exploitation and Conservation (IRD/IFREMER/UM/CNRS)*** Director: Laurent Dagorn, marbec-dir@listes.ird.fr www.umr-marbec.fr/en	110/110																						
ONERA Midi-Pyrénées • **Office national d'études et de recherches aérospatiales** Director: Dominique Le Quéau (Occitanie), dominique.lequeau@fondation-stae.net www.onera.fr/en	NC*																						
SHOM • **Service hydrographique et océanographique de la marine** ***(Toulouse branch)*** Leader: Caroline Bru, caroline.bru@shom.fr www.shom.fr/en - https://data.shom.fr	11/20																						
TETIS (UMR) • ***Land, Environment, Remote Sensing and Spatial Information (AgroParisTech/CIRAD/CNRS/IRSTEA)*** Director: Christiane Weber, christiane.weber@teledetection.fr www.umr-tetis.fr	3/80																						

Private research bodies	Number of scientists involved/ Total number of scientists	Chap. 1			Chap. 2		Chap. 3				Chap. 4						Chap. 5					Chap. 6	
		1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	5.4	5.5	6.1	6.2
Andromède Océanologie Leader: Pierre Descamp, pierre.descamp@andromede-ocean.com www.andromede-ocean.com	6/6																						
BRLI • **BRL Ingénierie** Director: Gilles Rocquelain, brlingenierie@brl.fr https://brli.brl.fr/en	8/20																						
CERFACS • **Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique** Director: Catherine Lambert, catherine.lambert@cerfacs.fr www.cerfacs.fr	5/70																						
CLS • ***Collecte Localisation Satellites*** Director: Christophe Vassal, info@cls.fr www.cls.fr/en	37/83																						
ECOCEAN President: Gilles Lecaillon, contact@ecocean.fr www.ecocean.fr/?lang=en	5/15																						
GEOMATYS • ***(Montpellier Agency)*** Director: Vincent Heurteaux, vincent.heurteaux@geomatys.com www.geomatys.com/en	6/16																						
Mercator Ocean International DG: Pierre Bahurel, pierre.bahurel@mercator-ocean.fr www.mercator-ocean.fr/en/ http://marine.copernicus.eu	45/80																						
NEOCEAN Director: Vincent Dufour, contact@neocean.com www.neocean.com	2/2																						
NOVELTIS CEO: Richard Bru, richard.bru@noveltis.fr www.noveltis.com/en	12/37																						
QEM • **Quadran Énergies Marines** DG: Olivier Guiraud, contact@eolmed.fr www.quadran-marines.com	0/12																						
TAS • ***Thalès Alenia Space*** Director (Toulouse site): Albert Cerro, albert.cerro@thalesaleniaspace.com www.thalesgroup.com/en	NC*																						
Telespazio France CEO: Jean-Marc Gardin, contact@telespazio.com www.telespazio.fr/en	10/300																						
Waves'n See Director: Yves Soufflet, yves.soufflet@wavesnsee.com www.wavesnsee.com/en	2/2																						

* NC: not communicated

Federative research bodies	Chap. 1			Chap. 2		Chap. 3				Chap. 4						Chap. 5					Chap. 6	
	1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	5.4	5.5	6.1	6.2
EID Méditerranée • *Interdepartmental Agreement for Mosquito Control on the Mediterranean Coast* Director: Bruno Tourre, btourre@eid-med.org www.eid-med.org																						
EMBRC-France • *European Marine Biological Resource Center (Sorbonne University/CNRS)* Director: Bernard Kloareg, kloareg@sb-roscoff.fr www.embrc-france.fr/en																						
GEOSUD (EQUIPEX) • *GEOinformation for SUstainable Development (AgroParisTech/Cerema/CINES/CIRAD/CNRS/IGN/IRD/IRSTEA/UM/Univ. of the French Antilles/Univ. of French Guiana/Univ. of Reunion Island /AFIGEO/ GEOMATYS)* Coordinator: Pierre Maurel, pierre.maurel@irstea.fr http://ids.equipex-geosud.fr																						
InToSea (LabCom) • *Joint Laboratory "Innovative Tools under the sea" (UM/Andromède Océanologie)* Directors: Nicolas Mouquet and Julie Deter, nicolas.mouquet@cnrs.fr / julie.deter@umontpellier.fr https://labcomintosea.edu.umontpellier.fr/																						
OHM-LM • **Observatoire Hommes-Milieux Littoral Méditerranéen** *(CNRS)* Directors: Samuel Robert & Patrick Monfort, samuel.robert@univ-amu.fr / patrick.monfort@umontpellier.fr www.ohm-littoral-mediterraneen.fr																						
OMP (OSU) • **Observatoire Midi-Pyrénées** *(UT3/CNRS/CNES/IRD/Météo-France)* Director: Mike Toplis, michael.toplis@obs-mip.fr www.obs-mip.fr/en																						
OOB (OSU) • **Observatoire océanologique de Banyuls-sur-Mer** *(Sorbonne University/CNRS)* Director:Vincent Laudet, vincent.laudet@obs-banyuls.fr wwwphp.obs-banyuls.fr/en																						
OREME (OSU) • **Observatoire de Recherche Méditerranéen de l'Environnement** *(UM/CNRS/IRD/IRSTEA)* Director: Éric Servat, eric.servat@umontpellier.fr www.oreme.org																						
Pôle Mer Méditerranée • *(Occitanie Representation)* Director: Patrick Baraona, landi@polemermediterranee.com baraona@polemermediterranee.com Occitanie Delegate: Julie Person, person@polemermediterranee.com https://en.polemermediterranee.com																						

Basket star. © *Thomas Changeux / IRD*

Occitanie: a region committed to the sea and to its coast

While the Mediterranean is a factor of attractiveness and economic development, it is also an essential social and cultural marker for the region and its 5.7 million inhabitants. It is therefore with a *bona fide* political will that the Region is developing its maritime ambition for and with Occitanie's inhabitants.

The *Parlement de la Mer*: a unique tool in France

This drive to democratize the Mediterranean led to the creation in 2013 of the ***Parlement de la Mer***, **a novel consultative body that brings together and represents the regional maritime community**. The governance set-up of this inclusive tool consists of an open forum of more than 2,000 members, an assembly of 200 members representing local authorities, socio-professionals and civil society, as well as a board of 15 people, including socio-professionals and elected representatives.

Beyond democratisation, the re-appropriation of maritime and coastal space is a major challenge for companies, users, citizens and local authorities. This requires in particular rolling out a strategic and forward-looking vision of the coast in order to give fresh impetus to the economy and shape the coast of the 21st century, with new means to sustainably develop the coast and modernise its aging infrastructure.

The Coastal Plan 21 *(Plan Littoral 21)*: "in our region, a new ambition for the coast"

The second tool, the **Costal Plan 21, aims to support the economic, ecological and social transition of the coast**. Ecological resilience, economic development and innovation, territorial attractiveness, 'living well together', and openness to the Mediterranean Sea, are all strategic orientations of this Plan. It makes this breakthrough innovation possible for Occitanie's coast with the mobilisation, by the end of 2020, of €1 billion of investment from the State, the Region, the *Caisse des Dépôts*, local authorities and private companies. Since 2017, the Coastal Plan 21, with more than **300 projects** and **nearly €600 M** of **investment,** has been a catalyst for the investment dynamics implemented on Occitanie's coast. For 71% of the investments, the Coastal Plan 21 focuses on "an innovative economy that permeates the entire territory".

Innovation, Occitanie Region's DNA

Stimulating economic growth and development, transforming habits, looking to the future while respecting territory's traditional activities and identity, etc. are challenges facing Occitanie's coast. In order to meet these challenges, innovation must be at the heart of ambitions.

Since 2007, each Region has been developing a **Regional Innovation Strategy (SRI)** at the request of the European Commission, in the framework of the Structural Funds policy. This was supplemented in 2014 by what the Commission calls the 'smart specialisation strategy' which aims to concentrate investments on a limited number of innovative sectors, with the aim to stand out and be competitive on a global scale. Part of the structural funds, but also national and regional funding (regionalized PIA3, Calls for regional collaborative projects, etc.), are dedicated to specific areas, including areas with high potential and emerging areas.

As part of the **SRI**, **co-managed by the State and the Region, under the impetus of Europe, seven areas of 'smart specialisation' have been defined for Occitanie up to 2020, including "the economy of the coast and the sea".** The latter includes the environment and sustainable development of the coast, marine mining and energy resources, marine biological resources, recreational boating and nautical activities, maritime safety and security, ports, maritime infrastructure and transports. More generally, it responds to the **challenge of making Occitanie a model of innovation for the coast and the sea**.

▲ *The* Maison Régionale de la Mer, *headquarters of the Parlement de la Mer.* © *Laurent Boutonnet*

Democratizing the sea and providing inhabitants with prospects for blue ecological and economic transition

Littoral +: the innovation component of the Coastal Plan 21

Aiming at "**making Occitanie's coast a model territory for tomorrow's attractive and sustainable coastal areas",** the **Littoral+ project, led by the Region,** is one of the 24 winners, out of 117 applications, of the Call for Expressions of Interest of the 'Territories of highly ambitious innovation' (TIGA) action launched in 2017. This application and the project's general ambition draw upon three issues:

- The performance and diversification (traditional activities, new activities) of coastal economy
- The economy of coastal natural resources and the conservation of natural heritage
- The resilience of the coast.

The proposed actions illustrate these issues: coastal big data, territorial labs on Thau Basin, reuse of treated wastewater, production of green hydrogen from offshore wind turbines, habitat resilience to natural hazards, development of a hinterland area with modular habitat, etc.

Since January 2018, thanks to engineering studies, the Region, with its industrial and academic partners has been strengthening 'Littoral +' actions in order to meet the expectations of the 'Territory of Innovation' Call for projects.

A rich pool of skills in science, technology and support to breakthrough innovations in maritime sectors

The region counts with a unique wealth of skills to support its transformation, with four competitiveness clusters (Water, Sea, Renewable Energy, French Tech), an Economic Development Agency (Ad'Occ), a technical centre dedicated to the fisheries sector (Cépralmar), more than 500 companies working in the water sector, more than 600 companies in the renewable energy sector, more than 16,000 companies in the digital sector and **more than 700 scientists strongly involved in the 'sea and coast' thematic.**

With its 7 universities, 11 research organisations, and more than 20 *grandes écoles*, the Occitanie Region has exceptional potential in terms of higher education and research. Drawing upon the dual principle of excellence and proximity, the Region is implementing a comprehensive policy redesigned to support higher education, technology transfer and research.

The Regional Scheme for Higher Education, Research and Innovation

As part of its Regional Strategy for Employment and Growth (SREC), the Plenary Assembly of the *Conseil Régional* adopted on 2 February 2017 the Regional Scheme for Higher Education, Research and Innovation (SRESRI). **This plan is the reference policy framework for Occitanie Region's action in the field of higher education, research and innovation for the 2017-2021 period.** It defines the orientations and priorities for the intervention of the Region and other territorial authorities in these areas, in accordance with the State's national strategies. In addition, the SRESRI is intended to be linked up to all the other regional schemes pertaining to higher education or innovation, in particular the Regional Planning Agreement for Training and Vocational Guidance (CPRDFOP) and the Regional Scheme for Economic Development, Innovation and Internationalisation (SRDEII).

To implement the SRESRI over the 2017-2021 period, the Region has developed **17 support schemes for trainings and research projects, technology transfer to businesses and dissemination of science, with an annual budget of over €100 M.**

The Region is committed to building tomorrow's jobs by strengthening equity of access to higher education and stimulating research, which is a prerequisite for innovation, in all its forms and throughout the entire territory.

▲ *Carole Delga, President of the Occitanie Region, at the* Parlement de la Mer. *© Laurent Boutonnet / Région Occitanie*

For further information:
Parlement de la Mer: www.laregion.fr/Parlement-de-la-mer
Coastal Plan 21: http://occitanie.direccte.gouv.fr/sites/occitanie.direccte.gouv.fr/IMG/pdf/plan_littoral_21.pdf
SRI: www.sri-occitanie.fr
SRESRI: www.laregion.fr/SRESRI

"The Economy of the Sea and the Coast: a priority area for Occitanie's Regional Innovation Strategy"

List of acronyms & abbreviations

AFIGEO	*Association française pour l'information géographique*
AIS	Automatic Identification System
ANR	French National Research Agency
BRGM	*Bureau de Recherches Géologiques et Minières*, France
BWM	International Convention for the Control and Management of Ships' Ballast Water and Sediments
CeMEB	Mediterranean Centre for Environment and Biodiversity, France
Cerema	*Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement*, France
CERFACS	*Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique*, France
CestMed	Centre for Research and Conservation of Mediterranean Sea Turtles, France
CINES	National Computing Centre for Higher Education, France
CIRAD	Agricultural Research for Development, France
CNES	National Centre for Space Studies, France
CNRS	French National Centre for Scientific Research
CPIE	*Centre permanent d'initiatives pour l'environnement*, France
CREM	*Centre de Recherche sur les Écosystèmes Marins*, France
EHESS	School for Advanced Studies in the Social Sciences, France
EID	Interdepartmental Agreement for Mosquito Control, France
EMBRC	European Marine Biological Resource Centre
EPHE	*École Pratique des Hautes Études*, France
EQUIPEX	Laboratory equipment enhancement projects
ERDF	European Regional Development Fund
ESA	European Space Agency
FFESSM	*Fédération française d'études et de sports sous-marins*, France
GEM	*Groupe d'Étude du Mérou*, France
GIS	Scientific Interest Group
ICCAT	International Commission for the Conservation of Atlantic Tunas
IFREMER	*Institut Français de Recherche pour l'Exploitation de la Mer*
IGN	National Institute of Geographic and Forest Information, France
IMT	*Institut Mines-Télécom*, France
INRA	National Institute for Agricultural Research, France
INRIA	French National Institute for Computer Science and Applied Mathematics
INSU	National Institute for Earth Sciences and Astronomy
InToSea	Innovative Tools under the Sea
IRD	French Research Institute for Development
IRSTEA	National Research Institute of Science and Technology for Environment and Agriculture, France
I-Site	Initiatives – Science - Innovation - Territories - Economy
IUCN	International Union for Conservation of Nature
LabEx	Laboratory of excellence
LEFE	Earth's fluid envelopes and the environment programme (*Les Enveloppes Fluides et l'Environnement*)
LIDAR	Light (or Laser Imaging) Detection And Ranging
MEDIMEER	MEDIterranean platform for Marine Ecosystem Experimental Research, France
MPA	Marine Protected Area
MUSE	Montpellier University of Excellence
NAO	North Atlantic Oscillation
NAPPEX	Artificial Nurseries for Exemplary Ports
NASA	National Aeronautics and Space Administration
OHM-LM	'Mediterranean coast' Human-Environments Observatory, France
OMP	Midi-Pyrénées Observatory, France
ONERA	*Office National d'Études et de Recherches Aérospatiales*, France
OOB	Banyuls-sur-Mer Oceanologic Observatory, France
OREME	Mediterranean Research Observatory of the Environment, France
OSU	Earth Science and Astronomy Observatory
PACA	Provence-Alpes-Côte d'Azur
PIA	Investments for the future programme (Investissements d'Avenir)
R&D	Research and Development
RTMMF	French Mediterranean Sea Turtle Network
SNO	National Observation Service
SRI-3S	Regional Innovation Strategy – Smart Specialisation Strategy
UM	University of Montpellier, France
UMR	Joint research unit (*unité mixte de recherche*)
UMS	Joint service unit (*unité mixte de service*)
UNEP	United Nations Environment Programme
UPVD	University of Perpignan Via Domitia, France
UPVM	*Université Paul-Valéry Montpellier 3*, France
USR	Service and research unit (*unité de service et de recherche*)
UT3	*Université Toulouse III - Paul Sabatier*, France

This document was published with the support of Occitanie/ Pyrénées-Méditerranée Region, I-SITE MUSE and IFREMER

Member organizations and partners of Agropolis International involved in this *Dossier*
*** Member organizations of Agropolis International**

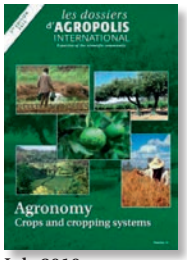
AFIGEO
AgroParisTech*
Ailerons
Andromède Océanologie
BRGM*
BRL Ingénierie*
Cerema
CERFACS
CestMed
CINES
CIRAD*
CNES
CNRS
Collecte Localisation Satellites
CPIE Bassin de Thau
Cybelle Planète
ECOCEAN
EID Méditerranée
EMBRC-France
EPHE
FFESSM
GEM
GEOMATYS
GEOSUD
GRAINE Occitanie
IFREMER
IGN
IMT Mines Alès
INRA*
INRIA
Institut marin pour les écosystèmes méditerranéens
InToSea
IRD*
IRSTEA*
Kimiyo
Mercator Ocean International
Météo-France
Montpellier SupAgro*
NEOCEAN
Noveltis
OHM-LM
OMP
ONERA
OOB
OREME
Parc des calanques
Parc naturel marin du golfe du Lion
Peau-Bleue
Pôle Mer Méditerranée
Quadran Énergies Marines
Quai des Savoirs
Région Occitanie*
Réserve naturelle marine Cerbère-Banyuls
RTMMF
Science Animation
SHOM
Sorbonne Université
Telespazio France
Thalès Alenia Space
Train du Climat
UM*
Université de la Guyane
Université de La Réunion
Université des Antilles
UPVD*
UPVM*
UT3
Waves'n See

Participated in this issue:
N.-E. Abriak, C. Alazard, C. Aliaume, J. Almany, R. Almar, I. Amsallem, M. Andrello, C. Arnal, S. Arnaud-Haond, D. Aubert, J.-C. Auguet, N. Azema, Y. Balouin, J. Bandelier, E. Bappel, M. Barral, L. Barthelmebs, A. Bas, M.-A. Bassetti, L. Batté, J. Baudart, C. Bazart, B. Bec, S. Bejannin, R. Benshila, A. Berger, A. Berger Sabbatel, S. Bernard, I. Berry-Chikhaoui, Y. Bettarel, N. Bierne, F. Birol, F. Bonhomme, S. Bonhommeau, P. Bonifácio, D. Bonnet, F. Bouchette, F.-Y. Bouget, D. Boulet, G. Boulet, T. Boulinier, J. Bourjea, F. Bourrin, T. Bouvier, L. Bramanti, X. Briottet, R. Bru, J.-R. Brunet, J. Cabaret, F. Cadene, R. Caillibotte, M. Callier, S. Campagna, F. Carcaillet, C. Cassou, J. Catanzano, J.-P. Cauzac, A. Célérier, R. Certain, R. Chailan, B. Chatain, M. Chaumont, V. Chavagnac, J. Claudet, P. Conan, P. Constantin, P. Courtois, D. Covès, V. Creuze, L. Crosnier, L. Dabbadie, L. Dagorn, G. Darmon, A. Darnaude, G. David, J. de Lorgeril, C. de Nicola, G. Dera, V. Derolez, J. Deter, M. Dégremont, R. de Wit, V. Ducrocq, V. Dufour, X. Durrieu de Madron, E. Emmanuelli, H. Escriva, C. Estournel, É. Fache, M.-H. Favant, S. Fillon, S. Fonbonne, A. Fontcuberta, P.-Y. Foucher, É. Fouilland, N. Fraysse, J.-M. Fromentin, P.-A. Gagnaire, P. Galand, P. Gaspar, C. Gesnin, J.-F. Ghiglione, D. Giband, A. Gigou, O. Gimenez, K. Godary-Dejean, C. Gonzalez, C. Goyet, D. Grémillet, J.-M. Groul, M. Groc, A. Gudefin, Y. Gueguen, K. Guizien, T. Hattab, L. Hédouin, C. Hérivaux, M. Herrmann, G. Herrouin, V. Heurteaux, H. Heutefeux, F. Holon, F. Houngnandan, B. Hubert, I. Hubiche, D. Ienco, P. Ienny, C. Iovan, C. Jacob, A. Jadaud, C. Jeandel, F. Jeliazovski, D. Jourdan, G. Junqua, A. Justice-Espenan, P. Kerhervé, V. Kerzérho, Jean-Luc Khalfaoui, H. Labach, C. Labrune, D. Lacroix, V. Lajarige, C. Lambert J. Langot, L. Lapierre, M. Lapinski, G. Larnicol, V. Laudet, T. Laugier, E. Launay, A. Laurent, V. Lavaud-Letilleul, P. Lebaron, G. Lecaillon, G. Le Cozannet, F. Lefevre, P.-Y. Le Meur, P. Lenfant, M. Leonard, F. Leprieur, Y. Leredde, D. Lestang, P. Louisy, C. Lucion, W. Ludwig, F. Lyard, J. Macaruella, A. Maillard-Lenoir, P. Maisongrande, S. Manel, A. Mangos, P. Marchesiello, P. Marin, F. Marques, G. Marre, S. Mas, P. Masaleix, S. Mathieu, L. Mathon, B. Maurel, P. Maurel, O. Maury, A. Melet, F. Messal, B. Meyssignac, C. Miaud H. Michaud, J.-M. Miossec, G. Mitta, P. Monfort, C. Montagnani, M. Morineaux, B. Mostajir, D. Mouillot, N. Mouquet, S. Muttoni, N. Pade, D. Parin, A. Pasquet, C. Payri, D. Perrin, M. Petit, L. Phalippou, N. Picot, G. Piganeau, S. Pioch, S. Planton, J. Poirier, F. Poisson, N. Quérou, H. Rey-Valette, M. Richard, N. Rivière, E. Rodary, P. Romans, E. Roque, A. Rousseau, V. Rousseau, T. Rouyer, J. Sacchi, D. Salas y Mélia, M. Salgues, J.-M. Salles, S. Sanchez, C. Saraux, A. Schneider, J.-B. Sénégas, E. Servat, F. Sevault, V. Severac, Y. Shin, E. Simon, C. Skandrani, J.-C. Souche, Y. Soufflet, S. Somot, D. Stien, M. Suzuki, I. Taupier-Letage, M. Tchakérian, L. Terray, C. Thomas-Courcoux, S. Thorin, C. Tison, L. Tokarski, M. Toplis, G. Toulemonde, F. Touratier, W. Travers, J. Triboulet, A.-S. Tribot, N. Turque, P. van Beek, S. Vaz, F. Vidussi, L. Vigliola, M. Vittecoq, R. Vuillemin, R. Waldman.

Illustrations: we thank all contributors to this Dossier as well as Éric Bappel (GEOSUD), Anaïs Deprez (Ocean & Climate platform), Rémy Dubas (ECOCEAN), Daina Rechner (*Photothèque* INDIGO), Pascal Romans (OOB), Sébastien Villeger (MARBEC).

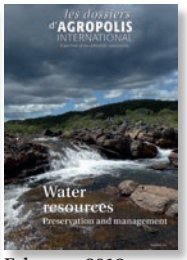
Also available in **French.**

The information presented in this Dossier is valid as of 31/12/2018.

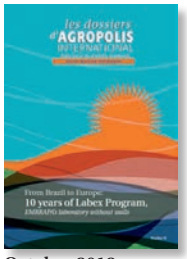


July 2010
68 pages (2nd ed., 2012)
French & English

October 2010
84 pages
French & English



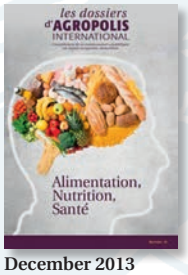
February 2012
72 pages
French, English, Spanish



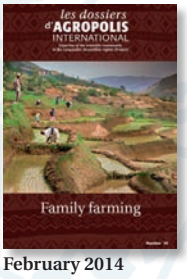
October 2012
48 pages
French & English

February 2013
48 pages
French, English, Spanish

October 2013
76 pages
French

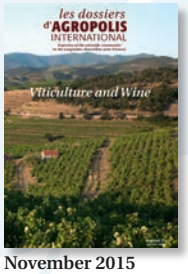


December 2013
72 pages
French

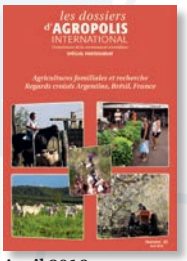


February 2014
64 pages
French, English, Spanish

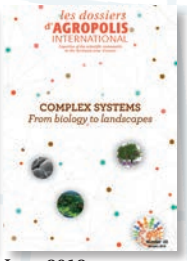
February 2015
88 pages
French & English



November 2015
76 pages
French & English



April 2016
72 pages
French



June 2018
80 pages
French and English

Dossiers d'Agropolis International

The *Dossiers d'Agropolis International* collection is a flagship vehicle for presenting and promoting the expertise of Agropolis International members on major scientific issues. Each Dossier is devoted to a specific theme. The research units and training courses concerned are showcased, alongside the research and associated results. Contributions of civil society, the economic sphere and local authorities in the target areas are also highlighted.
Each *Dossier* is available in hardcopy and digital format, generally in two languages (English and French).

Dossier issues can be downloaded at:
www.agropolis.org/publications/thematic-files-agropolis.php

Director in Chief:
Patrick Caron (President, Agropolis International)

Communication and diffusion:
Nathalie Villeméjeanne (Agropolis International)

Translation: David Manley (chapters 1 & 5), Chloé Robert (other parts)

Layout and Computer Graphics: Frédéric Pruneau (pruneauproduction@gmail.com) • Printing: LPJ Hippocampe (Montpellier, France)

Scientific Coordination:
John Bandelier (Kimiyo), Bernard Hubert (INRA, EHESS, Agropolis International), Catherine Jeandel (CNRS), Philippe Lebaron (Sorbonne Université, CNRS), Michel Petit (Agropolis International), Hélène Rey-Valette (UM), Pierre Soler (OMP)

Editorial Coordination and writing:
Isabelle Amsallem (Agropolis International) and Michel Petit (Agropolis International)

ISSN: 1628-4259 • **Copyright registration:** July 2019

AGROPOLIS INTERNATIONAL

1000 avenue Agropolis
F-34394 Montpellier CEDEX 5
France
Tel. +33 (0)4 67 04 75 75
Fax +33 (0)4 67 04 75 99
agropolis@agropolis.fr
www.agropolis.org