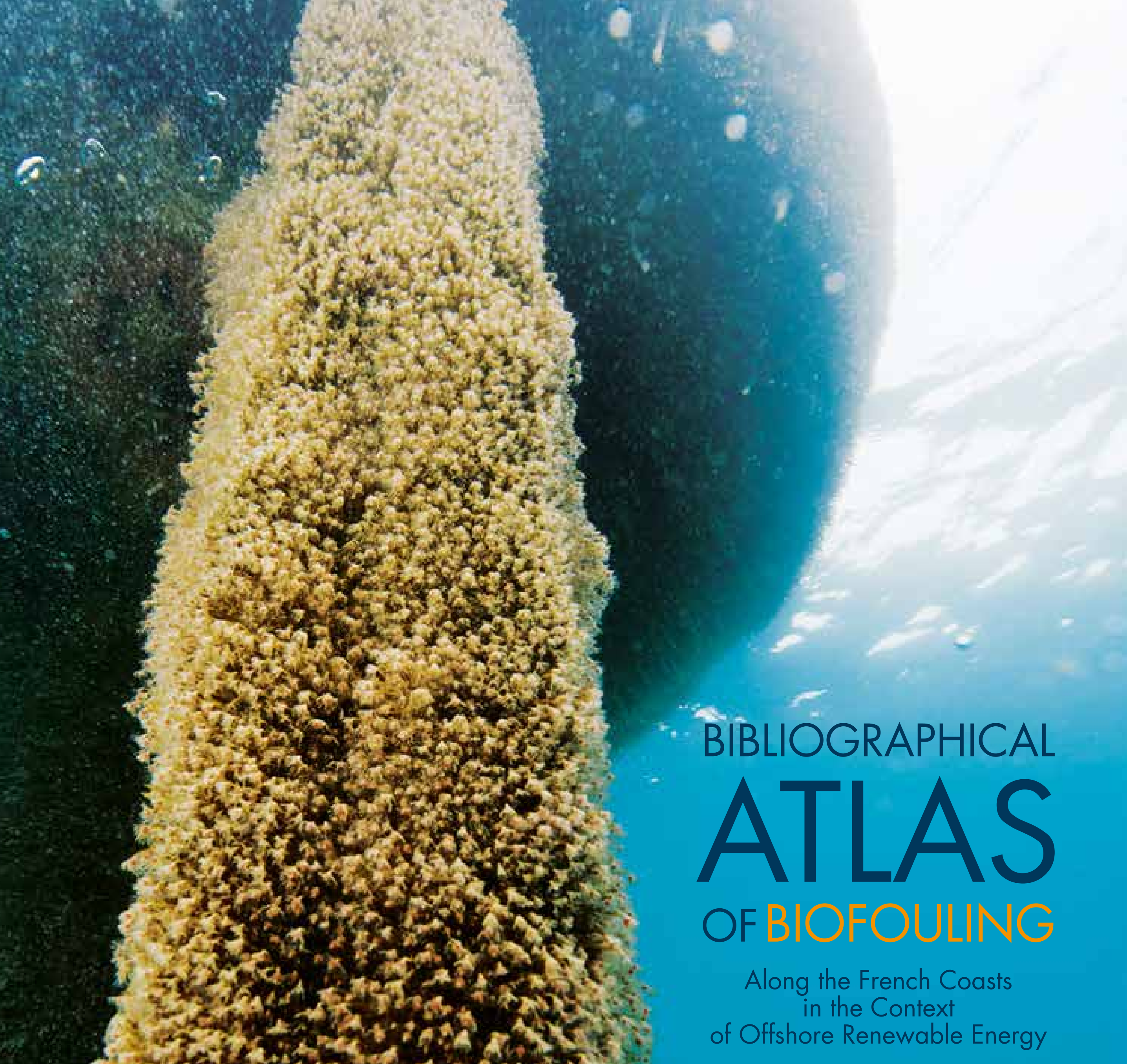

BIBLIOGRAPHICAL ATLAS OF BIOFOULING

Along the French Coasts in the Context of Offshore Renewable Energy

FRANCE ENERGIES MARINES Editions

BIBLIOGRAPHICAL ATLAS OF BIOFOULING

Along the French Coasts in the Context of Offshore Renewable Energy

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Preface

This atlas was produced as part of the ABIOP project (AAP-EMR-ITE FEM 2016; Fig. 1) on ***A**ccounting for **BIO**fouling through established **P**rotocols of quantification.* The primary objective of this 18-month project, launched in March 2017, is to improve the knowledge and monitoring of biofouling in order to increase the reliability of the input data required to correctly dimension and maintain Offshore Renewable Energy (ORE) systems. This project aims to achieve five goals:

- to summarise knowledge of biofouling along the French coasts
- to inventory existing protocols for characterising biocolonisation and issue methodological recommendations for measuring biofouling in the context of OREs
- to develop biofouling characterisation methods suited to the ORE context (Fig. 2)
- to conduct *in situ* testing of the methods and protocols developed through the project (Fig. 3)
- to acquire biofouling data for 3 study sites (SEM-REV, UN-SEA-SMS, Banyuls) (Fig. 1).

This project constitutes the first building block in terms of research and development on the theme of biofouling at France Energies Marines where **all ORE-related systems and sub-systems (connectors, cables, moorings, etc.) are taken into consideration.**

The project **consortium** is composed of 10 partners: the University of Nantes, France Energies Marines, Corrodys, Ecole Centrale de Nantes, EDF, EDF Renouvelables, Ifremer, Naval Group, Naval Energies and the University of Toulon. It thus comprises scientists **(biologists, ecologists, specialists in material engineering, metrology, fluid/structure interactions), test site personnel** and offshore renewable energy **developers** in order to acquire data, share knowledge and develop relevant expertise in the context of OREs.

The primary objective of this atlas is to **summarise the knowledge acquired on biofouling,** and more generally on the communities of organisms living on the hard substrates available today in mainland and overseas France, **with a view to foreseeing the problems generated by this phenomenon in the ORE context.**

This atlas is based on an exhaustive as possible **literature review**, including A-ranked scientific articles, reports (internships, monitoring, studies), and publications presenting the results of studies conducted in French waters aimed at characterising **biofouling** and/or **assemblages on hard substrates** in the subtidal zone. This know-ledge review provides readers with the available data on biofouling and on potential colonists. The availability of data from the analysed documents was mapped and the key information extracted and summarised in a short paragraph.

The atlas is organised into four sections (each relating to a different biogeographical area) and also includes background information to introduce the issues raised by biofouling for the offshore renewable energy sector, as well as a user guide. This document is thus designed as an **illustrated**, **tailored review** (scope of engineering) gathering the currently available knowledge on **biofouling along the French coastline.**

Fig. 1. *ABIOP project logo and study site locations.*

Fig. 2. *One of the experimental protocols developed through the ABIOP project.*

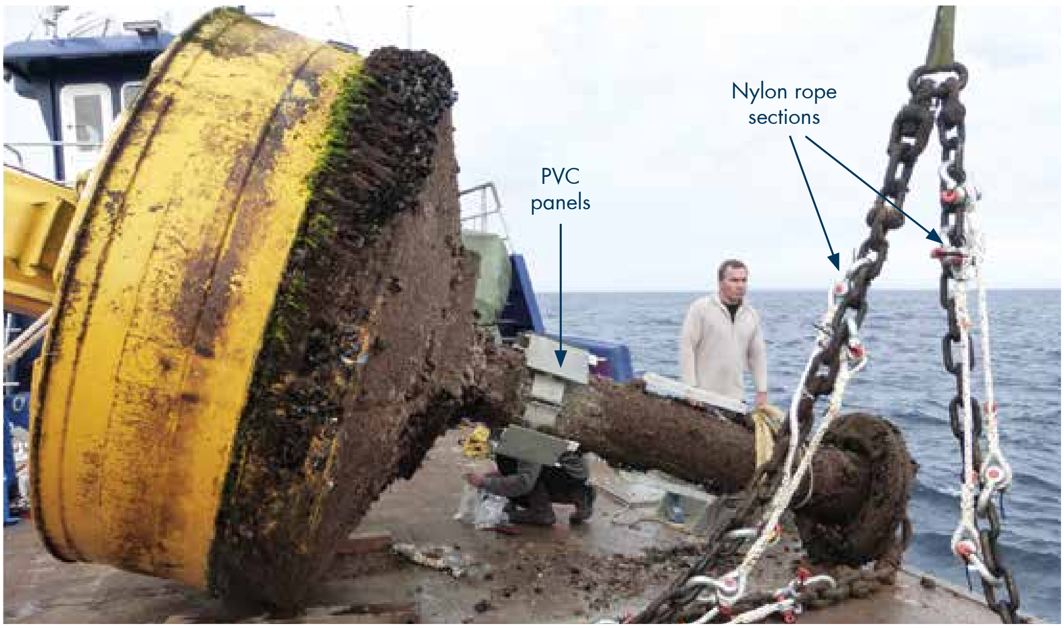


Fig. 3. *In situ data acquisition.*

1 - A cross-disciplinary vision of biofouling: biology and engineering

1.1 Definition of the biological process

Biofouling is the result of a biological process known as biocolonisation which occurs whenever a medium is introduced into an aquatic environment, or a surface already present in the environment becomes bare. These natural or man-made structures (e.g. a wave-cut platform, mollusc shell, pontoon, ship's hull) form a new available surface where attached living organisms (sessile organisms) can develop. In this atlas, only marine (and possibly estuarine) biofouling is considered.

1.1.1 Four key development phases

When a new hard substrate (e.g. wind turbine jacket, tidal stream turbine foundation, pontoon, ship's hull) is introduced into the sea, this surface is colonised by living organisms. This process is referred to as **biocolonisation** (Wahl, 1989) or **ecological succession** (i.e. a gradual change in the species composition of an ecosystem from (re)colonisation to the stage of dynamic equilibrium) (Noël *et al.*, 2009; Richmond & Seed, 1991). According to the model of Wahl (1989), biocolonisation can be broken down into **four main phases** (Fig. 4).

Almost instantly after the medium enters the water, **macromolecules** such as proteins, sugars, humic acids, glycoproteins and mineral matter (e.g. salts, silica) are spontaneously attracted to the structure's surface by **adsorption** (Fig. 4, phase 1).

Within the following minutes and hours, a bacterial film develops (Fig. 4, phase 2). The **bacteria** are also adsorbed and adhere to the surface of the immersed structure by secreting compounds commonly known as EPS *(Extracellular Polymeric Substances)*. Several days after immersion of the medium, groups of **unicellular organisms,** mainly composed of diatoms, become attached to the substrate by secreting mucus (Fig. 4, phase 3). Finally, after several days or weeks, the first **multicellular organisms** colonise the structure's surface in the form of **larvae** and **sporelings**, which develop and grow (Fig. 4, phase 4) until they reach a climax, the dynamic state of equilibrium of the succession. It is important to note that this equilibrium is relative: a climax is a state which varies over time and space according to environmental conditions (which vary on a seasonal basis and are locally modified by colonising organisms) and various mechanisms, such as competition. This species can replace others (those previously established) as they are more competitive in (i.e. better suited to) the altered environment. These new species in turn modify the physical, chemical and biological properties of their habitat, promoting or inhibiting the installation of other species until the climax is reached.

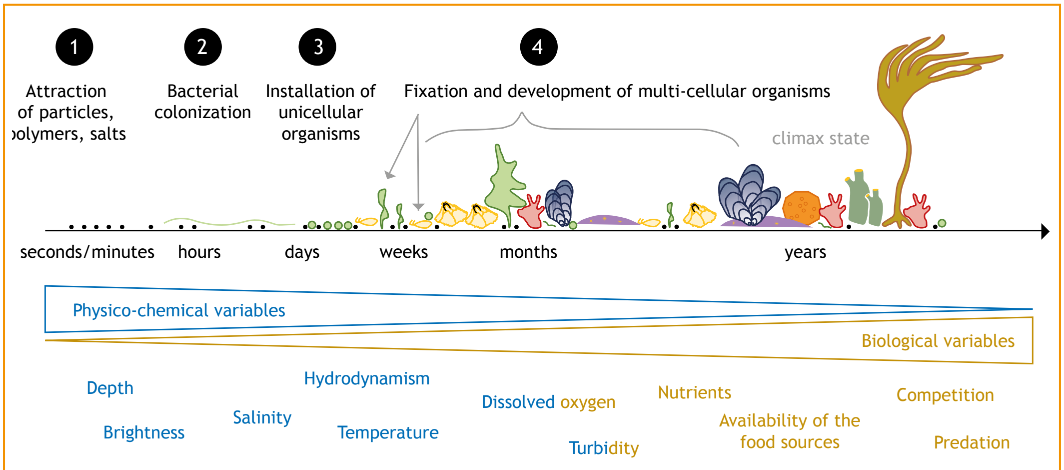


Fig. 4. *Schematic representation of biofouling and the influence of environmental variables based on the model of Wahl, 1989.*

The **first three phases** in the biofouling process **overlap with the fourth.** Macromolecules, bacteria, micro-algae and larvae continue to adhere and attach to the substrate which is left bare following a disturbance and/or to certain macro-organisms (e.g. kelp stems, mussel valves) which themselves constitute a substrate. The time scales indicated in the biocolonisation model (Wahl, 1989) are approximate. The succession sequence has been discussed by several authors who have observed that certain phases can occur simultaneously or even be absent (e.g. Roberts, Rittschof, Holm, & Schmidt, 1991). Furthermore, the different phases can follow on from each other at varying rates (Fig. 5, example of relatively rapid colonisation).

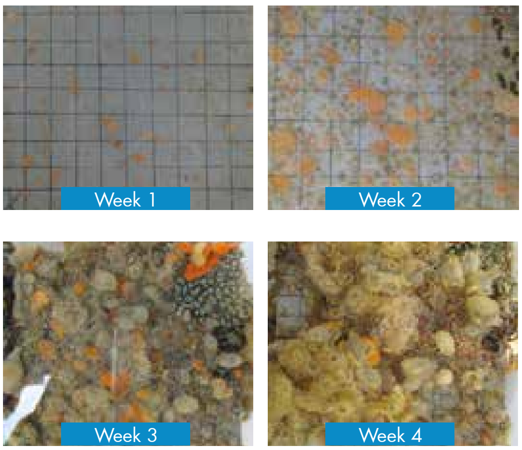


Fig. 5. *Example of weekly monitoring of the biofouling of panels placed in a marina in Connecticut (USA) between 2nd and 24th July 2014 (adapted from Lord, 2017).*

This atlas compiles the knowledge available on **macro-colonisation,** i.e. the installation of multicellular organisms with an adult size of over 1 mm (phase 4, Fig. 4) and also presents some data on the micro-colonisation process (phase 3, Fig. 4) in overseas France where fewer studies have been conducted.

1.1.2 A complex and variable process

Ecological succession may be **primary** (whereby a community colonises a "new" substrate) or **secondary** (whereby organisms colonise a previously colonised area which has become available following a disturbance such as a storm). The biofouling community thus becomes a relatively complex **patchwork**, composed of assemblages of organisms at different stages of succession.

As concerns macro-fouling, **pioneer species** (species which become established at the beginning of the macro-colonisation of a new or disturbed substrate) are often those with extensive recruitment periods and are generally poor competitors compared to **dominant species** which recruit over a shorter time period (J. H. Connell & Slatyer, 1977).

If we take the example of macro-colonisation of a substrate introduced into a euphotic zone of the the marine environment (i.e. the zone in which sufficient light is available for photosynthesis to occur) (Noël *et al.*, 2009): first, **pioneer species** from the phylum of Chlorophyta (i.e. green algae such as *Ulva* spp.) develop, then species of turf-forming algae (e.g. *Corallina* spp.) and/or sessile organisms (e.g. *Balanus* spp., Serpulidae) become established. **Species with longer** life cycles **and more complex morphologies** then develop, in particular Fucales and Laminaria as well as macro-invertebrates such as *Mytilus* spp. (Benedetti-Cecchi, 2000) (Fig. 6).

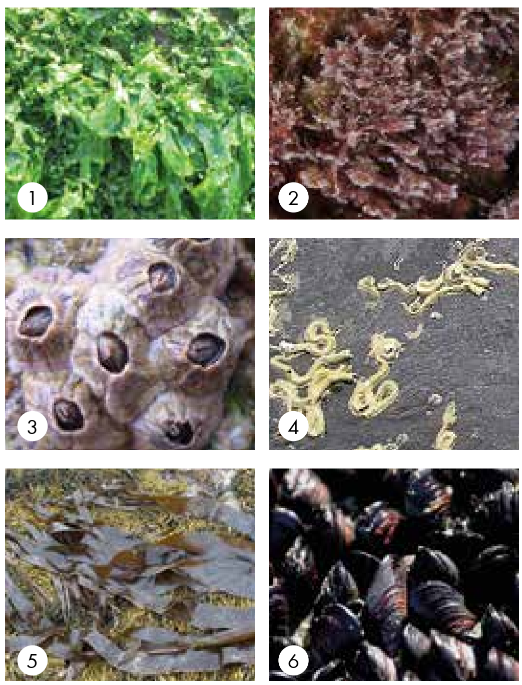


Fig. 6 *1 - Ulva spp., 2 - Corallina sp., 3 - Balanus perforatus, 4 - Pomatoceros triqueter, 5 - Laminaria digitata lying on Fucales of the genus Ascophyllum, 6 - Mytilus spp.*

During the initial stages of colonisation, the **three-dimensional nature of biofouling** is negligible, but as the attached organisms develop, the assemblage itself constitutes a **habitat** for many mobile and sessile species (Fig. 6, 7). A whole **ecosystem** is thus formed and interactions (in particular predation and competition) between species intensify. The influence of these biological variables on the composition of biofouling communities rises (Fig. 4). In the case of the colonisation of man-made structures, we can talk about an **artificial reef effect** (e.g. Langhamer, 2012).

Fig. 7. *Kelp forest and species associated with this habitat above a rocky crevice in Brittany.*

When we consider biofouling at a more advanced stage, the most commonly found species belong to the following phyla: anthropods (in particular: **barnacles**), **bryozoa,** annelids (in particular: **Serpulidae**), Chordata (in particular: **ascidians**), Porifera (or **sponges**), Cnidaria (in particular: **Hydrozoa**), Chlorophyta, Rhodophyta and Ochrophyta (i.e. **green, red and brown algae**). Guidelines to help to identify marine fouling organisms are available: Catalogues of Marine Fouling, 1963, vol. 1 to 7 as well as many identification aids to determine the organisms in the biofouling community as exhaustively as possible.

For each biogeographical area of the atlas, the main biocolonising species are presented. The annotated references inform readers of the environmental conditions (in particular the hydrodynamics, depth and type of substrate) at the studied sites. Further details are available in the database developed as part of the ABIOP project (FEM/ANR AAP-EMR-ITE, 2016).

Very large numbers of propagules are available in the marine environment, yet the oceans are exposed to meteorological and hydrodynamics events which lead to a certain amount of **variability** in the establishment process of biofouling species, the rate of ecological succession and ultimately in the composition of the biofouling community (Valiela, 1995). These factors are explored in detail and their influence explained in the following section.

1.1.3 Factors contributing to variability

Biofouling varies over space and time according to **numerous physico-chemical and biological parameters** (Fig. 4, 8), whether of **natural or anthropogenic origin**. Thus, as the water depth increases, **light intensity,** hydrodynamics and temperature drop. These physical gradients affect the composition of communities of marine organisms which develop according to their affinities to these different variables (e.g. Rule & Smith, 2007). As light intensity decreases, macroalgae progressively disappear (Hiscock & Mitchell, 1980).

Example of distribution of dominant algae types with increasing depth: erect macroalgae → bushy algae → encrusting algae → no algae.

Beyond a certain depth, macroalgae can no longer photosynthesise, preventing their development. While the role of light is indisputable for the vertical zoning of algae, this factor appears to be far less crucial for animals. Sponges can be quite sensitive to light, but hydrozoans and bryozoans mainly react to variations in hydrodynamics and turbidity (Castric-Fey, 1974).

Hydrodynamics (waves and tidal currents), which vary seasonally and geographically, also significantly affect assemblages of marine sessile organisms (Burrows, 2012; Castric-Fey, 1988). For instance, Castric-Fey & Chassé (1991) determined four types of facies (i.e. four different organism assemblages) according to exposure to waves and tidal currents and depending on depth in the Brest area (Tab.1).

	Depth -	Depth +
Waves +	• *Alaria* sp. • *Mytilus* sp. • *Balanus perforatus* • *Metridium senile* • *Pollicipes cornucopiae*	• *Axinella dissimilis* • *Aglaophenia tubulifera* • *Eunicella* sp. • *Gymnangium* sp. • *Alcyonium glomeratum*
Tidal currents +	• *Laminaria digitata* • *Mytilus* sp. *(in order of appearance on species lists)*	• *Hydrallmania* sp. • *Raspailia ramosa* • *Bougainvillia ramosa* • *Haliclona* sp. • *Polymastia mamillaris* • *Nemertesia antennina* • *Cellaria salicornioides* • *Alcyonium digitatum*

Tab. 1. *Assemblages of sessile organisms observed at sites at greater depth (Depth +) or lower depth (Depth -) and exposed to waves or tidal currents (adapted from Castric-Fey & Chassé, 1991).*

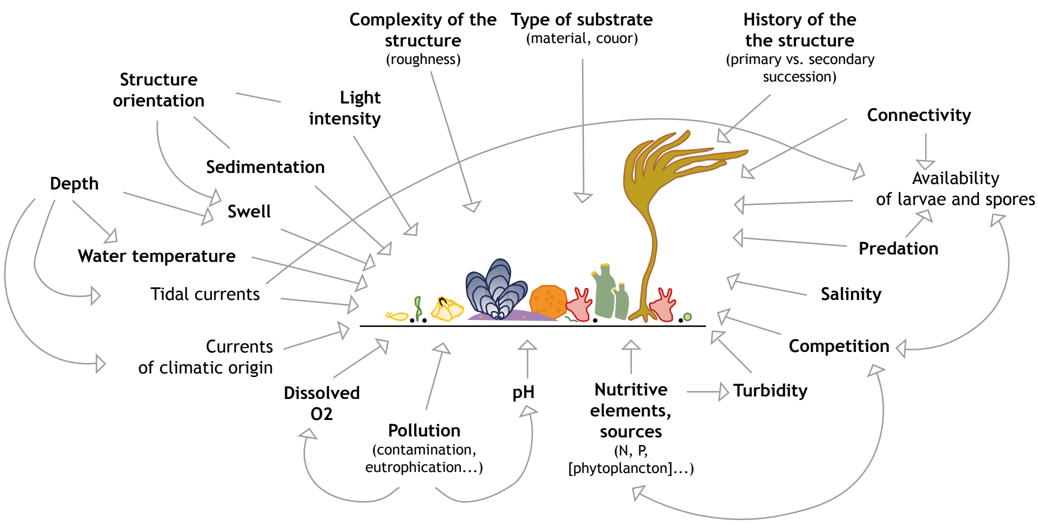


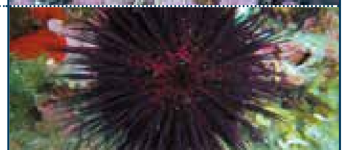
Fig. 8. *Illustration of environmental variables and co-variables influencing biofouling.*

The **availability of larvae and spores,** as mentioned previously, also varies with time in response to climate forcings, changes within genitor populations, etc., which alters the spatial and temporal structure of the biofouling (Richmond & Seed, 1991). Throughout the year, recruitment can vary greatly from one month to another, both qualitatively and quantitatively (Castric-Fey, 1974). Remoteness from the coast can also explain larval availability. DePalma (1982) observed a 50% and 90% decrease in colonisation respectively at 800 m and 5,500 m from the coast of Florida.

Fig. 9. *Settlement of honeycomb worms, barnacles and oysters on unusual structures, here a disused tractor abandoned in the Mont-Saint-Michel Bay some twenty years ago. The metal components are completed covered with organisms while the tyres are almost fouling-free.*

The **type of substrate** (type of **material**) mainly affects the first stages of biocolonisation. Certain materials nevertheless appear to have an influence on more advanced stages of colonisation. For instance, the tyres of an abandoned tractor in the Mont-Saint-Michel Bay are colonised by a few reefs of honeycomb worms (*Sabellaria alveolata*) while the metal parts of the vehicle are completely covered in them (Observation, N. Desroy) (Fig. 9). This difference could be explained by the release of toxic substances contained in the rubber of the tyres.

On the other hand, the **direction of the hard substrate** significantly and lastingly structures communities of marine organisms causing biofouling (Glasby & Connell, 2001; Langhamer, Wilhelmsson, & Engström, 2009) (Fig. 10). For instance, biofouling developing on the upper side of a horizontal surface will be a photophilic community which is not sensitive to sedimentation (deposit of organic and mineral matter), whereas communities which become established on the underside will be composed of sciaphilous organisms (Castric-Fey, 1974). The accumulation of matter by sedimentation inhibits the attachment of certain organisms (Ghobashy & El Komy, 1980). For instance, the hydrozoan *Tubularia larynx* cannot attach to

Predators	Area of distribution	Prey	Illustrations
Gilthead seabream *(Sparus aurata)*	• North-East Atlantic • Mediterranean	• Mainly bivalve molluscs (e.g. blue mussel [*Mytilus edulis*])	
Green sea urchin *(Strongylocentrotus droebachiensis)*	• North-West Atlantic • Eastern Pacific	• Kelp	
Purple sea urchin *(Paracentrotus Lividus)*	• Very common in the Mediterranean	• Brown seaweed (especially *Sargassum muticum*)	
Common starfish *(Asterias rubens)*	• Channel • Atlantic	• Bivalve molluscs (especially oysters, mussels), barnacles, ascidians *(Ciona intestinalis)*	

Tab. 2. *A few examples of predators of biofouling organisms.*

a surface covered with organic deposits and minerals, while certain species of bryozoa can survive in areas with strong sedimentation. Similarly, biotic factors such as **predation** or **competition** for the substrate can control recruitment and community composition (J. H Connell & Slatyer, 1977). Space is often considered to be the limiting factor for the development of fouling (Canning-Clode & Wahl, 2010; Richmond & Seed, 1991). Competition for space is considered to be a forcing variable with a very significant influence on the structure of biofouling communities (Joseph H. Connell, 1972; Vance *et al.*, 2009). Predation is also probably a very significant factor, however its influence on biofouling dynamics on man-made substrates is not well documented (but see for instance Osman & Whitlatch, 2004). Predation pressure may be exerted at different stages in the substrate colonisation process and at different stages in the life cycle of the biofouling organisms (biofilm grazing, consumption of larvae, juvenile or adult macro-organisms, seaweed). Table 2 presents a few examples of predators which can have an influence on the colonisation of structures introduced into French waters (including overseas France). Generally speaking, **organic matter** produced on site or of non-native origin (nutrient transport, detritus brought by currents) has an influence on the development of biofouling. This influence is more marked in coastal waters which are generally richer than ocean waters.

Fig. 10. *Effect of substrate orientation (and hence luminosity and sedimentation) on the colonisation of a structure; example of biofouling of the sides (top photo) and underside of the Pelamis Wave Energy Converter (bottom photo), figure extracted from Loxton et al., 2017.*

The **mobility of the structure** on which the fouling occurs also affects its composition. For instance, Hunsucker, Hunsucker, Gardner & Swain (2016) measured the influence of rotation speed of a structure on its percentage cover by marine organisms. These authors showed that the static components were always less colonised than the dynamic components and were colonised by different communities. The dynamic panels were covered with algae and biofilm, while the static panels were covered with bryozoa, hydrozoa and barnacle recruits. **A moving structure can also modify the behaviour of certain organisms and induce changes in biocolonisation,** for example by reducing grazing by sea urchins or limpets, leading to an increase in the algae biomass on the structure (Tiron, Pinck, Reynaud, & Dias, 2012).

1.2 Biofouling from an engineering perspective

Biofouling **affects all man-made structures placed in the marine environment.** From the first wooden ship hulls damaged by shipworms (i.e. boring molluscs of the genus *Teredo* spp.) (Fig.11) to offshore platforms colonised for instance by mussels or corals (Fig. 12), biofouling is a well-known phenomenon among engineers who design these structures.

Biofouling has many consequences on offshore structures. From the onset of colonisation, fouling can create a **hydrodynamic screen,**

Fig. 11. *Wooden piles damaged by boring organisms (top) such as shipworms (Teredo sp.) (bottom).*

Fig. 12. *Coral on the jackets of an oil platform off Guinea.*

affecting heat exchange, blocking mechanical functions, inducing **fatigue of certain materials** and **accelerating corrosion** and **biodegradation** (Compère, 1999). Engineers thus often see biofouling as a nuisance, hence the terms **fouling**, **incrustation**, and **concretions**. When structures are covered by organisms, this directly leads to:

- An increase in **diameter** (Fig. 13) which influences the Archimedes' principle, wave loading, drag and added mass;
  - **modification of the profile** of a surface or dissymmetry/eccentricity of a circular structure which affects drag but can also generate lift effects, hence the structure may be prone to self sustaining fluid-structure instability such a "galloping" (Damblans *et al.* 2013), which can jeopardise the structure's integrity. These phenomena have been identified in the oil & gas sector on slender cylindrical structures for which colonisation spreads dissymmetrically and/or with a marked eccentricity (Fig. 14).
  - **modification of surface roughness with an irregular increase in thickness** (Fig. 13) (affects drag);
- An increase in the **weight** of the structure, (i.e. additional mass) which affects the Archimedes' principle, the inertial forces of the moving structure and shifts the normal modes/the response of the structure with respect to its initial design.
- An increase in **added mass** (i.e. the fluid force to which the moving structure is subjected proportionally to its acceleration).

These changes (indirect impacts of biofouling) **hinder the visual inspection of structures and can even prevent them from functioning** (e.g. fouling of a propeller), calling for costly cleaning and maintenance operations. To illustrate a case of biofouling preventing a component from operating correctly, we can take the example of a dynamic export cable for a floating wind turbine deployed in moderate water depth (<50m) colonised along almost its entire length.

To absorb wave dynamics as well as the movements of the float, the dynamic cable has an extra length supported by a series of buoys. The additional weight of the cable due to biofouling (added weight of marine organisms on the cable) results in the disappearance of this extra length, which can lead to damage to, or even rupture of, the cable. The length of the cable is calculated so that it does not touch the bottom, given that repeated abrasion can be critical, as can the direct transmission of the float's dynamics which can result in connection pull-out.

Within the framework of another project coordinated by France Energies Marines (ANR-EMR-ITE 2015 OMDYN project), based on observations recorded at the SEM-REV site (a project partner), it was determined that colonisation of a cable by mussels (*Mytilus edulis*) can lead to:

- A 3.5-fold increase in the weight of the cable in air
- A 1.8-fold increase in the mass of the cable in water
- A 5.8-fold increase in the added mass.

The preliminary study did not present the impacts on the structural responses, although they are very likely to be non-negligible (Damblans, 2017). Both hard and soft biofouling organisms increase the mass and size of a biocolonised structure, but not necessarily proportionally to their length/height. **A cylinder colonised (in comparable proportions) by both hard organisms and soft organisms will have different hydrodynamic coefficients to a cylinder colonised by hard-bodied organisms alone** (Heideman & George, 1981). The response of the cylinder itself, or the ORE structure, is liable to be affected by the soft organism's own dynamics (e.g. kelp), creating a complex physical issue of fluid/structure interaction. To accommodate this issue, specific experimental investigations and numerical developments are required.

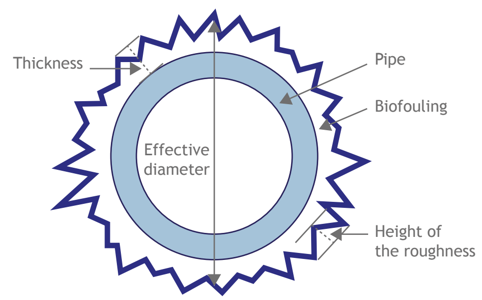


Fig. 13. *Diagram showing the variables of thickness, roughness height and effective diameter of a pipe colonised by calcified and/or hard species (taken from Heideman & George, 1981).*

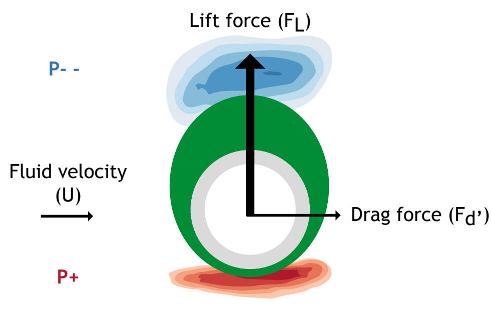


Fig. 14. *Diagram illustrating the principle of lift force (FL) related to negative pressure (P- -) and drag force increase (Fd') due to the dissymmetry of biofouling on a circular cross-section.*

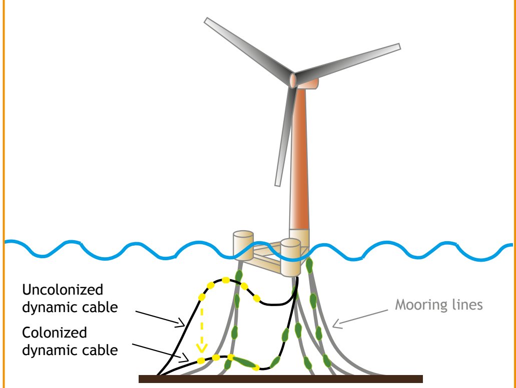


Fig. 15. *Diagram of a floating wind turbine and its subsea components with mooring lines and the dynamic cable whose weight increases, and thus buoyancy decreases (yellow arrow) as biofouling accumulates.*

2 - The challenges of biofouling for the ORE sector

Although the issue of biofouling is well known and has been extensively studied in the marine environment (navigation, offshore activities, etc.) it raises **new challenges in the context of offshore renewable energy** (details available in the ABIOP project deliverable entitled: *Etat de l'art des problématiques liées au biofouling rencontrées pour les différentes technologies EMR*) (Fig.16). Offshore renewable energy systems may be composed of **new materials** whose sensitivity to fouling has not yet been fully established. Furthermore, ORE devices are installed in **very dynamic environments** (areas with strong current, waves and wind), **far from the coast** and/or in deep waters, which are therefore difficult for scientists to access and **poorly known.**

Fig. 16. *A tidal current turbine colonised by kelp after 3 years of immersion at the Race Rocks site, Canada (www.racerocks.ca).*

The challenges raised by biofouling can be divided into three categories: environmental, technical and economic. The main environmental challenge, which is an acceptability criterion for ORE projects, is to **maintain (or improve) the ecosystem's functionalities**. The main technical challenge is to **define the optimal size of the structures,** while **ensuring good long-term resistance and functioning by driving regulatory changes** (i.e. fine-tuning recommendations issued by certification bodies). **Limiting or better managing maintenance operations to keep the Levelized Cost Of Energy (LCOE) as low as possible** constitutes the main economic challenge (ABIOP deliverable *Synthèse des enjeux du biofouling pour la filière EMR;* Loxton *et al.*, 2017).

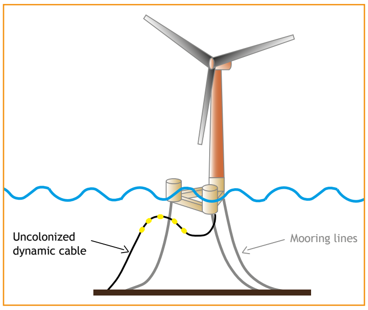
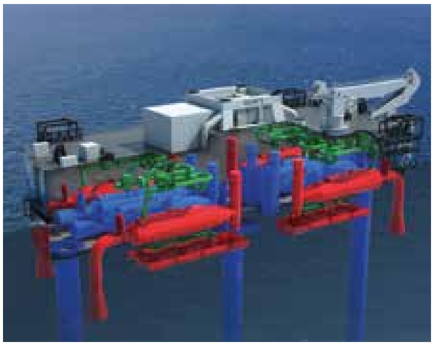
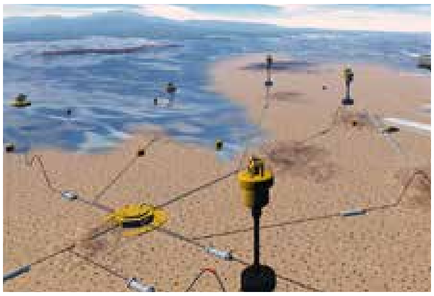
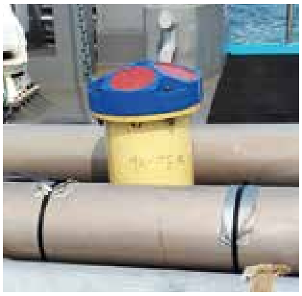
Estimations (Want, 2018) suggest that **reduced maintenance (one visit or less per year)** would reduce the economic and environmental cost of a tidal current turbine by €23K and 4 tonnes of carbon. **On the scale of a moderately sized farm** (composed of 10 turbines) operating for 25 years, this would **mean a saving of €5.8 million.** It is therefore very important to have a clear understanding of the biofouling process in order to plan the maintenance of ORE systems more efficiently and to reduce the LCOE.

To promote the environmental integration and technical and economic viability of ORE projects as effectively as possible, it is important to determine, among the broad range of existing technologies, **how sensitive the components are to biofouling.**

Biofouling may be tolerated by, or even advantageous for, certain components such as the foundations of fixed-foundation wind turbines or the protective mattresses of power transmission cables (e.g. Taormina *et al.*, 2018, Fig. 17). When appropriately dimensioned, these components can withstand fouling and promote the **reef effect**. With the development of ecosystems on or around these structures, combined with any fishing restrictions which may be in place around the wind turbines (**reserve effect**), ORE farms can constitute areas of refuge and repopulation for several commercially exploited species (Langhamer, 2012; Taormina *et al.*, 2018) and thus act as marine protected areas. This effect can have a major socio-economic impact and **can improve the acceptability of ORE projects.**

Fig. 17. *Mattress, protecting the cable that runs between the Paimpol-Bréhat trial site and the mainland, colonised by sessile species (Ascidiacea, Serpula, etc.) and mobile species such as lobster (Homarus gammarus), photo taken for the ANR-EMR-ITE-FEM SPECIES project and taken from Taormina et al., 2018.*

Certain components of ORE structures are however more sensitive to biofouling. Working groups conducted by FEM from 2015 and organised within the ABIOP project consortium identified eleven **components for which biofouling is a priority issue to be taken into account** (Tab. 3).

Technology	Components	Illustrations
Tidal turbines	Stator Ducts and blades Rotor	
Floating wind turbines (and other floating technologies)	Moorings Dynamic cable	 
Ocean thermal energy	Moorings Dynamic cable Pipes	
All technologies	Subsea connectors Measurement devices (sounders, ADCP, etc.)	 Subsea connectors  ADCP

Tab. 3. *Determination of the ORE technologies and/or components that are most sensitive to biofouling.*

The **acquisition of knowledge on biofouling is a major challenge** in the highly dynamic environments (strong currents) in which ORE systems are installed. It is also important to determine the variables characterising biofouling, **which will be useful to respond to both environmental and engineering science issues** (Macleod, Stanley, Day, & Cook, 2016; Want *et al.*, 2017). The ABIOP project deliverable entitled "Synthesis of existing in situ protocols and recommendations for biofouling monitoring methods adapted to ORE" reviews the existing methods for characterising biofouling and the potential solutions for adapting them to the ORE context (Quillien *et al.*, in prep.).

It has been recommended that the following variables be measured:

- Biovolume,
- Thickness (and ultimately roughness),
- Fresh weight,
- Linear mass/distribution,
- Dissymmetry (colonisation geometry),
- Functional groups,
- Species richness,
- Presence/absence of non-native species,
- Percentage of surface covered,
- Abundance.

The measurement of these variables depends on the initial objectives of the biofouling study (prospecting/preliminary study, monitoring or assessment of environmental effects/impacts) (see ABIOP project deliverable entitled "Synthesis of existing in situ protocols and recommendations for biofouling monitoring methods adapted to ORE").

3 - Atlas development methodology

3.1 Composition of the corpus of literature

By combining a **literature review with requests issued to the partners** of the ABIOP project, a corpus of literature was gathered which forms the basis of this atlas. The literature review was conducted using two search engines **(Web Of Science and Google Scholar)** and the search system to identify documents available at the **La Pérouse library** (specialised in books and journals relating to the marine environment) (Tab. 4).

In total, nearly 200 documents (scientific articles, theses, reports, books) were identified. **A subset of documents** was then compiled by selecting the **studies conducted in French waters** (including overseas France) and aimed at characterising biofouling and/or hard substrate assemblages in the subtidal zone. The vast majority of targeted studies focus on macrocolonisation (see ABIOP project deliverable entitled "Synthesis of existing in situ protocols and recommendations for biofouling monitoring methods adapted to ORE"). A few studies focusing on the initial stages of biofouling have been included (in particular studies conducted in overseas France).

Furthermore, studies specifically focusing on biofouling in relation to offshore renewable energy but which were not conducted within the geographical area covered in this study were nevertheless added to the subset. These studies are not summarised in this atlas, however they provided input for its introductory section.

Theme	Keywords
Biofouling	*Biofouling, successional development/succession écologique, marine growth, biocolonization/biocolonisation, biosalissures, macrofouling, recolonization/recolonisation, colonization/colonisation, epibenthic communities/communautés épibenthiques, encrassement biologique, encrassage, benthic succession, fouling, epibiosis/épibiose, subtidal epifauna, sessile assemblages, hard bottom fauna, épifaune, faune de substrats durs*
Type of substrate	*Artificial reef/récif artificiel, reef effect/effet récif, hard substrate, hard substratum, substrat dur, rocky habitat/habitat rocheux, structure, device, renewable energy, MRED/structures EMR, MRE/EMR, wave power/houlomoteur, turbine, offshore wind power, offshore wind farm/ferme éolienne offshore, water power, tidal power/hydrolien, oil & gas platform/plateforme, oil rig/plateforme pétrolière, steel platform, marine cables/câbles sous-marins, piling, pontoon/ponton, wharf, buoy/bouée, boat/navire, rocky reef, offshore structure, gas platform/plateforme gazière, hull/coque, hard bottom/subtrat dur*
Geographical area	*France, Bay of Biscay/Golfe de Gascogne, Mediterranean/Méditerranée, Polynesia/Polynésie, Réunion island/île de la Réunion, Martinique, Brittany/Bretagne, Paimpol-Bréhat, Alderney Race/Raz-Blanchard, Caribbean coast/Caraïbes*

Tab. 4. *List of keywords used in the research.*

3.2 Analysis of the corpus of literature

This atlas is based on the analysis of **45 documents** which fall within the boundaries defined for the ABIOP project (French waters). Precise information was extracted from these documents and was fed into two main databases: 1) document analysis (109 categories) and 2) geographical coordinates of sites and stations monitored in the studies analysed (55 categories). During the document analysis phase, the following main fields were completed where the relevant information was available:

- **Source:** general information (authors, journal, title, etc.), general theme;
- **Focus(es) of the study:** issue(s), aim(s), explanatory variables and response variables measured;
- **Study site characteristics:** spatial scale (country of the study, atlas zone, geographical coordinates, depth), supplementary information (pollution, etc.);
- **Protocol(s):** data acquisition methods (sampling technique, surface area sampled, numerical analyses, etc.), time scale (duration, frequency, etc.);
- **Explanatory variables:** context (type of surface, material, orientation of the structure, etc.), physico-chemical variables (temperature, waves, pH, etc.), biogeochemical variables (nitrates, contaminants, etc.), biological variables (competition, predation, etc.), transversal variables (type of habitat, connectivity);
- **Biological response variables:** variables with an impact on the geometry of the component (coverage, eccentricity, roughness, etc.), variables with an impact on the structure as a whole (biomass, volume, etc.), variables of specific interest from a point of view of engineering and the assessment of environmental effects (species richness, species size/dimensions, evolution over time, etc.);
- **Study results:** main results and discussion, conclusion(s), limits identified by the authors;
- **Comments:** benefits and limits of the study, transposition to a possible ORE context, number of citations;
- **Link to log book**: date of bibliographical search, document reference number.

These databases take the form of **Excel files** and are associated with **metadata**. A **Geographic Information System (GIS)** was established to map the information extracted from the documents analysed and will be **updated every time new information is entered into the two databases developed for the atlas.** A third database was created to summarise the existing biofouling characterisation protocols (ABIOP project deliverable entitled "Synthesis of existing in situ protocols and recommendations for biofouling monitoring methods adapted to ORE").

3.3 Atlas zoning

The atlas has been divided into **four zones,** which are differentiated by their **biogeographical characteristics** (set of physical and hydrological mechanisms and/or characteristics which regulate biodiversity):

- **The Channel,** with its homogeneous water mass (orange zone, Fig. 18);
- **The Bay of Biscay,** which shows more marked seasonal variation than the Channel with stratification of the water mass in the summer and an increase in the associated water temperature (pale blue and pale pink zones, Fig. 18);
- **The Mediterranean,** which is an enclosed sea containing saltier water than the Channel or the Atlantic, and with a specific biodiversity (Fig. 19);
- **Overseas France,** and in particular French departments and territories in the Indian Ocean, the Caribbean and French Polynesia which harbour tropical ecosystems where ORE technologies are currently being tested, have been grouped together as the fourth zone.

For each of these zones, **the knowledge available through the analysis of the subset of literature was summarised, the availability of data from the documents analysed was mapped** and the **key information extracted from each of the sources analysed summed up** in a short paragraph. Information on the study's **location**, **duration**, the **type of substrate** studied and the **variables measured** is set out.

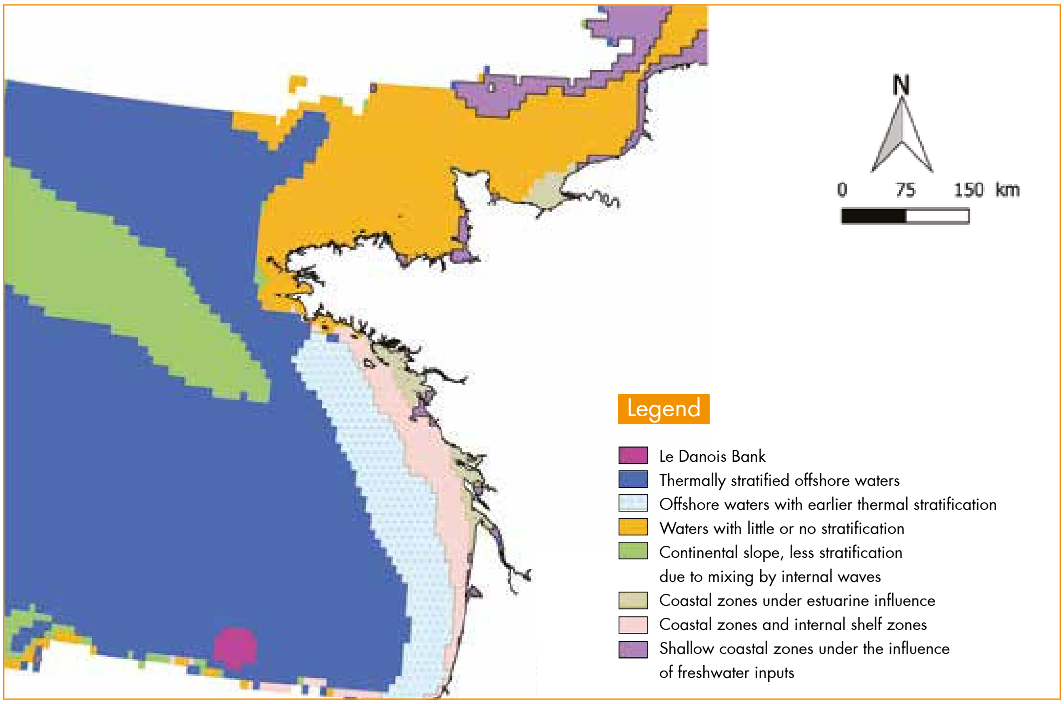


Fig. 18. *Contrasting hydrological landscapes along the French Atlantic and Channel coastlines (data source: Ifremer).*

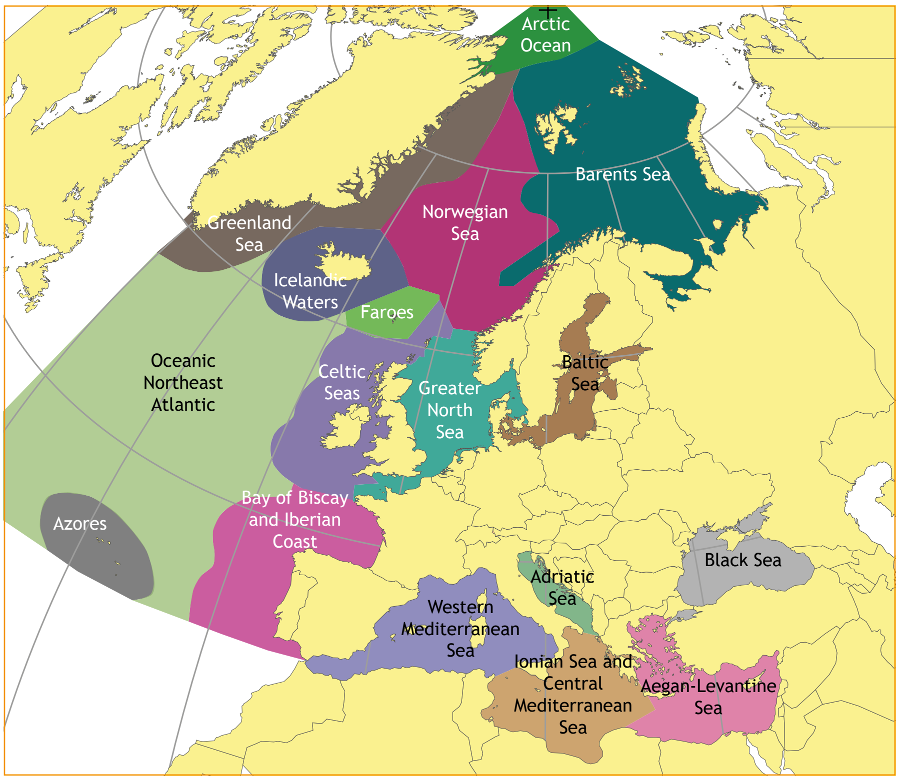


Fig. 19. *Marine ecoregions of Europe (source: ICES).*

3.4 Quick-start guide for readers

Each of the 4 sections (Channel, Bay of Biscay, Mediterranean and overseas France) **comprises** (in order of appearance):

• A **1st page** presenting the location of the atlas zone, the section, key information on the biogeographical area and a list of the main biofouling species (and more widely communities of hard substrates) in the zone based on the analysis of the documents available for this geographical area;

• A **2nd page** featuring a map pinpointing the locations of the sites studied within the atlas zone. Each point is identified by a number which corresponds to the reference analysed. Certain numbers appear several times on the map when the study in question covers several sites.

• The **subsequent pages** present the documents analysed in summarised form (annotated bibliographical references) together with 5 informative maps showing:

- The **depth** and **type of sampling** at each point: depth is a parameter which significantly influences the composition of a biofouling community. It is important to know this variable before considering the results of a study. In the same way, the sampling strategy (station or transect) gives an indication of the degree of integration of the data considered (station sampling = samples taken at a given point, and therefore depth; transect sampling = samples taken at different depths). The characterisation of biofouling which varies according to depth is a sort of average;

- The **type of substrate** studied: man-made, natural or both. The studies analysed present the results of monitoring conducted on different types of substrates. The substrate material (e.g. concrete, metal, rock) is also indicated in the text which accompanies each of the references;

- The **availability of abundance data**: a green square indicates that information is available on the abundance (number of individuals per unit of surface area) of the species or groups of species sampled. More detailed data may be presented in the text provided with each reference and all the details are included in the atlas database;

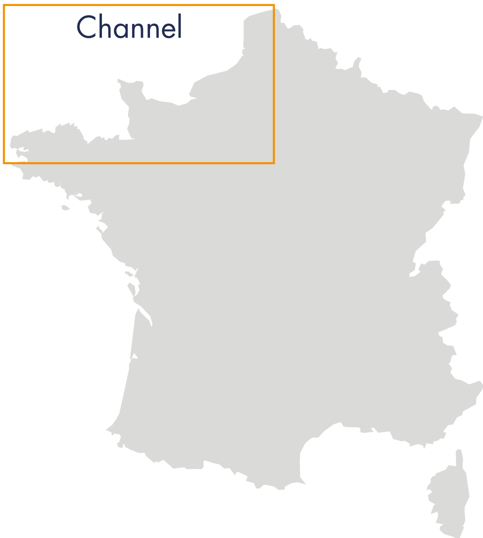
- The **availability of biomass data**: a green square indicates that information is available on biomass (weight of a given species or the whole community per unit of surface area). On these maps, the biomass includes fresh weight (or wet weight), dry weight and/or ash-free dry weight. The fresh weight is a particularly interesting variable in the ORE context as it can constitute input data for device design. Information on the type of biomass measured and a few values are described in the text provided with each reference. The detailed data were entered into the atlas database;

- The **availability of species richness data**: a green square indicates that information is available on species richness (number of species sampled). This information is useful for tackling the environmental challenges of biofouling for ORE devices.

A short section presenting more general results (across the four atlas zones) is included at the end of the four sections.

4 - Atlas of biofouling and hard substrate communities

4.1 Biofouling in the Channel



Characteristics of the area:

Epicontinental sea; average depth of 54 m (maximum depth 185 m); western basin strongly influenced by the Atlantic and eastern basin influenced by freshwater inflow from the Seine estuary; strong tidal currents (mixing of the water column); coarse sediment predominant on a basin-wide scale; winter T° of 6 to 9°C; summer T° of 12 to 17°C; one of the most heavily affected seas by human activities: marine granulate extraction, presence of major sea ports (Le Havre, Rouen, Dunkirk), presence of four nuclear power plants (Paluel, Penly, Gravelines, Flamanville), and fisheries (fish, crustaceans, bivalves) covering extensive areas.

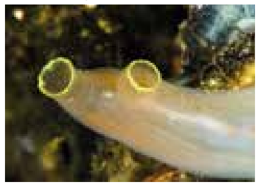
Main fouling species in the Channel:

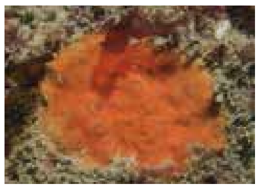
B. crenatus, B. perforatus, B. improvisus, Eliminius modestus, Botryllus schlosseri, turf-forming hydrozoans, Tubularia indivisa, T. larynx, Ciona intestinalis, Schizomavella auriculata, Solieria chordalis, Laminaria hyperborea, Metridium senile, Mytilus edulis, Alcyonium digitatum, Ascidia mentula, Corynactis viridis, Urticina felina, Tethya aurantium, Anomia ephippium, Pomatoceros triqueter.


B. crenatus


Botryllus schlosseri

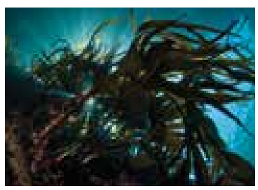

Tubularia indivisa


Ciona intestinalis


Schizomavella auriculata


Solieria chordalis


Tethya aurantium


Laminaria hyperborea

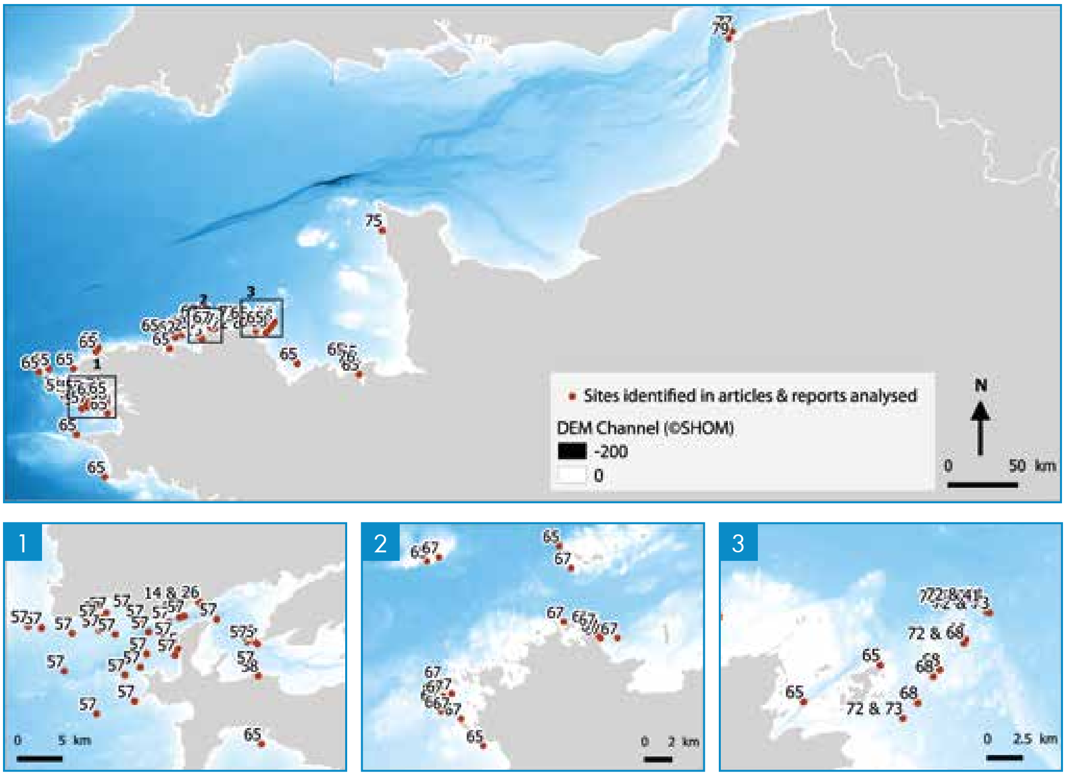

Mytilus edulis


Alcyonium digitatum

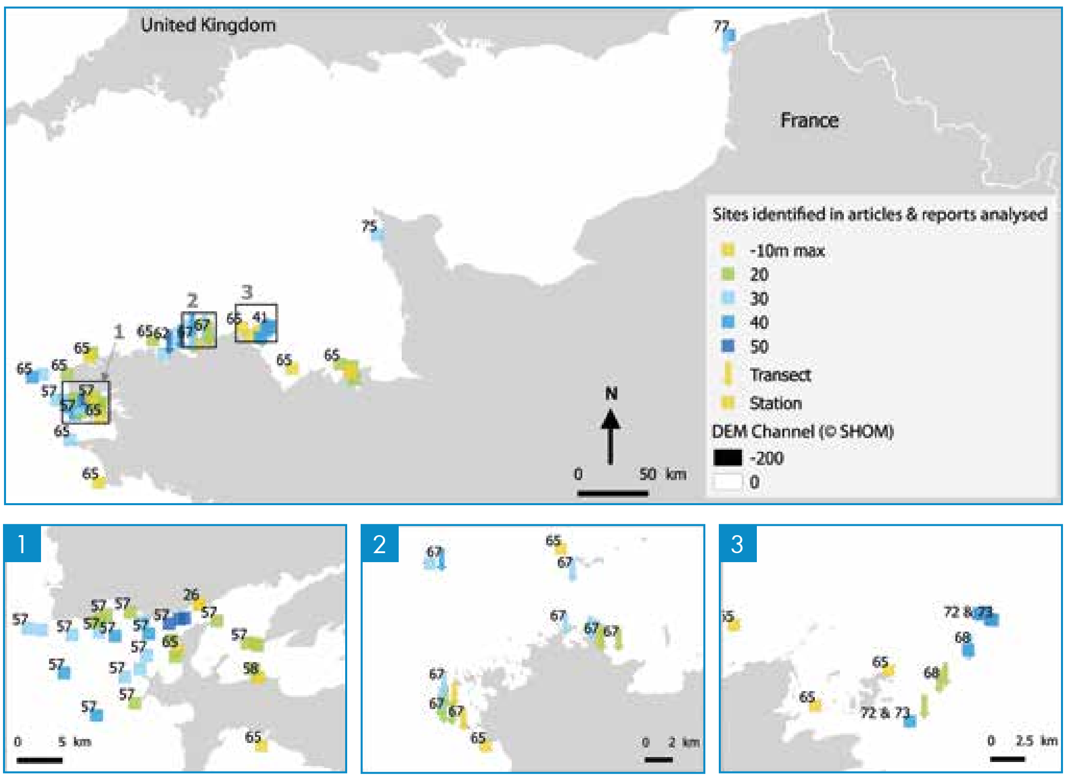

Anomia ephippium


Pomatoceros triqueter

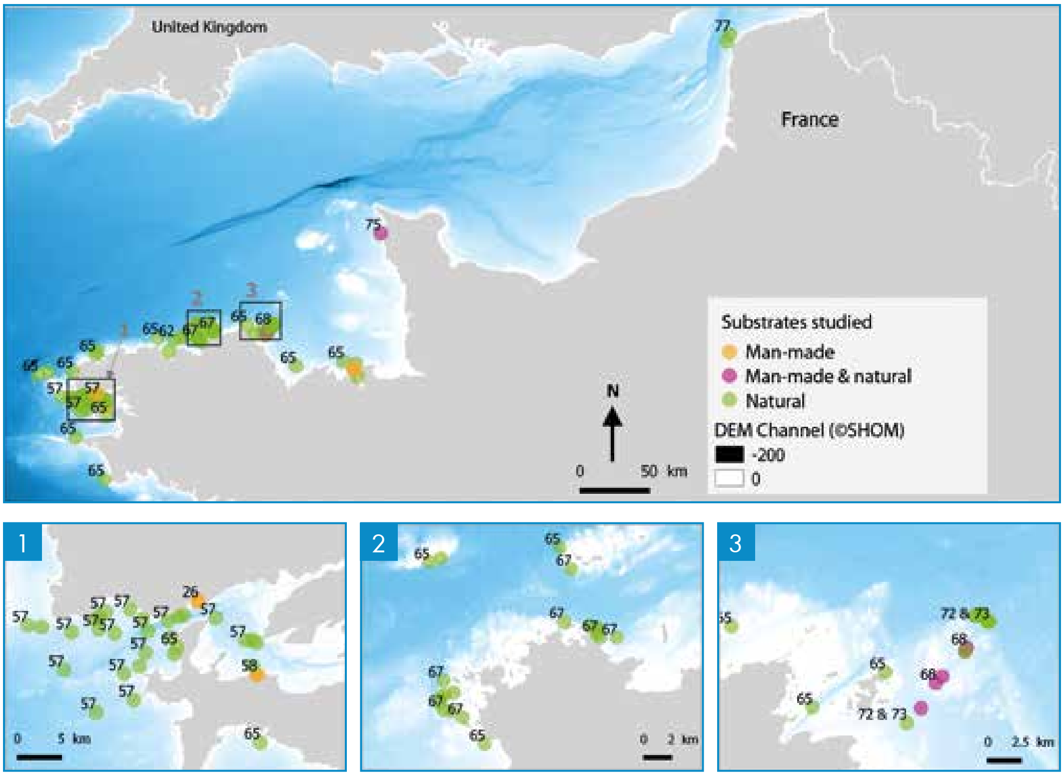
Study site locations in the Channel



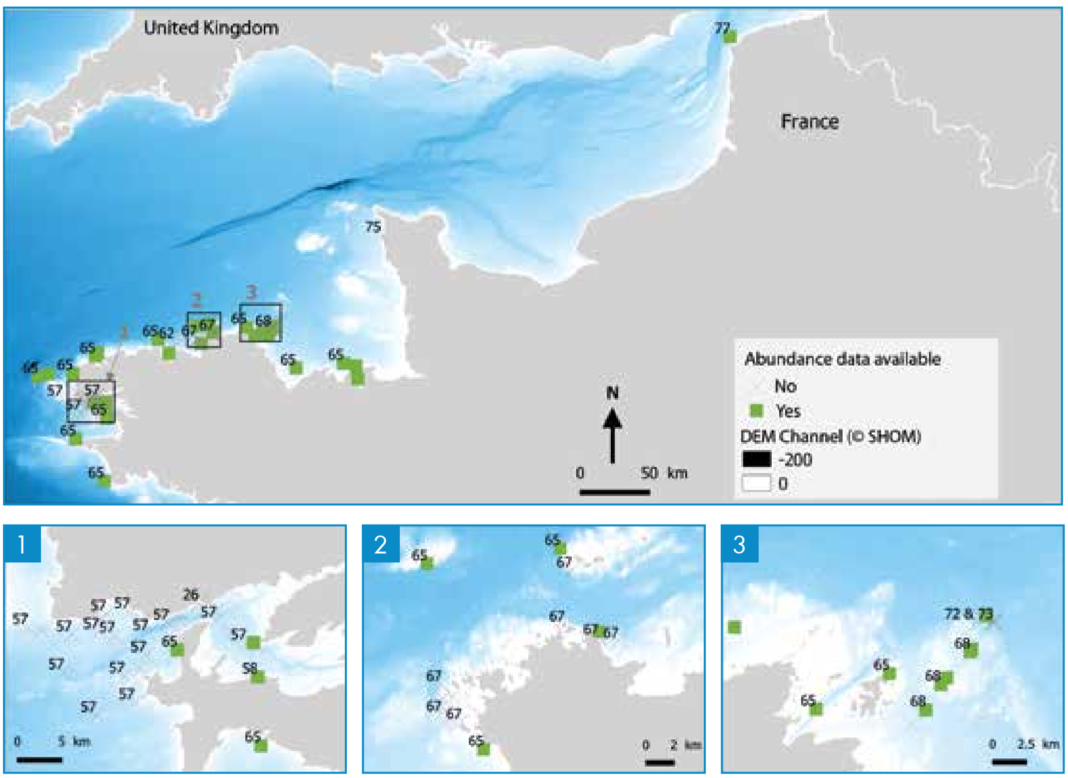
Type of sampling and maximum depth of sites in the Channel



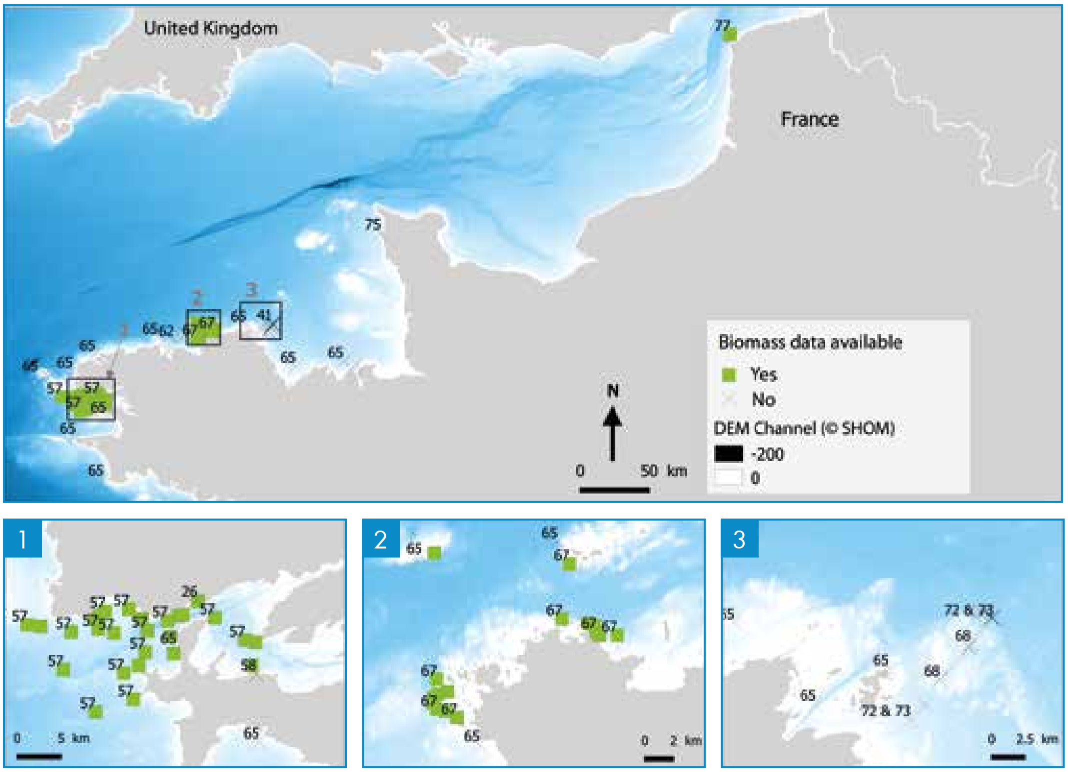
Type of substrate studied at the different sites in the Channel



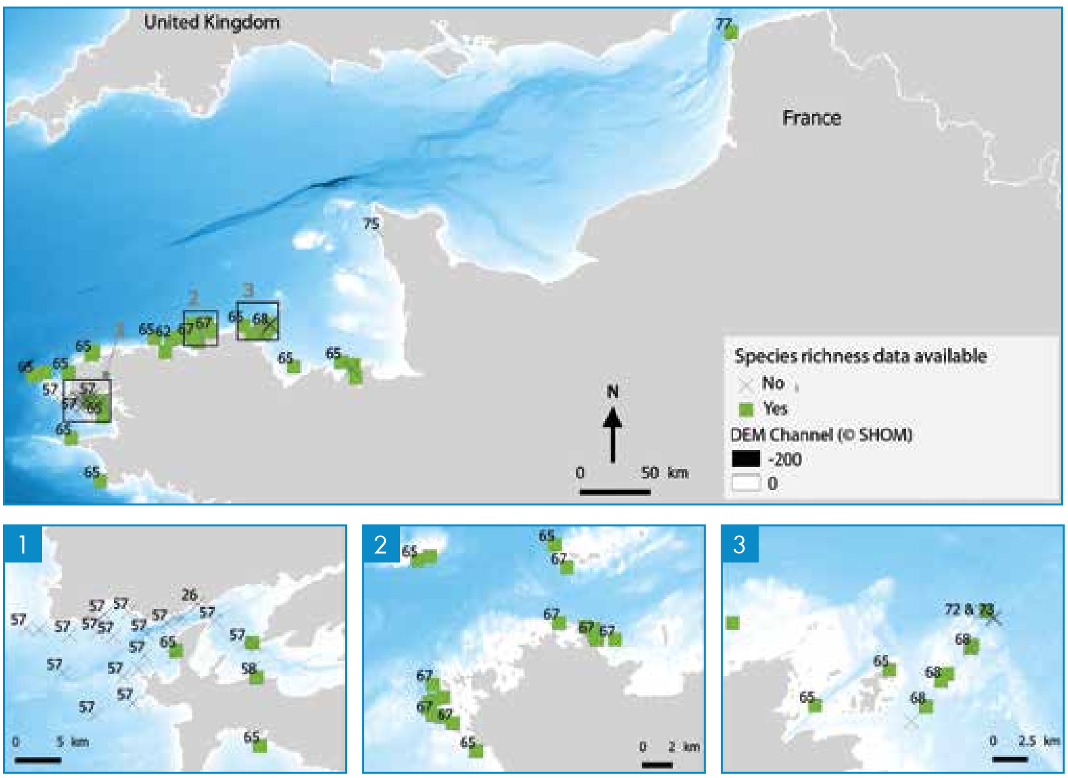
Availability of abundance data for the Channel



Availability of biomass data for the Channel



Availability of species richness data for the Channel



Annotated key references

[14] Antoine E., 1978. ***Etude du Fouling sur la station d'essais en milieu marin de Sainte-Anne du Portzic.*** CNEXO internal report, 6pp. **Sainte-Anne du Portzic**, Brest roadstead (Finistère); **June to Dec. 1977**; panels of **slate** positioned vertically **8 m** deep; monitoring **(freq. ≈ 2 mos.)** of biofouling development and of periods of benthic organism attachment; variables measured: **absolute abundance, relative abundance, % cover, average species size**; after 6 months, colonisation > 100 % (overlapping organisms); interannual variability of attachment periods, but identical order: ascidians (May and June), barnacles (June and July), bryozoa and Serpula (July and August).

[41] Duchêne J., 2014. ***Evaluation du biofouling sur la machine test OH-OCT-1***. Istrenn internal report, 10pp. **Paimpol-Bréhat**, Plateau de la Horaine (Côtes-d'Armor); **Dec. 2013 to April 2014**; **composite** and **steel with antifouling coating** and uncoated steel base of an OpenHydro **tidal stream turbine** positioned **40 m** deep; qualification and quantification of fouling of the turbine; response variables measured: **% cover, A, S**; S = 3 on the base; *Balanus balanus, Tubularia indivisa, Tubularia larynx*; S = 0 on the blades. No fouling on the blades and the duct (= antifouling coating); low level of fouling of the base's vertical bars (< 5 % cover); differences between port and starboard (more fouling on starboard bar), but no explanatory factor identified.

[63] Bridier G., 2016. ***Dynamique temporelle d'une communauté benthique sur substrat artificiel en rade de Brest***. Internship report (Master 1) IUEM, 25pp. **Lanvéoc**, Brest roadstead (Finistère); **Jan. 2013 to Oct. 2015**; inclined **plexiglass** panels placed on the sediment at a depth of **9 m** in spring 2012; monitoring **(monthly freq.)** of fouling for almost 3 years; explanatory variables measured: T°C, sal., O_2, pH, NH_4, NO_3^-, NO_2, PO_4, $SiOH_4$, POC, PON, MIS, Chla, $\delta^{15}N$, $\delta^{13}C$; response variables measured: **Species A, S**; S = 79; identification of cycles in the species succession (except for Serpulidae); decrease in density (sometimes even disappearance) of certain species present in first stages of macro-colonisation (e.g. bryozoa and ascidians); *Balanus crenatus* and *Anomia ephippium* are very heavily dominant in terms of A; interannual variability of % cover; positive temporal autocorrelation (communities sampled at two successive dates were similar); explanatory variables selected in ascending order: T°, pH, $\delta^{15}N$, $[PO_4^{3-}]$, Chla, PON (var. due to phytoplankton blooms); other factors which may explain variations (not measured and therefore not tested): predation, competition for substrate.

[58] Chauvaud A., 2017. ***Dynamique temporelle d'une communauté benthique sur substrat artificiel en rade de Brest : influence de l'environnement et des interactions spécifiques***. Internship report (Master 1) IUEM, 25pp. Follow-up to the work of Bridier, 2016; **Lanvéoc**, Brest roadstead (Finistère); **Jan. 2013 to Nov. 2016**; inclined **plexiglass** panels placed on the sediment at a depth of **9 m** in spring 2012; monitoring **(monthly freq.)** of fouling for almost 4 years; explanatory variables measured: T°C, sal., O_2, pH, NH_4, NO_3^-, NO_2, PO_4, $SiOH_4$, POC, PON, MIS, Chla, $\delta^{15}N$, $\delta^{13}C$; response variables measured: **% species cover, % free space, S, J'**; S = 39 for 2016; J' ↘ between 2013 and 2016 = community tends to be dominated by one or a limited number of species; dominant taxa: 2013 = *Anomia*, 2014 = *Balanus crenatus* (50 % cover), 2015-2016 = *Schizomavella auriculata* (40 % cover); different degrees of seasonal variability; time alone explains over 50 % of variation in the community, the environment alone (sole variable selected = T°), 3 %; dynamic equilibrium achieved after 4 years (community dominated by highly competitive species such as *S. auriculata*); at equilibrium, bryozoa and sponges are dominant.

[26] Faimali M. *et al.*, 2016. ***Report on JERICO Biofouling Monitoring Program (BMP)***. Internal report, 26pp. **2 Ifremer Brest sites** (+ other European sites: Italy [Genoa, Venice], Greece); monitoring (at **3 mos.** for the site in Brest) of fouling on **glass**, **metal** and **plastic** panels with variable orientation (panels attached to several inner and outer sides of a box) positioned at an unspecified depth; explanatory variables measured: material, position on the structure, geographical location; response variables measured: **total % cover**, **% cover by functional group**; wide diversity of soft organisms; % hard fouling low-

4

Channel atlas

er than in Genoa; arborescent bryozoans, hydrozoans and ascidians present on all surfaces (all materials and orientations); dark conditions: barnacles and encrusting bryozoans; light conditions: red and green algae + pres. of cnidaria on vertical surface; at 3 mos., cover = 35 to 60 % (dark) and 60 to 80 % (light); heterogeneity between ≠ sites; importance of light exposure and material type for the first stages of colonisation.

[65] Derrien-Courtel S. *et al.*, 2013. ***Regional-scale analysis of subtidal rocky shore community***. Helgoland Marine Research, Vol. 67: 697-712. **38 subtidal sites along the coast of Brittany**; transects with depths of **0 to 31 m** max. (depth variable between stations); exposure gradient; explanatory variables measured: turbidity, $T°_{water}$, depth of infralittoral–circalittoral boundary (last kelp individual), response variables measured: **flora/fauna A** (n° ind. and colonies for each species), **kelp density**; identification of three typical assemblages according to turbidity and stratification: turbid sites (*Solieria chordalis, Ulva* sp., *Gracilaria multipartita, Chondracanthus acicularis, Chondria dasyphylla, Aiptasi mutabilis, Bougainvillia muscus, Nemertesia antennina, Hydrallmania falcata, Aplidium elegans, Morchellium argus, Tethya aurantium, Polymastia penicillus, Sabella spallanzanii, Ophiothrix fragilis*), stratified clear water sites (*Saccorhiza polyschides* forests with *Pterosiphonia complanata, Hypoglossum hypoglossoides, Lomentaria clavellosa, Marthasterias glacialis* and *Asterias rubens*) and homogeneous clear water sites (*Laminaria hyperborea* forests with *Desselaria sanguinea, Phyllopora crispa, Plocamium cartilagineum, Meredithia microphylla, Balanus* spp., *Dysidea fragilis*); infra-circa boundary between -1.6 m (turbid) and -32.2 m (clear); higher kelp density in clear water than turbid water (32.5 compared to 14.8 ind/m²); main factors affecting flora and fauna in rocky environments = temperature and turbidity.

[68] Cudennec N., 2015. ***Dynamique de la colonisation benthique sur les substrats artificiels des installations EMR - Cas du câble de raccordement du site pilote hydrolien de Paimpol Bréhat***. Internship report (Master 1) Ifremer, 66pp. **Paimpol-Bréhat**; **5 stations** (mattress + natural subs.) and **transects** (10 m long for cable monitoring) at a max. depth of **30 m**; 1650 images acquired between 2013 and 2014; monitoring (each semester); explanatory variables measured: **structure type** (cable vs mattress), **exposure to currents** (qualitative): **occurrence frequency, A, pres./abs., S, H', J'**; ↗S and H between 2013 and 2015 and between winter and summer; greater taxonomic diversity on natural subs. than man-made subs.; distinction of communities according to type of subs.; resemblance between man-made subs. and natural subs. communities increasing over time; monitoring of the abundance of two non-native species: *Crepidula fornicata* and *Styela clava*; *C. fornicata*: cable = 8 to 36 chains/m²; mattress = 1 to 8 chains/m²; *S. clava*: cable = 1 to 45 ind/m²; mattress = 0 to 23 ind/m².

[57] Castric-Fey A. & Chassé C., 1991. ***Factorial analysis in the ecology of rocky subtidal areas near Brest.*** JMBA UK Vol. 71: 515-536. **Goulet de Brest** and **mouth of Brest roadstead** (27 sites); **2 to 4 summer dives** at each station **from 1982 to 1984**; aim: to identify characteristic species of the different communities on **natural hard substrates** and assess the influence of environmental structures on these populations; explanatory variables measured: wave height, current speed, depth at kelp boundary, light conditions, response variables measured: **A, biovolume, % cover**; Algae (max. - 30 % light & 3 knot currents) = 15 kg/m²; Animals (max. - light area & turbid water) = 10 kg/m²; Animals (min. - dark area & clear water) = 0.5 kg/m²; cnidaria = 1/3 of total animal biomass i.e. in light area 0.2 to 1 kg/m² and in dark area 0.5 to 5 kg/m². **Group of wave-exposed sites // INFRALITTORAL FRINGE**: *Alaria, Mytilus, Balanus perforatus, Metridium senile, Pollicipes cornucopiae*, **INFRALITTORAL**: *Pachymatisma, Delesseria, Cellepora pumicosa, Clathrina, Corynactis, Sargatia elegans, Alcyonium digitatum*, **CIRCALITTORAL:** *Axinella dissimilis, Aglaophenia tubulifera, Luidia, Eunicella, Gymnangium, Alcyonium glomeratum;* **Group of sites exposed to strong tidal currents // INFRALITTORAL FRINGE:** *Laminaria digitata, Mytilus;* **INFRALITTORAL:** *Balanus crenatus, Bicellariella, Diphasia attenuata, Alcyonidium gelatinosum, Dysidea, Sertularia argentea;* **CIRCALITTORAL:** *Hydrallmania, Raspailia ramosa, Bougainvillia ramosa, Adocia, Polymastia mamillata, Nemertesia antennina, Cellaria salicorni, Alcyonium digitatum.* For the groups of open sites but sheltered from strong currents (waves and tides) and very sheltered sites: see detailed list in publication.

[67] Castric-Fey A., 1996. ***Richesse et biodiversité en mer mégatidale : communautés sublittorales rocheuses de la région*** **Trébeurden-Ploumanac'h** *(Nord Bretagne, France)*. Cahiers de Biologie Marine Vol. 37: 7-31. **Trébeuden-Ploumanac'h** (Region of Lannion, Finistère); **16 sites** (natural rock) studied (variable exposure to waves and tidal currents); 3 depth ranges explored: **level 2** – dense kelp beds **(3.7 – 11 m), level 3** – sparse kelp beds **(11 – 16 m)**, **level 4** – no kelp **(16 – 30 m)**; explanatory variables measured: depth, sediment type, currents, waves; response variables measured: **abundance rates, S,** biomass (**fresh weight** via biovolume method); distinction between communities first by substrate orientation: horizontal (predominance of algae) vs vertical (predominance of sciaphilous animals such as *Eunicella verrucosa, Pentapora foliacea, Chartella papyracea*) + indifferent species *(Henricia oculata, Cliona celata, Diazona violacea, terebellids)* and then by depth; Overall mean biomass = 12.7 kg/m², variable according to site **(greater biomass outside the roadstead** of Brest in areas of stronger current).

[62] Taormina B., 2016. ***Inventaire de la faune et flore marines et caractérisation des assemblages benthiques des milieux rocheux d'un site remarquable de la région de Roscoff : le Plateau de la Méloine***. Internship report (Master 2) Univ. Pierre et Marie Curie, 93pp. **La Méloine marine archipelago**, located between Roscoff/Morlaix bay (W) and Lannion/Côte de Granit rose (E): strong currents, waves; 3 sites studied (with a gradient of environmental conditions) at two bathy. (**infra and circa**); characterisation of communities on natural rocky substrates; explanatory variables measured: bathy. level for site and season; response variables measured: A_{flora}, pres./abs., A_{rel}; characteristic species of infra: ***Perforatus perforatus***, *Modiolula phaseolina, Bonnemaisonia asparagoides, Polocamium* sp., *Acrosorium ciliolatum*, ***Laminaria hyperborea***; and circa: ***Pentapora foliacea***, *Ocinebirna aciculata, Aplidium punctum, Parvicardium exiguum, Margelia coastata, Serpularia argentea/cupressina, Raphitoma linearis, Chartella papyracea, Dictyopteris membranacea, Heterosiphonia plumosa, Erythroglossum laciniatum*; vertical subs.: *Corynactis viridis*, flustridae, encrusting calcareous algae and other undetermined encrusting organisms (bryo, sponges, ascidians); and (only for circa) horizontal: ***Eunicella verrucosa***, *Stolonica socialis,* bladed red algae and turf-forming bryo/hydrozoans; in total **361 taxons** determined (78 algal taxons and 283 of macrofauna); variable depth which explains the majority of variability in flora/fauna assemblages; inclination explained by a significant proportion of variability for circa populations (not tested in infra); lower inter-site variability than that related to depth.

[72, 73] Derrien-Courtel S. & Catherine E., 2013, 2015. ***Inventaire vidéo de la biodiversité benthique sur le site d'essai hydrolien de Paimpol-Bréhat.*** Internal reports produced by MNHN for FEM, 21 and 22pp respectively. 57 (**15 to 19/03/2012**) and 25 (**20 to 22/03/2013**) videos (4 to 15 min) of the seabed at the **Paimpol-Bréhat** site edited; video transects at around 40 m deep; response variables measured: **pres./abs., occurrence freq.**; comparison of 2012-2013 communities and those sampled for ZNIEFF Bréhat; description of the main facies according to their hydrodynamics: strong current = facies featuring *Cliona celata, Alcyonium digitatum, Corynactis viridis, Tubulariidés, Halidrys siliquosa-Ciocalypta penicillus*, and turbid areas with strong current = sand-dwelling ascidians-micropolychaetes, *Ascidiella aspersa-Mimachlamys varia, turf-forming hydrozoans, Ulosa stuposa*, hydrozoans/barnacles; list of taxons inventoried in 2012 (n=105, n_{flora}=14, n_{fauna}=91) and 2013 (n=104, n_{flora}=26, n_{fauna}=78); common taxons (relatively high occurrence): ascidians (solitary, social or colonial) in particular *Pycnoclavella aurilucens* and *Polyclinum aurantium*, cnidaria *(Uriticina felina and Sagartia elegans)* and hydrozoans *(Sertularia argenea)*.

[75] Rudeault P., 2004. ***Le Wharf de la mine de Dielette - les récifs artificiels.*** Internal report, 28pp. Dielette, **1 site** (offshore wharf) opposite the Flamanville electric power plant; reinforced **concrete**/**rock**; opportunistic observations during amateur dives; between **-15 m** (min. depth) and **-22 m** (max. depth); visual estimations; response variable measured: **S**; qualitative review of dominant sessile species in populations on man-made hard susbtrates in Cotentin; dominant species: *Dylsea carnosa* (Rhodophyta), *Actinothoe sphyrodeta, Balanus crenatus, B. perforatus*; S_{total} = 165; S_{algae} = 12 ; $S_{sponges}$ = 16; $S_{cnidaria}$ = 12; S_{worms} = 10; S_{bryos} = 11; $S_{ascidians}$ = 8; + other groups, see report.

[76] Claquin P. *et al.*, 2015. ***Suivis environnementaux : colonisation des matériaux en mésocosmes et in situ.*** Internal report, RECIF project, 78pp. **Saint-Malo, Le Buron; 18 breeze blocks** (2 types of concrete: oyster shell and non-oyster shell) placed at **1 site** at a depth of **5 m**; explanatory variables measured: material, bathy. level; response variables measured: **S, % cover, organism size, A, biomass**; monitoring **(freq. = 2 mos.)** of the development of flora and fauna on 2 types of concrete over **6 mos.**; July 2015 to Jan. 2016; cover = 60% after 2 months of immersion and total cover after 6 months; S_{total} at 6 mos. = 34 to 37; Dominance of ***Botryllus schlosseri*** after 2 mos., ***Dictyopteris polypodioides*** after 4 mos., dominance of **red algae** after 6 mos.; rapid colonisation of the new substrate in the subtidal zone and by all the taxa present in the benthic environment (hydrozoans, bryozoans, ascidians, sponges, annelids, Chlorophyceae, Rhodophyceae, Phaeophyceae); no difference in colonisation between conventional concrete and oyster shell concrete (sand replaced with shell debris ok).

[77] Migné A. & Davoult D., 1995. ***Multi-scale heterogeneity in a macrobenthic epifauna community.*** Hydrobiologia 300/301: 375-381. **Pas-de-Calais**, 1 site studied (**coarse sediment**) at a depth of **37 m**; measurement of the structure and functioning of communities (sessile epifauna) settling on coarse sediment exposed to strong water currents; explanatory variables measured: T°C, sal., fluorescence; response variables measured: S, biomass (ash-free **dry weight**); **monthly** samples; study duration = **9 mos.** from June 1992 to April 1993; total AFDW: July = 425 g/m² and February = 155 g/m²; mean AFDW: 270±107 g/m²; S_{total} = 98; S_{avg} = 51±7; dominant species (in terms of biomass): ***Ophiothrix fragilis*** = 62±12 % of biomass; ***Urticina felina*** = 32±11 %; ***Alcyonium digitatum*** = 5±3 %.

[78] Migné A., 1996. ***Rôle des organismes suspensivores dans les transferts pelago-benthiques d'une zone de fort hydrodynamisme.*** PhD thesis, Station Marine de Wimereux, 263pp. **Pas-de-Calais**, 1 site studied (**coarse sediment**) at a depth of **37 m**; site with very **strong hydrodynamics**; aim: to reinforce previously acquired knowledge on matter flows in an ecosystem exposed to very strong hydrodynamics (**natural rock**) studied **monthly** in **1992-1993** (**12-month** study from June 1992 to June 1993); explanatory variables measured: T°C, sal., fluorescence; response variables measured: **Biomass** (ash-free dry weight), determination of **trophic groups**, **S**, **H'**, **J'**, total AFDW: July = 425g/m² and Feb. = 155g/m²; average AFDW: 270±107g/m²; S_{total} = 101; S_{avg} = 51±5; H' = 1.24 ± 0.17; J' (E) = 0.28 ± 0.04; relative density in terms of biomass: *Ophiothrix fragilis* (mobile species) = 62±12 % biomass; *Urticina felina* = 32±11 %; *Alcyonium digitatum* = 5±3 %; dominant sessile species = ***Urticina felina*** & ***Alcyonium digitatum***; **max. biomass in July and min. biomass in Feb.** (moderate temporal variability); young colonies of *Alcyonium digitatum* observed in samples from February; diversified population showing very high biomass, although with only 3 species of quantitative importance.

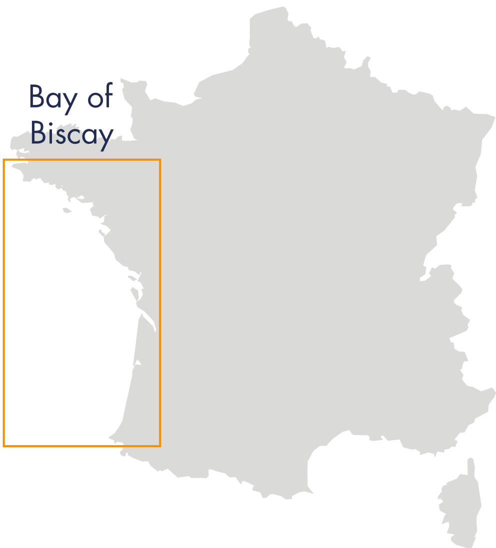
[79] Prygiel J. *et al.*, 1988. ***Description et richesse des peuplements benthiques de la partie française de la Mer du Nord.*** CR de l'Académie des Sciences, t. 306, Série III, 5-10. Study of the **seabed** (**rocks and sediment**) in the Pas-de-Calais area between **1973 and 1976**, then between **1985 and 1986**; approx. **6 years** of monitoring; depth between **15 and 30 m**; strong hydrodynamics; aim: to map benthic populations in the zone; response variables measured: **pres/abs**, **dominance**, **A**; dominant species: mobile species (see article as less relevant to ABIOP); well represented sessile species: ***Haliclona oculata, Raspiailia ramosa, Tethya aurantium, Abietinaria abietina, alcyonium digitatum, Halecium halecinum, Hydrallmania falcata, Sertularia cupressina, Urticina felina, Alcyonidium gelatinosum, Flustra foliacea***; hydrodynamic gradient revealed in populations from Dunkirk to Cap Gris-Nez (fine → coarse sediment).

[83] Antoine E., 1978. ***Etude du Fouling sur la station d'essais en milieu marin de Sainte-Anne du Portzic*** *(Dec. 1977-Dec. 1978)*. CNEXO internal report. **Brest roadstead, Sainte-Anne du Port-**

zic; study of the colonisation of **slates** during the year 1978; follow-up to previous monitoring (ref. 14); start = June 1977 (T+ 8 mos.) to June **1978**; acquisition of **monthly data**; aim: to perform a calibration for the Sainte-Anne du Portzic trial station; response variables measured: $A_{absolute}$, $A_{relative}$, **% species cover**, mean species **size**, **total fresh weight** (density); temporal monitoring of cover: at T+8 mos. = 96 %, at T+10.5 mos. = 106.6 %, at T+11 mos. = 42.45 %, at T+12 mos. = 77.5 %, at T+13 mos. = 100.06 %, at T+14 mos. = 97.47 %, at T+15 mos. = 82.2 %, at T+16 mos. = 39.8 %; cover by dominant organisms: *P. triqueter* = 13.6 %; *Balanus crenatus* = 25-50 %; encrusting bryos = 13-40 %; erect bryos = 12.5-50 %; *Ascidia mentula* = 17-47 %; **fresh weight temporal monitoring** mean(kg/m²): at T+8 mos. = 3, at T+10.5 mos. = 6.7, at T+11 mos. = 3, at T+12 mos. = 6, at T+13 mos. = 9.6, at T+14 mos. = 6.8, at T+15 mos. = 4.5, at T+16 mos. = 4.3; species abundance: ***A. mentula*** = 130-150/m²; ***Pomatoceros triqueter*** = approx. 6,000/m²; ***Balanus crenatus*** = approx. 5,000/m²; dominant species: Barnacles ***(Eliminius modestus, B. perforatus, B. improvisus)***, ***Botryllus scholosseri***, Serpula ***(P. triqueter)***, turf-forming hydrozoans, ***Ciona intestinalis*, encrusting cheilostomes, *Anomia ephippium***; measurement of species dimensions at each date: see report; classification of biofouling species into 2 groups: **annual species** = develop one season and disappear in winter (e.g. colonial ascidians, solitary ascidians, bryo); **permanent species** = certain individuals survive from one year to the next (e.g. barnacles, serpula); **main attachment period: June to August.**

[31] Chassé C. *et al.*, 1976. ***Etude écologique d'avant-projet sur le site de Ploumoguer.*** CNEXO internal report, 127pp. Region of **Ploumoguer** (Finistère): 1 site off the Pointe de **Brentec'h**, 1 in **Pors Ilien** and 2 sites on the nord-east side of the **Pointe de l'Ilette**; **1976**; monitoring of communities on **natural rocky substrates** between **0 and 14 m deep**; sampling in **summer** (July and September); **2 sampling times** at 4 sites; aim: to qualitatively and quantitatively characterise intertidal and subtidal communities in the area pre-selected for the installation of a power plant (focus on rocky substrates for this atlas, but soft substrates were also studied); explanatory variables measured: **T°C**$_{air}$, **wind**, **wave height**, **tidal currents**; response variables measured: **species** inventories, **biomass** (fresh weight only for algae), **demographic structure**, **production** (for *L. hyperborea* and *S. polyschides*); cover measured in intertidal zone only; ALGAE biomass: crustacean layer (depth <-20 m) = 0.2 kg/m², herbaceous/mossy layer (depth between +3 and -18 m) = max. 2 kg/m² (highly variable), shrub layer (20 cm < h < 2.50 m) (depth -14 to 0 m) = 5 kg/m² (max. = 12 to 13 kg/m²); invertebrates between 0 and 5 m: ***Balanus perforatus***, ***Didemnum maculosum, Desmacidon fruticosum***; invertebrates between 5 and 13.5 m: **club-shaped Polyclinidae**, ***Botryllus schlosseri***, **Crisiidae**; algae between 0 and 5 m: ***Laminaria hyperborea***, ***Saccorhiza polyschides***, ***Corallina officinalis***; algae between 5 and 13.5 m: ***Halidrys siliquosa***, ***Lithophyllum* sp.**; very high algal biomass in the region; on site, limited presence of rock (more sediment); **2 biomass maximums: one at -2 m (15 kg/m²) with dominance of *S. polyschides* and the other at -10 m (7 kg/m²) with dominance of *Halidrys siliquosa***; estimation of overall biomass on rocky substrate: no doubt lacking precision but gives an indication of production.

4.2 Biofouling in the Bay of Biscay



Characteristics of the area:

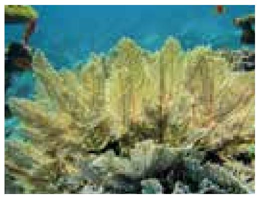
Large bay which opens into the North-East Atlantic; very broad continental shelf to the north (140 km), narrower to the south (50 km); continental slope at a depth of 200 m (max. depth 4,735 m); northward mean residual current; areas of upwellings (mainly south of the coast of Brittany and off the Basque coastline) and stratification; influence of the Loire and the Gironde rivers; tidal fronts; predominantly rocky seafloor to the north and sediment of varying grain size to the south; winter T° around 11°C (mixed water mass); summer T° can reach up to 21°C; main human activities: fisheries (bottom trawling targeting Norway lobster and common sole) covering large areas, defence (military port in Brest, naval base in Lorient), and other port activities (major sea ports of Nantes Saint-Nazaire, La Rochelle and Bordeaux).

Main fouling species in the Bay of Biscay:

Balanus spp., *Botryllus schlosseri*, shrubby hydrozoans, *Schizomavella sanguinea*, *Saccorhiza polyschides*, *Metridium senile*, *Corynactis viridis*, *Laminaria hyperborea*, *Mytilus edulis*, *Alcyonium digitatum*, *Tubulipora* sp., *Demosponges (e.g. Axinella disimilis)*, *Pomatoceros* sp., *Ctenosponges.*


Balanus spp.


Botryllus schlosseri


Shrubby hydrozoans


Schizomavella sanguinea


Saccorhiza polyschides


Metridium senile


Corynactis viridis


Laminaria hyperborea

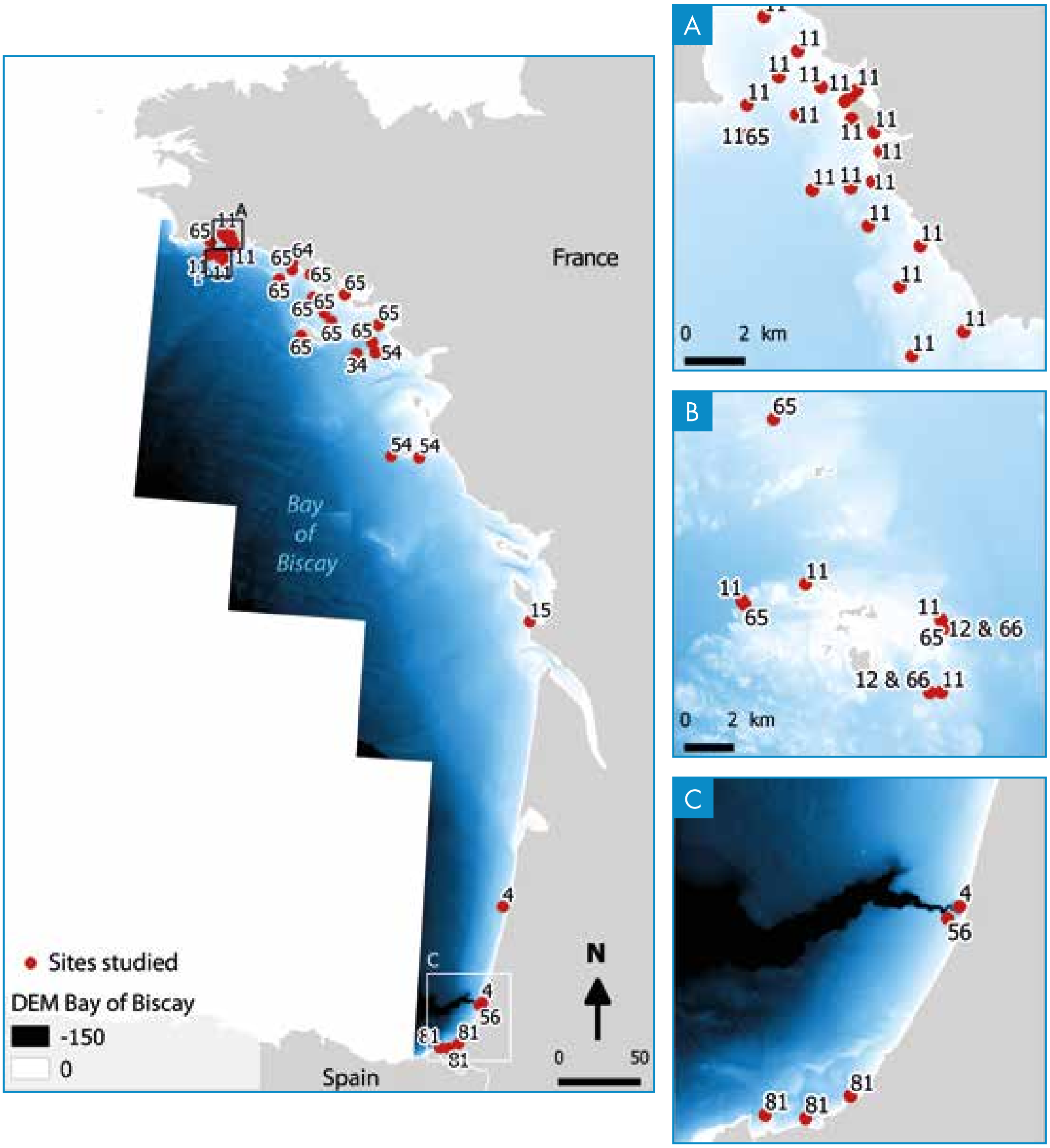

Mytilus edulis


Alcyonium digitatum

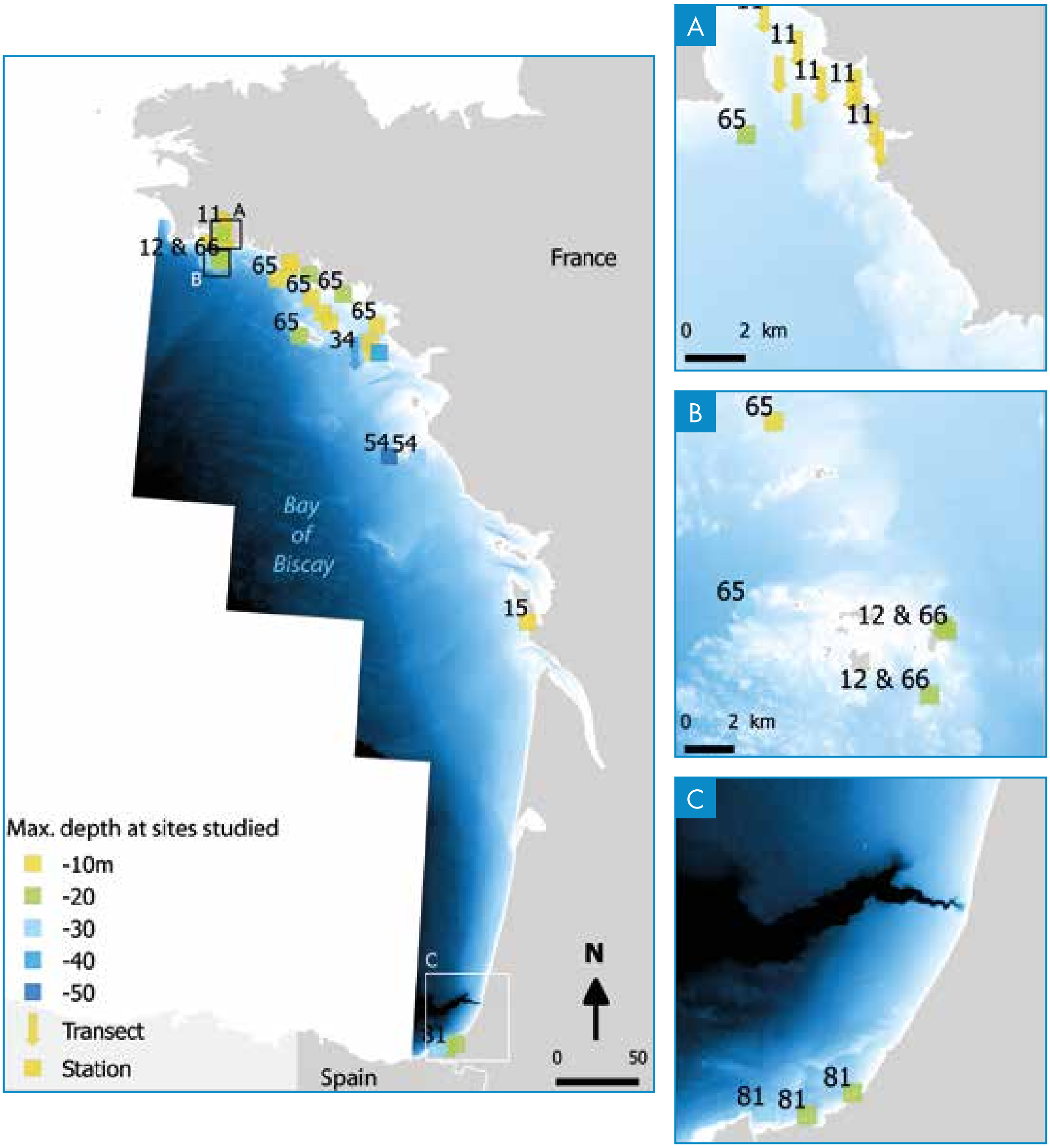

Axinella disimilis


Pomatoceros sp.

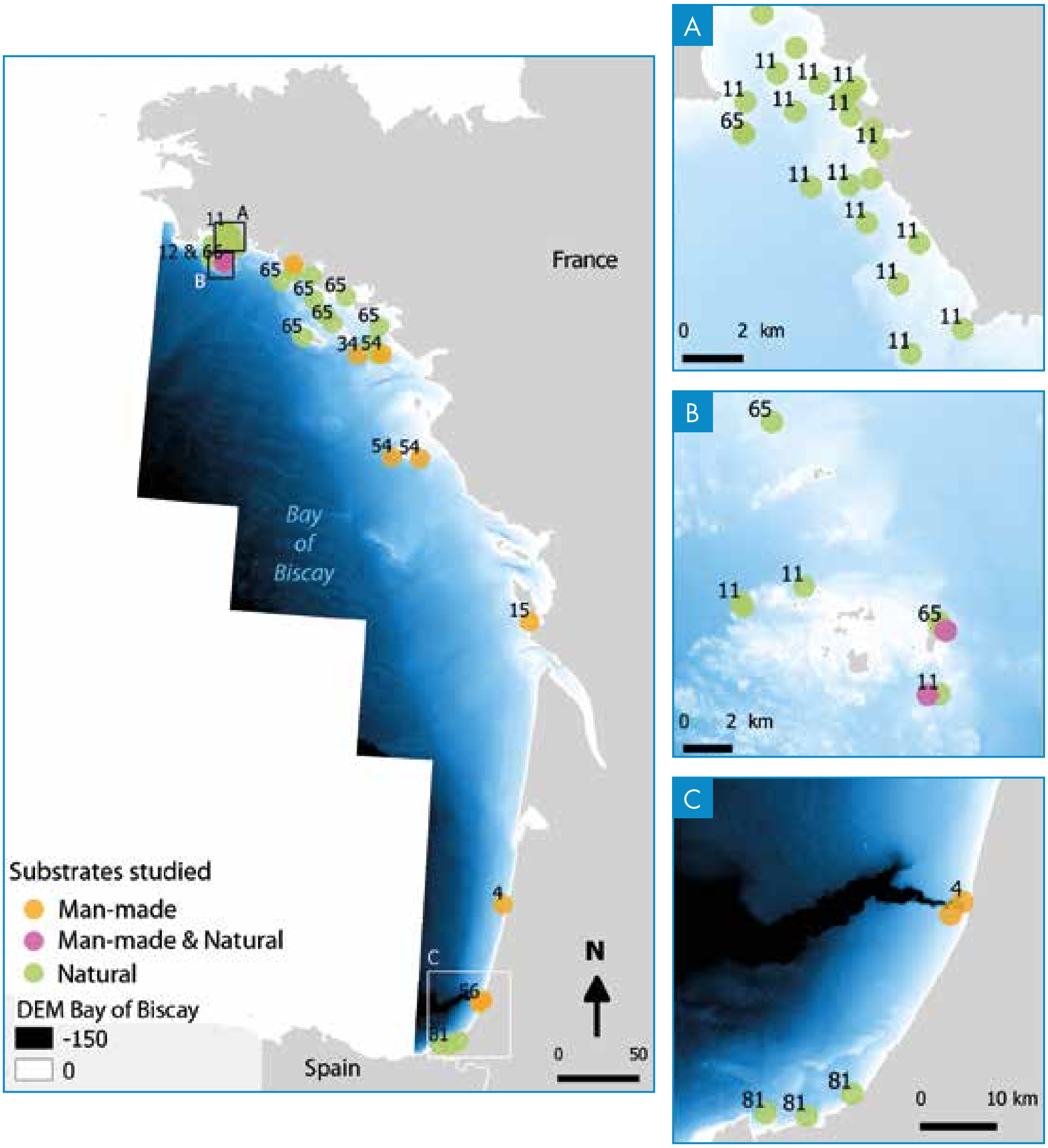
Study site locations in the Bay of Biscay



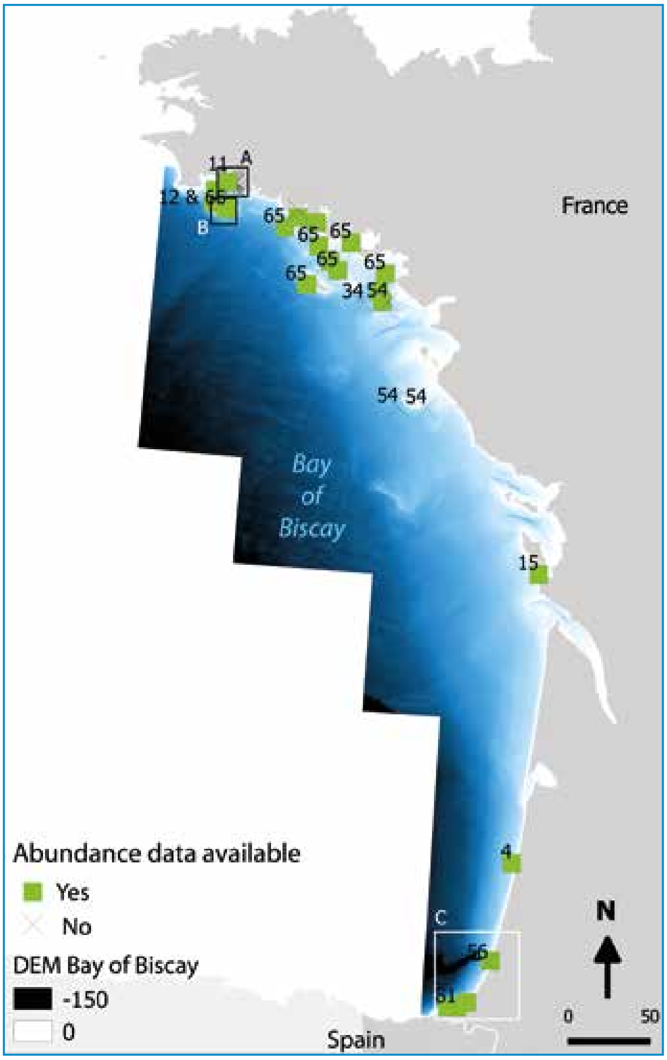
Type of sampling and maximum depth of sites in the Bay of Biscay

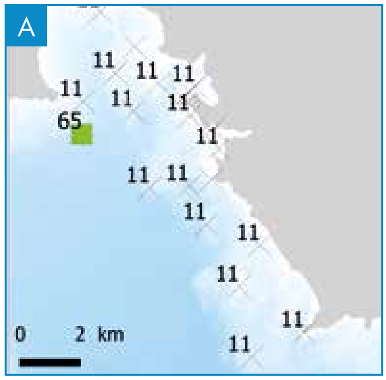


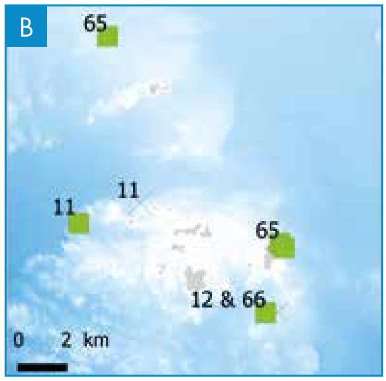
Type of substrate studied at the different sites in the Bay of Biscay

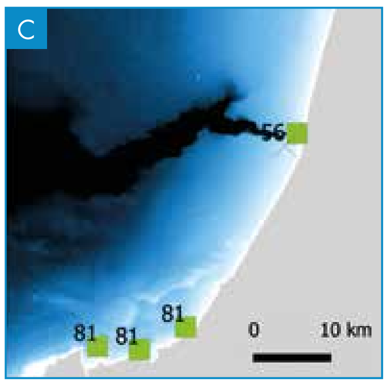


Availability of abundance data for the Bay of Biscay

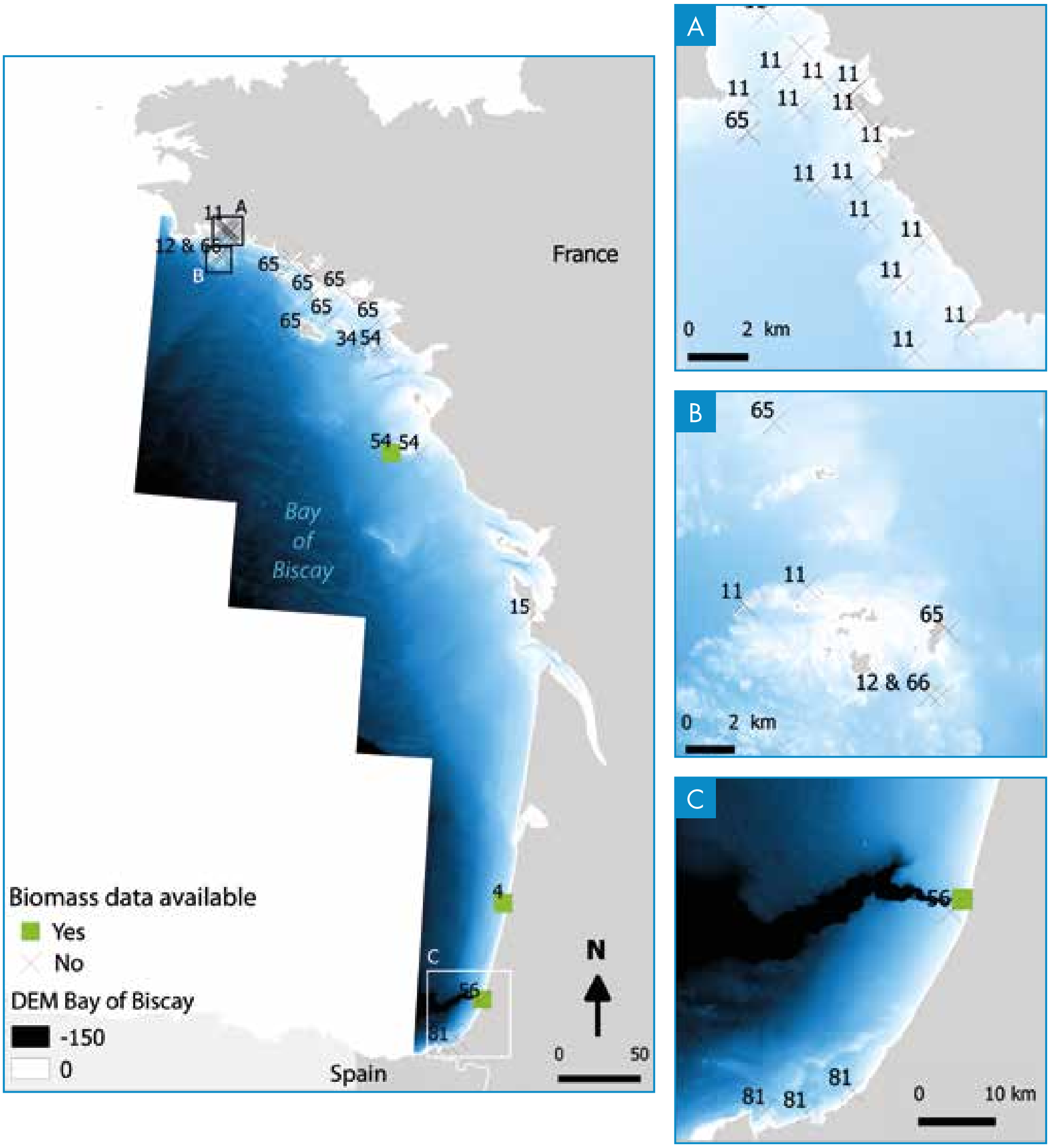




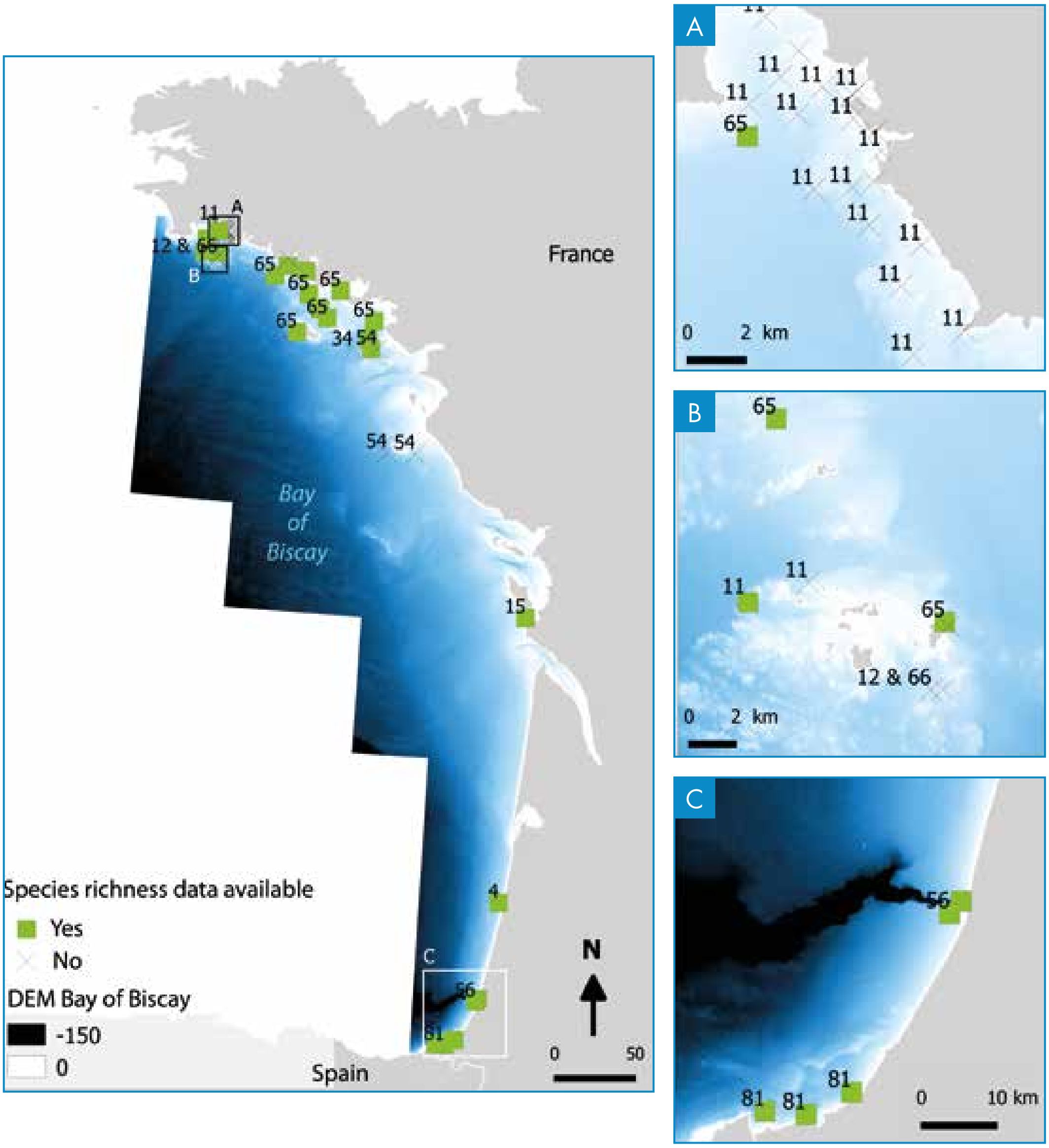




Availability of biomass data for the Bay of Biscay



Availability of species richness data for the Bay of Biscay



Annotated key references

[4] Castège I. *et al.*, 2016. ***First results of fauna community structure and dynamics on two artificial reefs in the South of the Bay of Biscay.*** ECSS, vol. 179, 172-180. *Caution: fish populations measured* (perhaps of interest for estimating the reef effect and predation pressure) **Mimizan** (and more specifically Porto, offshore site) and Capbreton (South West); from 2010 to 2013 (**Capbreton** Artificial Reef); **4 years** of study in summer (July, August or September), **annual monitoring** (1/year); **5 types of ARs**: **barge** (= **metal**) (18 x 3.5 m) installed in 1994, **concrete** modules installed in 2003 and isolated clusters of concrete (100 t) in 2003 and 2004; in Capbreton, concrete pipeline and Typi unit; at **12-25 m depth** (Porto) and **18 m** (Capbreton); explanatory variables measured: type of artificial reef; response variables measured: **A**, biomass (estimated **fresh weight**) **S**, **average length**; B_{fresh} = **1,000 to 6,000 g/m^3**; Porto = 22 species (including 11 benthic) and Capbreton = 36 species; dominant species: Atlantic mackerel, Atlantic horse mackerel & pouting (followed by sardine, blennie, conger, velvet crab, striped red mullet, edible crab, drum, octopus); no marked differences in terms of ichtyofaunal communities on the Porto ARs (barge and modules in place for a long time), interannual variation of Capbreton AR for the Typi unit as it was a recent installation.

[11] Castric-Fey A., 1988. ***Les facteurs limitants des peuplements sessiles sublittoraux en Baie de Concarneau (Sud-Finistère).*** Vie Milieu, 1-18. Concarneau Bay; easily identifiable **rocky areas**; depth of **0 to 25 m**; study of benthic communities living on rocky substrates in **moderately exposed to sheltered areas**; explanatory variables measured: turbidity, exposure to currents (qualitative variables); response variables measured: **pres., A rates** (from a list of 80 animal species and 10 plant species), cover; at offshore stations in clear water and exposed mode only: **demosponges cover 60-70 %** and **calcisponges cover 13 - 35 %**; dominant species: sheltered mode, 0-10 m = Bugula, Ctenostomata, ascidians, demosponges, 15 m = Melobesia (very small population), > 15 m = dominance of *Corynactis* // **wave-beaten mode, 0-10 m = calcisponges, Crisiidae, demosponges, > 15 m = *Corynactis***; two large groups of species appear in succession along the mixing-pelite double gradient: filter-feeders (or active suspension-feeders) are dominant in sheltered environments, while carnivores (or passive suspension-feeders) are dominant in wave-beaten environments.

[12] Castric-Fey A., 1974. ***Les peuplements sessiles du benthos rocheux de l'archipel de Glénan (Sud Bretagne) - Ecologie descriptive et expérimentale.*** PhD thesis, 333pp. **Glénan islands**; **1968 - 1972**, oldest panel = 26 months; all seasons; **monthly** sampling (for man-made subs.); **natural substrate** and **slates** (schist); depth **between 0 and 60 m**; aims: to describe hard substrate populations (notion of vertical zoning); explanatory variables measured: exposure, incline, time of immersion, duration of immersion; response variables measured: **Pres./Abs., species composition, species A, species size**; dominant species = young barnacles, *Anomia* sp., *Pomatoceros* sp., *Verruca stroemia*, *Tubulipora* sp.; **spring attachment** = barnacles & pomatoceros, **summer attachment** = Anomia and encrusting cyclostomes, **autumn attachment** = hydrozoans; succession: autumn series begins with *Tubulipora-Lichenopora-Chorizopora*, spring begins with *Anomia-Alcyonidium*, summer with *Pomatoceros-Hydroides* and winter with *Balanus crenatus* and *Pomatoceros lamarcki*; recruitment **very different from one month to the next** (both qualitatively and quantitatively); **max. attachment = July-Oct.; min. attachment = Dec.-Feb.**; species with specific attachment time vs species with longer ranging attachment period; **beginnings of succession different but similarity between panels after 16 months.**

[54] Labadie F. and Dubreuil J., 2010. ***Inspection des récifs artificiels des sites expérimentaux de l'Île d'Yeu et du Croisic.*** Internal report, 47pp. **Croisic** and **Île d'Yeu**; 2009/2010; artificial reefs in place for 6 years at the time of the study, sporadic visits to the two sites; from 6 to 10/09/2009 and 24 to 25/06/2010; Different types of **concrete** ARs; Croisic = **30 m** deep and Île d'Yeu = **20** and **47 m** deep; assessment of physical and ecological condition of the ARs from the colonisation inventory and comparison of communities with previous years; explanatory variables measured: type of artificial reef; response variables measured: **species composition**, **A**, abundance rankings (qualitative), **biomass** (fresh and dry weights); almost total cover for ARs in Croisic *(no information for Île d'Yeu)*; biomass on Île d'Yeu 47 m deep approx. 25 g/m²; S_{Yeu} = 8 to 14 *(but taxonomic level sometimes only to the family)*; dominant species = Y_{47m}: ***Metridium senile*** (+), ***Corynactis viridis*** (+), ***Botryllus schloressi, Actinothoe sphyrodeta***; Y_{20m}: ***Alcyonium digitatum*** (+), *Ophiotrix fragilis* (mobile species), ***Schizomavella sanguinea, Botryllus schlosseri,* hydrozoans, *Actinothoe sphyrodeta, Metridium senile, Corynactis viridis***; C_{30m}: ***Alcyonium digitatum, Metridium senile, Corynactis viridis, Antedon bifida*** (free to varying extents), **shrubby hydrozoans**, *Ophiotrix fragilis*; AR at 20 m deep ≠ AR at 47 m deep in terms of species composition: predominance of large species, greater cover (possible explanations: greater larvae & nutrient availability and hydrodynamics ≠ at -20 m); no algae observed at 20 m deep (turbid water).

[64] Consortium Biopaintrop (MAPIEM/UBS/Hydrô Réunion), 2017. ***Formulations intégrant les***

extraits actifs tropicaux et tests in situ. Confidential report, 30pp. **Lorient** (as well as Toulon and La Réunion, see atlas sections on Mediterranean and overseas France); **2016-2017**; **9 months** of monitoring (June 2016 to March 2017); **monthly** sampling; **PVC** panels (10 x 20 cm); aim: to observe the development of biofouling at 3 contrasting sites and on different coatings (including uncoated surface); explanatory variables measured: latitude, type of coating; response variables measured: **N** (coating effectiveness); **% cover** by functional group; cover by *Ulva* from 90 to 15 %, ascidians from 10 to 55 %, red algae approx. 10 %, high mud cover at end of monitoring; 90 % cover of panel after 1 month; **mainly non-encrusting organisms** = *Ulva* dominant in terms of cover until winter, when these seaweeds are replaced by ascidians.

[66] Castric-Fey A. *et al.*, 1973. ***Etagement des algues et des invertébrés sessiles dans l'archipel de Glénan - définition biologique des horizons bathymétriques.*** Helgoland Marine Research, 490-509. **Glenan islands**; **1968-1970**; sporadic sampling (in **summer**); **natural substrate** (rock); depth of **0 - 60 m**; aim: to study the vertical distribution of the most representative species and main distribution factors; overview of populations in the top 60 m layer; explanatory variables measured: depth; response variables measured: **pres/abs, density of kelp stems**; sometimes a single species covers 100% of the rock in a given quadrat (e.g. *Trididemnum cereum*); max. density (horizontal and vertical surfaces, respectively): ***L. digitata* = 30 and 25 ind/m², *L. hyperborea* = 31 and 19, *S. polyschides* = 15 and 4**; 4 horizons: that of *L. digitata*, *L. hyperborea* (down to approx. 26 m), Axinellidae/brachiopods and *Dendrophyllia cornigera/Swiflia rosea* (55-60 m); Glénan seaweed species identical to those of the Channel, but kelp penetrates deeper than in the Channel; substrate incline alters populations' bathymetric distribution; 4 populations identified: the first 2 in the infralittoral zone are characterised by algae, kelp, the second two in the circalittoral zone by arbuscular animal species.

[80] de Casamajor M.-N. and Lalanne Y., 2016. ***Intérêt biogéographique de la côte basque rocheuse.*** Bulletin société zoologique française, 3-13. **Basque country coastline** (from Biarritz to Hendaye); **natural substrate** (rock); aim: to define a few species whose monitoring will allow the impact of anthropogenically induced changes on ecosystems to be assessed in this zone through a literature review; warning, species of interest but not necessarily dominant: *Gelidium corneum, Leptogorgia sarmentosa, Paralcyonium spinulosum, Polycyathus muellerae,* a few nudibranch and fish species are also cited (mobile species); see paper for more detail; *Laminaria ochroleuca* have not been present on the Basque country coastline since 2008!; southern specificity of the rocky Basque shores.

[81] de Casamajor M.-N. *et al.*, 2014. ***Suivi DCE du paramètre "macroalgues subtidales".*** Internal report, 37pp. **Basque country** (3 study sites: Alcyon, Abbadia and Socoa); **2013**; sporadic recordings in June and July; **natural substrate** (rock); depth of 3, 8 and 13 m; max. depth: **Alcyon = 14.8 m; Socoa = 19 m; Abbadia = 25 m**; aim: to monitor seaweed populations at different sites to determine the health status of Basque marine ecosystems; response variables measured: **density** stems/m², **depth boundary**, **S**; (at two bathy. levels) : Alcyon = 33 and NA, Socoa = 38 and 19, Abbadia = 35 and 21; *Cystoseira* sp. = 20.8 ind/m² (Alcyon), 30.8 (Socoa), 18 (Abbadia).

[65] Derrien Courtel S. *et al.*, 2013. ***Regional-scale analysis of subtidal rocky shore community.*** Helgoland Marine Research, Vol. 67: 697-712. **38 subtidal sites along the coast of Brittany**; transects with depths of **0 to 31 m** max. (depth variable between stations); exposure gradient; explanatory variables measured: turbidity, $T°_{water}$, depth of infralittoral–circalittoral boundary (last kelp individual), response variables measured: **flora/fauna A** (n. of ind. and colonies for each species), **kelp density**; identification of three typical assemblages according to turbidity and stratification: turbid sites (*Solieria chordalis, Ulva* sp., *Gracilaria multipartita, Chondracanthus acicularis, Chondria dasyphylla, Aiptasi mutabilis, Bougainvillia muscus, Nemertesia antennina, Hydrallmania falcata, Aplidium elegans, Morchellium argus, Tethya aurantium, Polymastia penicillus, Sabella spallanzanii, Ophiothrix fragilis*), stratified clear water sites (*Saccorhiza polyschides* forests with *Pterosi-*

phonia complanata, Hypoglossum hypoglossoides, Lomentaria clavellosa, Marthasterias glacialis and *Asterias rubens*) and homogeneous clear water sites (*Laminaria hyperborea* forests with *Desselaria sanguinea, Phyllopora crispa, Plocamium cartilagineum, Meredithia microphylla, Balanus* spp., *Dysidea fragilis*); infra-circa boundary between -1.6 m (turbid) and -32.2 m (clear); higher kelp density in clear water than turbid water (32.5 compared to 14.8 ind/m²); main factors affecting flora and fauna in rocky environments = temperature and turbidity (Information valid for this geographical area as well as that of the Channel).

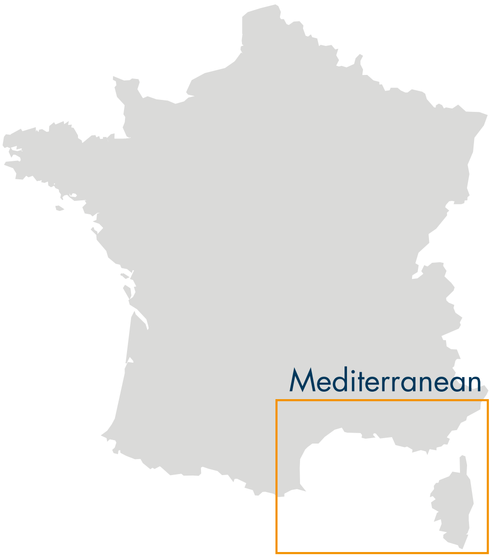
[56] Laborde A., 2010. ***Suivi scientifique des récifs artificiels Capbreton, Soustons/Vieux Boucau, Messanges/Azur/Moliets.*** Internal report, 62pp. **Capbreton**; 2010; **3-month study (summer)**; variable data acquisition intervals (weekly to monthly, 15 dives in total); **concrete** artificial reefs (some recently installed, others in place for 11 years); aim: to continue to monitor structures immerged in 1999 and to launch the monitoring of Typi units put in place in June 2010; response variables measured: A_{rel}, **abundance rankings**, **species composition**; **68 species (invertebrates and vertebrates combined)**; **36 species of invertebrates including 17 sessile species** and 11 cnidarian species (bryos and sponges no doubt underestimated); 29 fish species; presence of young/small individuals and of eggs = indicators of the reef's protective and productive role; structure and complexity of the reef = determining parameters for populations.

[34] Reynaud M., 2016. ***Analyse sur le biofouling présent sur SEM-REV.*** Internal report, 33pp. **SEM-REV**; **2013** and **2015**; Sporadic recordings in **autumn-winter**; variable acquisition intervals; monitoring of **mooring lines** made of Deltex© (**synthetic fibres**); depth of **35 m** (max.); aim: to measure the characteristics of the fouling (biomass, thickness) and its effects (drag coeff.) according to depth, cable portion, time; explanatory variables measured: depth, time; response variables measured: composition in terms of **major groups of organisms**, **thickness**; dominant species: filamentous algae (0 to -20 m), hydrozoans (-20 to -35 m), *Mytilus edulis* (0 to -29 m); max. height as a proxy for max. thickness: filamentous algae, h < 10 cm, hydrozoans, h = 6 cm, mussels (2 years) = 10 cm; mussel = species with greatest impact for cable dimensions; biofouling thickness independent of depth; extrapolation of biofouling weight after 2 years: 25.7 kg/m of cable (dry weight?).

[15] Brown C.J. *et al.*, 2003. ***Assessment of effects of chromated copper arsenate (CCA)-treated timber on nontarget epibiota by investigation of fouling community development at seven European sites.*** Archives of environmental contamination and toxicology, 37-47. **Île d'Oléron**; 1996 – 1997; **18 months** of monitoring; sampling **every 6 months**; panels of **wood** *(Pinus sylvestris)* CCA-treated or untreated (for review, focus on untreated panels); **depth of 0 and 5-10 m**; aim: to compare the communities on treated and untreated panels to assess the effects of CCA on epifaunal organisms; explanatory variables measured: geo. and bathy. locations (inter vs sub), sal., T°C; response variables mea-sured: **A**, **surface area** covered by colonies; total species richness = 14; avg. A/m²: hydrozoans = 5,550, *E. modestus/B. crenatus* = 900, *Electra pilosa* = 50; significant differences between treated and untreated panels; on the French site, experiment disturbed by adverse weather conditions.

[93] Augris C. *et al.*, 2009. ***Atlas thématique de l'environnement marin du Pays Basque et du sud des Landes.*** Ed. Quae, 128pp. **Saint-Jean de Luz** (2002-2003) and **Hendaye** (2007); aim: to produce an atlas of available knowledge on the marine environment of the Basque coastline.

4.1 Biofouling in the Mediterranean



Characteristics of the area:

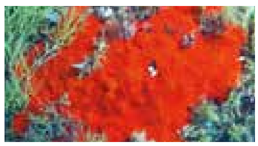
One of the world's largest semi-enclosed seas; this atlas focuses on the western basin; max. depth of the western basin: 1500 m; oligotrophic sea; mixing of the water mass by deep convection, the main mechanism for nutrient renewal (inducing blooms in spring); influence of two cold and dry winds (Mistral and Tramontane) on the water temperature and salinity (evaporation) which can reach up to 37 ppm; predominance of sedimentary seabeds (fine sediment); winter T° around 11°C (coldest area is the Gulf of Lion); summer T° can exceed 25°C; strong anthropogenic pressure related to intense urbanisation of the coastline, coastal areas affected by eutrophication (in particular influence of the Rhone).

Main fouling species in the western Mediterranean:

Ciona intestinalis, Phallusia mammillata, Botryllus sp., *Plocamium cartilagineum, Aphanocladia stichidiosa, Balanus perforatus, Pyura dura, Lithophyllum encrustans, Crambe crambe, Hemimycale culomella, Alcyonium acaule, Dysidea avara, Agelas oroides, Ircinia oros, Axinella damicornis, Schizomavella* sp., *Sycon* sp., *Bugainvillia ramosa, Hydroides norvegica, Pomatoceros triqueter, Spirobranchus polytrema, Serpula vermicularis, Eunice harasii, Spirographis spallanzani, Polycirrus aurantiacus, Balanus amphitrite* (then *B. perforatus*), *Anomia ephippium, Musculus subpictus, Hiatela rugosa, Mytilus galloprovincialis, Ostrea edulis, Spirographis mammillata, Microcosmus sabatieri, Codium fragile, Bryopsis plumosa, Dasya hutchinsiae, Scrupocellaria reptans.*


Ciona intestinalis


Phallusia mammillata


Crambe crambe

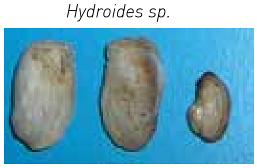

Alcyonium acaule

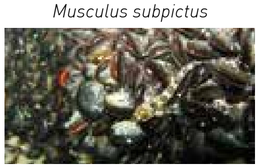

Sycon ciliatum


Bugainvillia ramosa


Hydroides sp.


Musculus subpictus

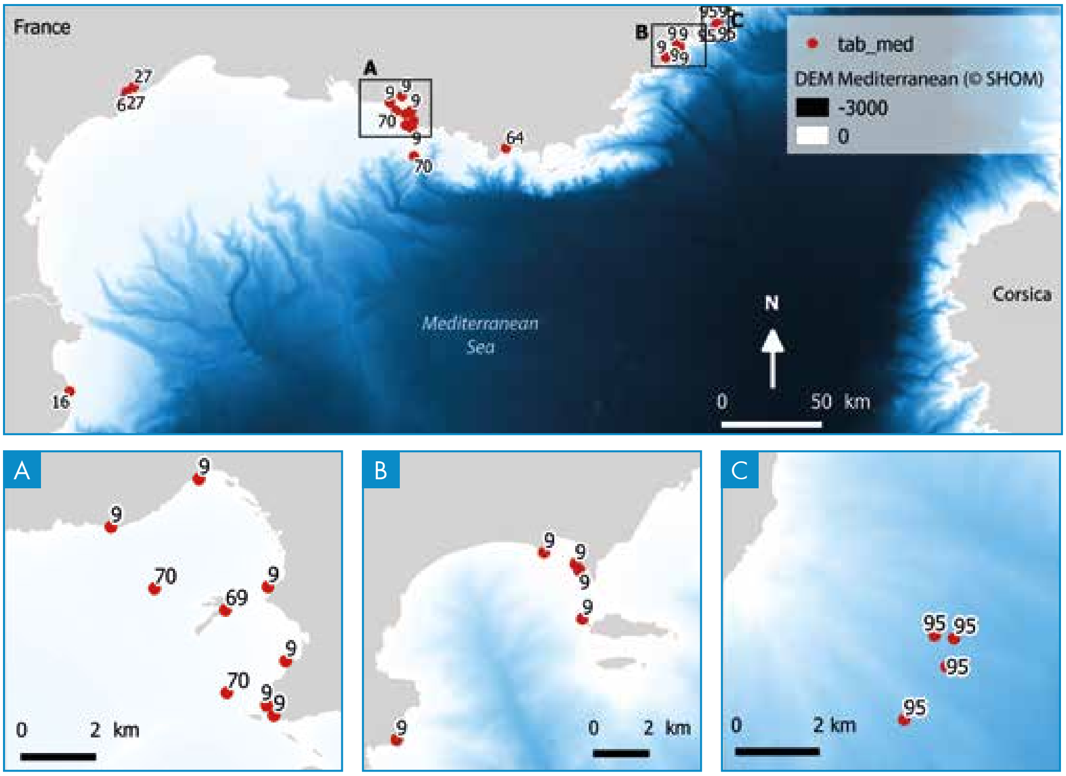

Hiatela rugosa


Mytilus galloprovincialis

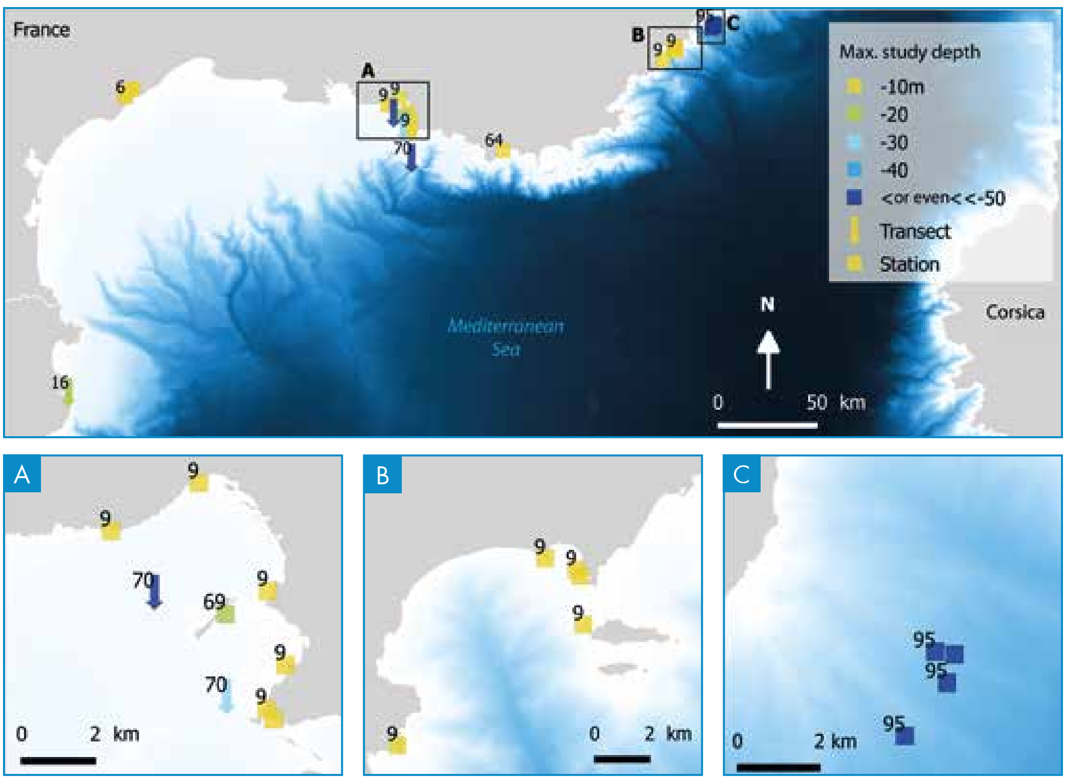

Ostrea edulis


Codium fragile

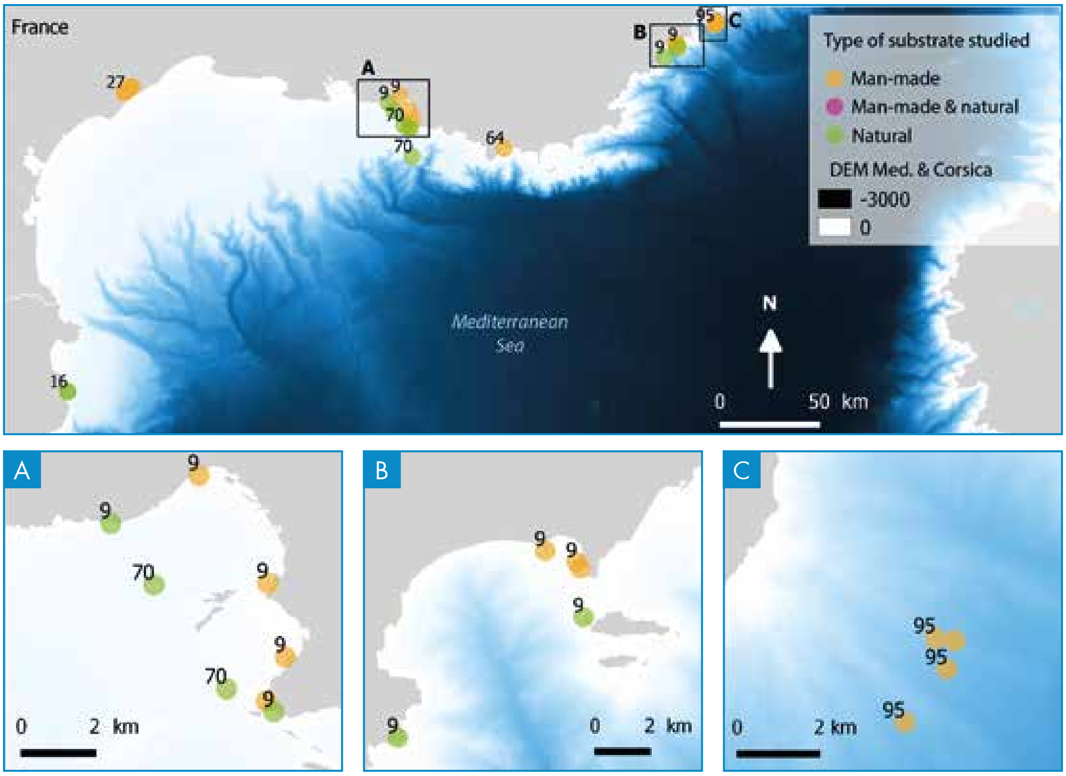
Study site locations in the Mediterranean



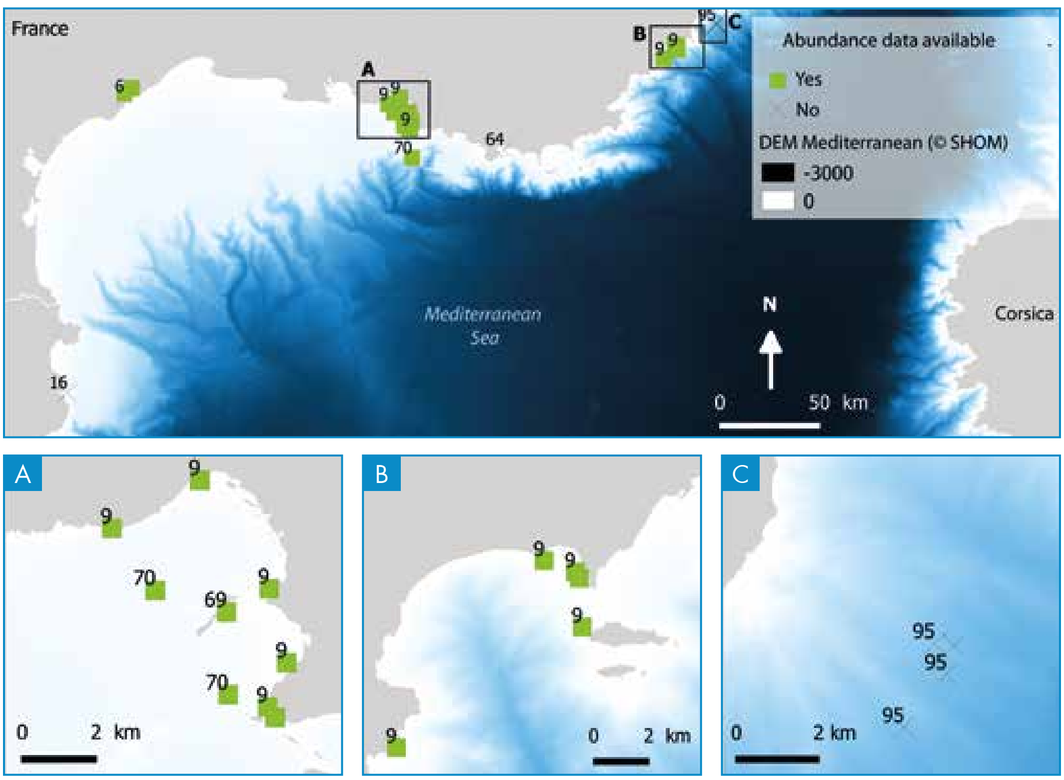
Type of sampling and maximum depth of sites in the Mediterranean



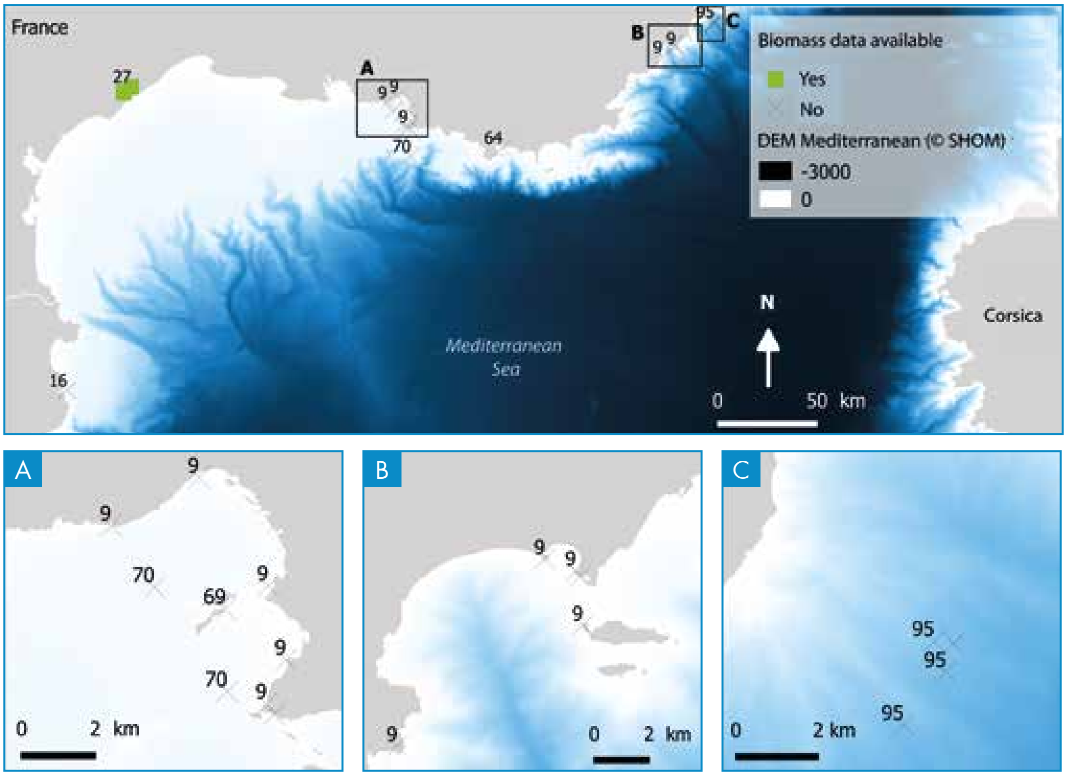
Type of substrate studied at the different sites in the Mediterranean



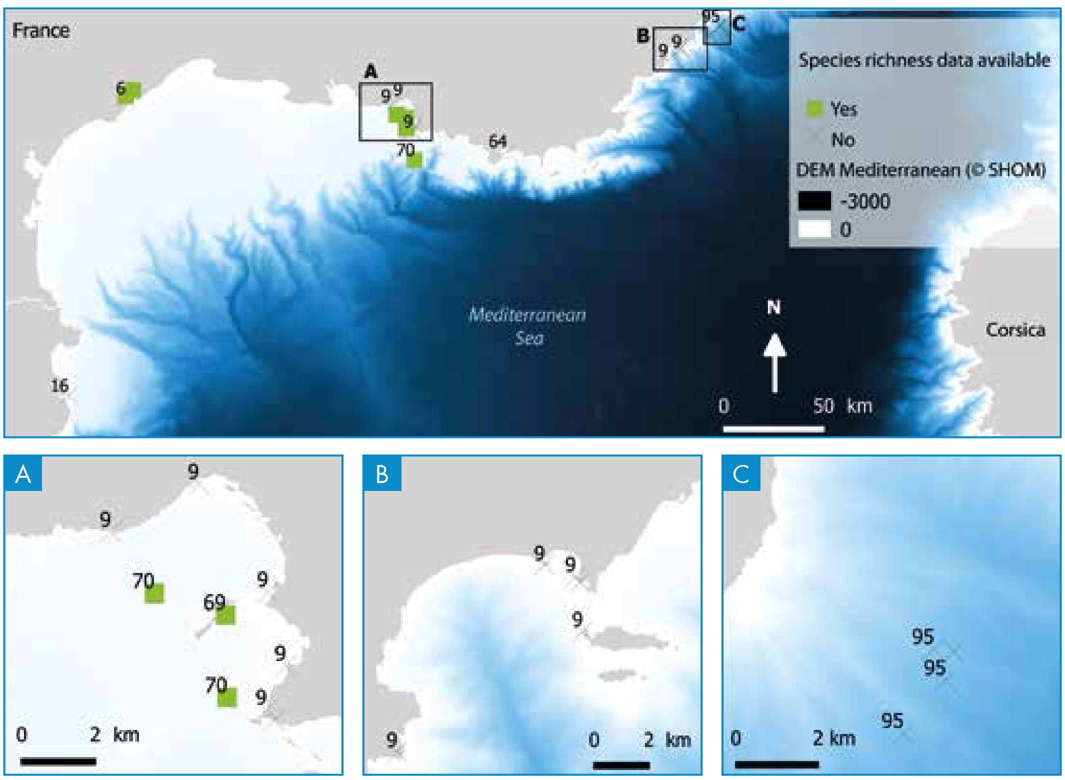
Availability of abundance data for the Mediterranean



Availability of biomass data for the Mediterranean



Availability of species richness data for the Mediterranean



Annotated key references

[69] Bellan-Santini D., 1970. ***Salissures biologiques de substrats vierges artificiels immergés en eau pure durant 26 mois dans la région de Marseille.*** Tethys, vol. 2 (2), 335-356. Near the **Îles du Frioul**; study conducted **between 1963 and 1965**; monitoring of the biofouling of a 300 m-long **vitrified pipe** (owned by the Compagnie française des pétroles) with a diameter of 1 m installed on site in 1963; **monthly monitoring** for **2 years**; pipeline **immersed in the open sea** (at **18 m depth** in a 60 m deep environment) and exposed to currents and light (pure water); aim: to characterise biofouling on a structure in the open sea; explanatory variables measured: time, type of coating; response variables measured: **S**, **A**, **species composition**; S_{total} = 269; $S_{polychaetes}$ = 84; $S_{molluscs}$ = 54; $S_{crustaceans}$ = 43; no units indicated for abundance but probably figures for 1/25 m²: *Anomia ephippium* and *Musculus subpictus* = 25,000/m² max., *Hiatella rugosa* = 75,000/m² max., *Mytilus galloprovincialis* = 7,500/m² max., *Balanus amphitrite* = 12,500 max. at the beginning of colonisation, *Balanus* sp. = 500/m² max. (NB: more fouling on upper side than lower side); common species = Sycon abundant on lower side, ***Bugainvillia ramosa*** and ***Hydroides norvegica*** (present during first months), ***Pomatoceros triqueter, Spirobranchus polytrema, Serpula vermicularis, Eunice harasii, Spirographis spallanzani, Polycirrus aurantiacus, Balanus amphitrite*** then ***A. perforatus***; in terms of abundance data, dominant species = ***Anomia ephippium***, ***Musculus subpictus***, ***Hiatela rugosa*** (only bivalve molluscs); evolution of species richness, at T+1 month = 17, ↗ 40 at 7 mos., stabilisation (but relative) at 46 at T+14 mos.; **population of upper side dominated by algae, molluscs and echinoderms; population of lower side dominated by sponges, bryos, and ascidians**; generally speaking, **polychaetes** and **molluscs are dominant** in the population; particularly strong development of certain species (e.g. giant sized *Ostrea edulis* and *Musculus subpictus*); definitive population in place before the end of the first year.

[95] Bellan-Santini D. *et al.*, 1969. ***Etude qualitative et quantitative des salissures biologiques de plaques expérimentales immergées en pleine eau.*** Tethys, vol. 1 (3), 709-714. Region of **Nice**; monitoring from **1964 to 1968**; points **monitored from 2.5 to 4 years**; **sporadic sampling** on panels made of different materials (Rilsan, polyurethane, polyester-glass fibre, tar epoxy) placed at different depths between **-40** and **-530 m**; aim: to study epifauna and epiflora developing on different types of materials; explanatory variables measured: length of immersion in the open sea (no measurements presented in the article valid for description of the protocol; response variables measured: species composition; only the methodological approach is presented in this paper, the authors were contacted to complete this section.

[70] Clausade M., 1969. ***Peuplement animal sessile des petits substrats solides récoltés dans trois biocénoses des fonds détritiques des parages de Marseille.*** Tethys, vol. 1 (3), 719-750. **Vicinity of Marseille**; monitoring conducted in **1969** (but no indication of sampling dates or acquisition frequency); study of populations on natural rock fragments sampled **between approx. 50 and 200 m deep** (DC = upper part of circa; DE = 70-80 m; DL = 95-200 m); aim: to determine whether there exists a population unit specific to these sparse substrates and neighbouring environments; explanatory variables measured: type of seabed, depth (these two variables co-vary), fragment size; response variables measured: **S**, **characterisation of communities**, **A**, **dominance** (quantified); S between 62 and 181 in study area; common species: DC = ***Josephella marenzelleri*** (Arel ~ 15 %) & ***Distomus variolosus*** (~13 %); DE = ***Vermiliopsis infundibulum*** (~10 %) & ***Epizoanthus arenaceus*** (~9 %); DL = ***Microporella ciliata*** (~12 %) & Serpulidae (***Omphalosoma gracilis*** + ***Vermiliopsis infundibulum*** = ~20 %); small hard substrates never 100 % covered; therefore potentially little competition for space; instability of these fragments observed during dives; only pioneer stages represented.

[64] Consortium Biopaintrop, (MAPIEM/UBS/Hydrô Réunion), 2017. ***Formulations intégrant les extraits actifs tropicaux et tests in situ.*** Confidential report, 30pp. **Toulon roadstead** *(as well as Lorient and La Réunion, see atlas sections on Bay of Biscay and overseas France)*; low hydrodynamics; **2016-2017**; **9 months** of monitoring (June 2016 to March 2017); **monthly** sampling; **PVC** panels (10 x 20 cm); aim: to observe the development of biofouling at 3 contrasting sites and on different coatings (including uncoated surface); explanatory variables measured: latitude, type of coating; response variables measured: **N** (coating effectiveness); **% cover** by functional group; covered with green and brown seaweed, as well as by spirorbes in the early stage of fouling (Ulva [20 %], Phaeophyceae [10 %] and spirorbes [10 %]); at the end of fouling = Phaeo. (60 %), Rhodo. (5 %), hydrozoans (10 %), spirorbes (10 %), bryo and polychaete tubes (5 % each) and sponges (< 5 %); wide diversity of organisms at the end of the experiment in Toulon (in comparison with the two other sites studied); this study highlights the importance of testing the spectrum of effectiveness of antifouling paints on different sites.

[84] Dalias N. *et al.*, 2008. ***Suivi scientifique des récifs artificiels de Valras-Plage.*** Report by Océanide, ADENA and the Laboratoire des écosystèmes aquatiques tropicaux et méditerranéens (UMR 5244) for the Valras-Plage local council, 100pp. **Valras-Plage**; presences of gyres and upwellings in the study area; monitoring of **ARs** (immersed in 2006) conducted in **2008** (**1 year**) in **2 seasons** (cold and hot); **concrete outfall pipes** and **steel baskets** located **9 to 20 m** deep were sampled; aim: to estimate the effects of ARs on the Valras coastal ecosystem (ecological aspects) and on local fisheries (socio-economic aspects); explanatory variables measured: T°, O_2, sal. ; response variables measured: **S**, **density** according to size classes, **biomass** (estimated wet weight for fish only); $S_{vertebrates}$ = 13 and 23; $S_{invertebrates}$ = 1 and 4 (in cold and hot seasons respectively) (this figure is probably greatly underestimated, at least for invertebrates, given the focus on species of commercial interest); common species = ***Mytilus galloprovincialis***, ***Ostrea edulis***, and a few other species: ***Spirographis mammillata, Microcosmus sabatieri, Phallusia mammillata, Pleurociona edwarsi, Crambe crambe***; reef effect for attached fauna, however for mobile organisms it is difficult to estimate the share of production of the AR; proposal to conduct more advanced monitoring to estimate reef effect (see report).

[16] Garrabou S. *et al.*, 2002. ***Structure and dynamics of north-western Mediterranean rocky benthic communities along a depth gradient.*** ECSS, vol. 55, 493-508. **Medes Islands** (Spanish islands approx. 40 km from Banyuls); 1992-1994; **2 years** of **monthly monitoring**; station = **rocky slope** between **5 and 20 m** deep; aim: to measure changes in terms of community structure along a depth gradient; testing of 3 hypotheses = ↗ in community structure with depth, ↘ in community dynamics and temporal variability with depth; explanatory variables measured: depth, time; response variables measured: **% cover, number of patches, patch size, H', % change**; algal communities (4-6 m and 8-10 m): **total cover by turf-forming algae in spring and summer, cover by a more complex animal and plant community in autumn/winter**; animal communities **from 12 to 20 m: complex cover, 80 % animals on average + 1 to 40 % algae** (winter vs summer); on average ↗ in H' (Shannon diversity index); dominant species = at 4-6 m (dominance of seaweed) ***Plocamium cartilagineum***, ***Aphanocladia stichidiosa***, ***Aglophenia kirchenpaueri*** (temporary), ***Balanus perforatus***, ***Pyura dura***, ***Clathrina coriacea***; at 8-10 m (dominance of seaweed): ***Corallina elongata***, ***Aphanocladia stichidosa***, ***Lithophyllum encrustans***, ***Crambe crambe***, ***Hemimycale culomella***, ***Microcosmus sabatieri***; at 12-14 m (intermediate horizon, codominance of algae and animals): ***Alcyonium acaule***, ***Crambe crambe***, ***Hemimycale columella***, ***Dysidea avara***, ***Mesophyllum alternans***, ***Peyssonnelia* spp.**; at 17-20 m, dominance of invertebrates: ***Agelas oroides***, ***Ircinia oros***, ***Axinella damicornis***, ***Alcyonium acaule***, ***Mesophyllum alternans***, ***Lithophyllum frondosum***, ***Diplastrella bistellata***, ***Oscarella lobularis***, ***Spirastrella cuntcatrix***, ***Parazoanthus axinellae***, ***Leptopsammia pruvoti***, ***Schizomavella* sp.**, ***Reteporella septentrionalis***, ***Cystodites dellachiajei*** (organisms distributed between 3 strata: erect, bushy, encrusting; see publication for details); high temporal variability at shallow depths (4-6 m, and 8-10 m), lower variability at greater depths (12-14 and 17-20 m); ↗ **in community complexity and diversity with depth**; at low depths in algae-dominated areas, algae distributed in large patches; greater % change for algal communities (low depths) than for animal communities (greater depth), fewer resources and disturbances at greater depths.

[71] Harmelin J. G. *et al.*, 1970. ***Etude expérimentale de la colonisation des surfaces vierges naturelles en eau pure et en eau polluée dans la région marseillaise (conditions de l'expérience).*** Tethys, vol. 2 (2), 329-334. **Marseille region**; strong hydrodynamics at certain sites; monitoring from **1969 to 1970**; **2 years and 4 months**; **monthly** monitoring initially, then **every 3 months**; study of the fouling of **panels of natural limestone** (extracted from the study area) placed at different depths from **-3 to -37 m**; aim: to monitor fouling on panels carved from locally occurring natural rock (Cassis limestone) at different bathymetric levels and in different hydrobiological conditions; explanatory variables measured: pollution level, panel orientation (outside vs inside = hidden side); response variables measured: for fauna = **A**, **biometry**, growth state/for flora: **cover**, **biomass**, **reproduction** level; only the methodological approach is presented in this paper, the authors were contacted to complete this section.

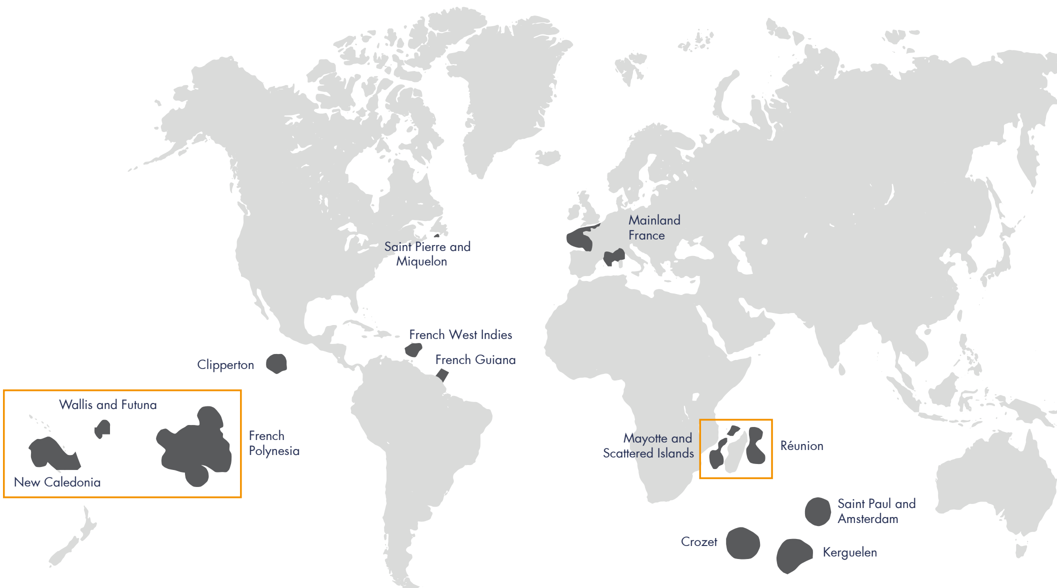
[27] Lamy N., 1996. ***Organisation, structure et dynamique des peuplements macrobenthiques d'une table conchylicole de l'étang de Thau.*** PhD thesis, University of Montpellier II, 397pp. **Etang de Thau**; monthly monitoring between **1992 and 1993** (01/04/92 → 10/10/93); sampling of collection panels (fibre cement panels) suspended at different stations in the lake between **0.5 and 8 m deep** in **zone A**, and **0.5 and 5 m** in **zone B**; aim: to study organisms (animal & plant) associated with farmed molluscs to answer the question (particular focus on fouling of oyster-farming tables here): what is the role, place and importance of macrofouling?; explanatory variables measured: current, T°, sal., pH, O_2, turbidity, MIS, phytoplankton; response variables measured: **biomass** (dry weight), **algae cover**, **abundance**, **S**, **biometry**, H'; B_{max} (dominant species only, for the rest see thesis) - *Ascidia mentula* = 59 g/m², *Ciona inestinalis* = 23.61 /m², *Scrupocelleria reptans* = 200 g/m², *Reneria* sp. = 237 g/m², *M. galloprovincialis* = 20 g/m² (juveniles), *B. amphitrite* = 11.79 g/m²; S_{total} = 146, $S_{molluscs}$ = 19, $S_{polychaetes}$ = 32, $S_{crustaceans}$ = 36, S_{algae} = 35; H' between 1.199 and 4.171 (fauna) and between 0.32 and 2.56 (flora); A between 100,000 and 800,000 ind/m² and B between 100 and 500 g/m² (dry weight); species abundance: *Ascidia mentula* = 4,000 ind/m², *Ciona inestinalis* = 2,698 to 9,008 ind/m², *Scrupocelleria reptans* = bryo most abundant and key biofouling species [*weighed but not counted see above*], *Mytilus galloprovincialis* = 700 ind/m² (juveniles), *Balanus amphitrite & B. eburneus* = 2 density peaks at 5,808 and 28,512 ind/m², *Spirorbis pagenstecheri* = 700 ind/m²; **dominant species: *Codium fragile, Bryopsis plumosa, Dasya hutchinsiae*** (only alga found on deep panels), ***Scrupocellaria reptans, Ciona intestinalis*** (deeper); sponges appeared last in the succession; average length (see doc for full data); A. *mentula* = 6 cm, C. *intestinalis* = 6 cm, S. *reptans* = 3.5 cm, B. *amphitrite* = 1.06 cm; **seasonal evolutions** A and B similar: **initial phase = colonisation by juveniles** (170,000 ind/m² and 500 g/m²), **winter phase = decrease in density** (< 100,000 ind/m² and 100 < Biom < 200 g/m²), **spring regrowth phase** (800,000 ind/m² and 400 g/m²), the phases vary in intensity from one year to another; higher S in deep waters than at the surface due to colonisation by soft substrate species in the sediment trapped in hard substrate communities; average A & B lower at the bottom than the surface, except for ascidians; factors explaining variation observed = inter and intraspecific competition for space and food, physical heterogeneity of environments, phenomenon of confinement within a table; analogy with the **Dean and Hurd model (1980) = the 1st colonists induce the settlement of subsequent colonists**; multi-step process: 1) biofilm formation, 2) fouling by diatoms and spirorbes, 3) appearance of macrophytes, 4) installation of ascidians, bryos and sponges, 5) appearance of associated species (crustaceans & polychaetes) → all these steps occur within 2 to 3 months of immersion.

[6] Mazouni N. *et al.*, 2001. ***Composition of biofouling communities on suspended oyster cultures: an in situ study of their interactions with the water column.*** MEPS, vol. 214, 93-102. **Etang de Thau**; low hydrodynamics, abundant light;

1992, 12 months of study (January to December, except February and September due to technical problems); monthly frequency; monitoring of Oyster Culture Unit (OCU) and in particular the nylon rope and oyster valves (calcium carbonate); depth = 3 m; aim: to produce a more realistic vision of the impact of aquaculture on marine ecosystems by integrating biofouling in the analysis and studying the seasonal dynamics of the community and interspecific interactions to answer two questions: Which factors control biofouling? What are the effects of the community on the surrounding systems?; explanatory variables measured: T°, O_2, NH_4, NO_2-NO_3, PO_4, sal., Chla; response variables measured: dry weight (relative biomass), diversity (multi); relative biomass of main groups: *Crassostrea gigas* = 10-60 %, ascidians = 25 - 80 %, sponges = 10 - 20 %, bryozoans = 5 - 15 %; spring characterised by max. diversity (development of bryozoans, sponges, polychaetes and algae) and in autumn, dominance of ascidians (75 % of total biomass) such as *Ciona intestinalis*, *Phallusia mammillata*, *Botryllus* sp.; ascidians are dominant in the epifauna population independent of water T°; after an episode of anoxia, all fouling disappeared then young ascidians appeared; biological activity of ascidians produces a large quantity of biodeposits which can lead to substrate modifications; the population structure of OCUs is based on a complex system of interactions between several compartments (macrofauna of hard and soft substrates, sediment) and trophic levels (primary producers, filter-feeders, deposit-feeders).

[9] Ruitton S. *et al.*, 2000. ***Relationships between algae, benthic herbivorous invertebrates and fishes in rocky sublittoral communities of a temperate sea.*** ECSS, vol. 50, 217-230. 11 sites in the Mediterranean Sea (Bays of Marseille and Cannes); no indication of year during which study was conducted; 7 to 40 years; sites studied for one year (all sites, all monitoring periods) + 1 year studying fish near man-made substrates; monitoring of algae and invertebrates in winter vs summer (2x a year)/monitoring of fish all year (6x a year); rocky substrate and concrete cubes, tetrapods or accropods; depth = 1 m, 3 m and 8 m; aim: to answer the following 3 questions, 1) How can we describe the complexity of large anthropogenic structures? 2) Does the depth and/or the complexity of the structure affect the relationships between algae, fish and herbivorous invertebrate cover? 3) Could a model integrating these relationships be developed for the "northwest Med" zone?; response variables measured: A, % cover; total cover at studied stations; algae (distinction between encrusting, turfy, shrubby and arborescent algae), variable cover by type of algae according to the site and depth; abundance of herbivorous invertebrates only; herbivorous invertebrates: *Paracenthrotus lividus*, *Arbacia lixula*, *Patella caeruela*; herbivorous or omnivorous fish: *Sarpa salpa*, *Symphodus* spp., *Diplodus* spp.; identification of 4 different groups (= different communities) according to the complexity of the structure: 1) max. size of boulders and cavities, 2) large boulders - small cavities, 3) small boulders and cavities, 4) smallest boulders and very small cavities; if sea urchin grazing is high, soft algae tend to be replaced by hard encrusting algae; fish and invertebrates may control the structure of algal communities, but their relative abundance varies with depth: at low depths, predation mainly linked to invertebrates (with *P. caerulea* and *A. lixula*) and at 8 m, predation by invertebrates and fish (*P. lividus, Diplodus* spp. and *S. salpa*).

4.4 Biofouling in overseas France

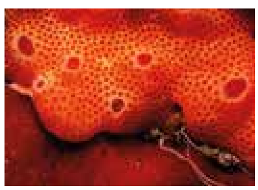


Characteristics of the area:

The characteristics of the marine ecosystems of French Polynesia, Réunion-Mayotte-the Scattered Islands and the Caribbean Islands are different. Nevertheless, generally speaking we note that: in tropical environments, the water temperature is far less variable throughout the year; the availability of larvae and spores is less cyclic and recruitment is therefore roughly constant (and the accumulation of fouling more or less continuous) (Richmond & Seed, 1991); water T° between 23 and 30°C; these high temperatures trigger the formation of tropical cyclones and hurricanes which regularly affect these environments.

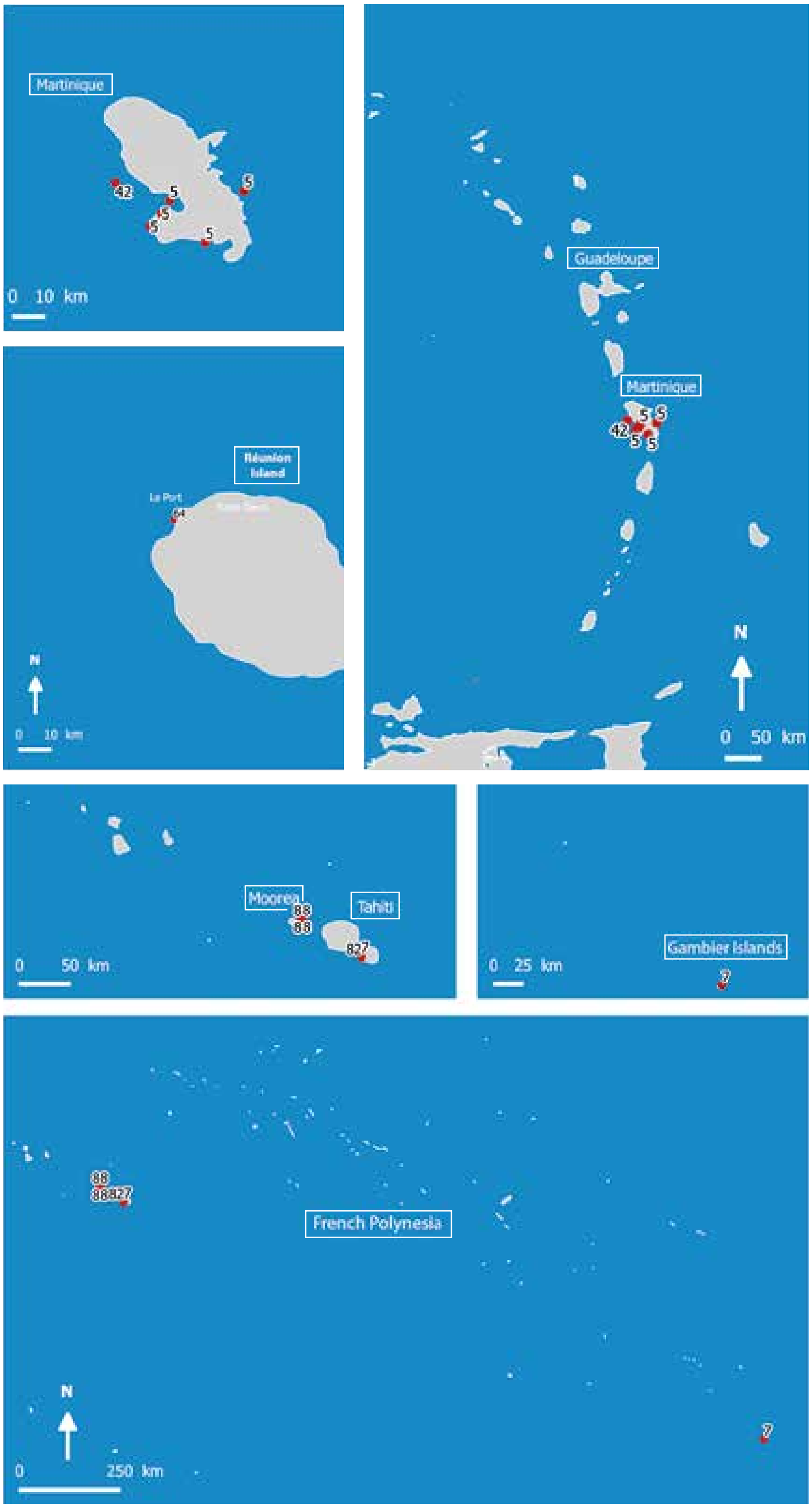
Main fouling species in tropical French overseas territories:

Example of one species, the other groups cannot be illustrated as their taxonomic level is too low: *Didemnum* sp., Ascidiacea, Polychaeta, Bryozoa, Bivalvia, Hydrozoa, Porifera, goose barnacles, red algae, corals.

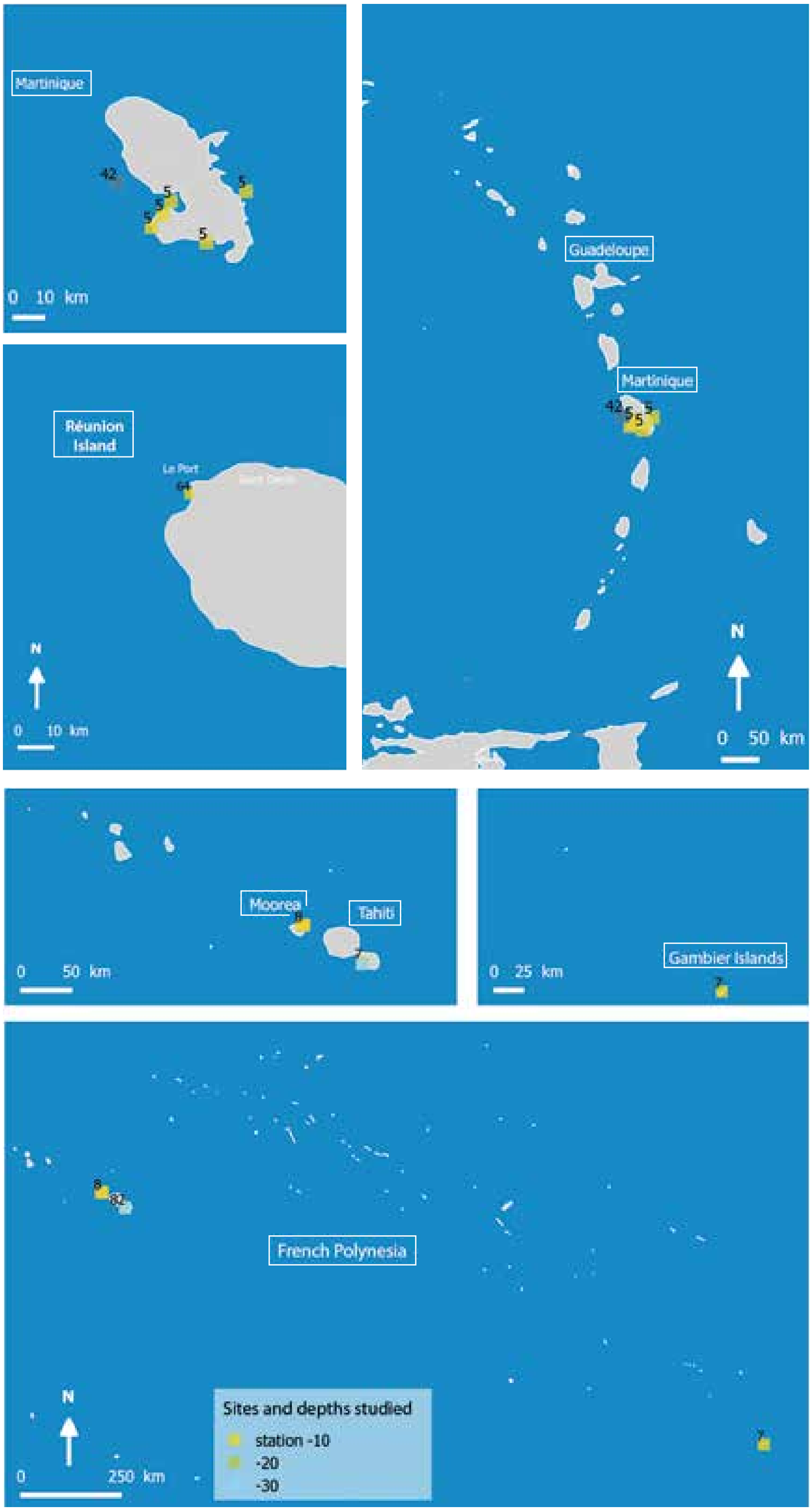


Didemnum fulgens

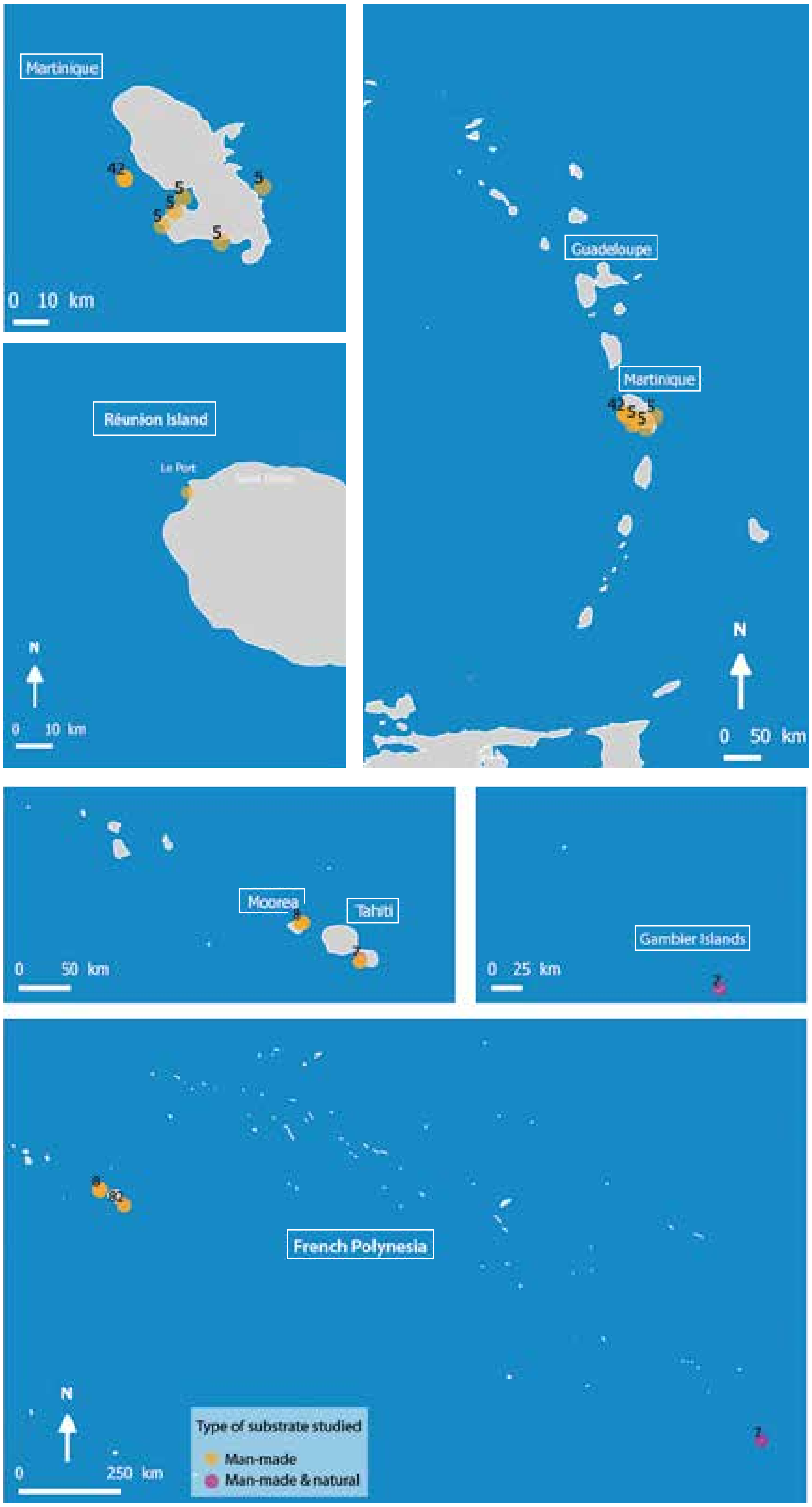
Study site locations in overseas France



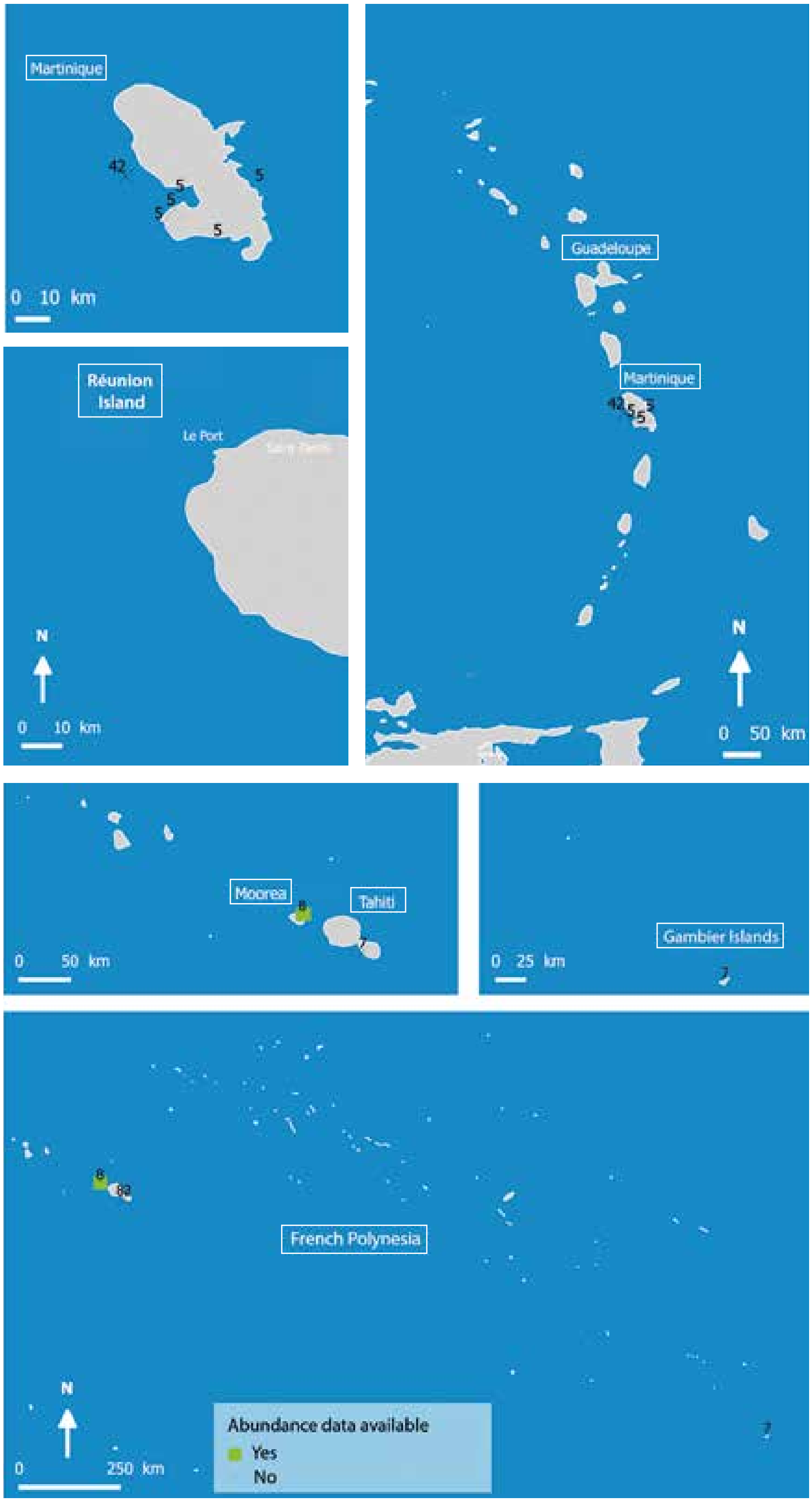
Type of sampling and maximum depth of sites in overseas France



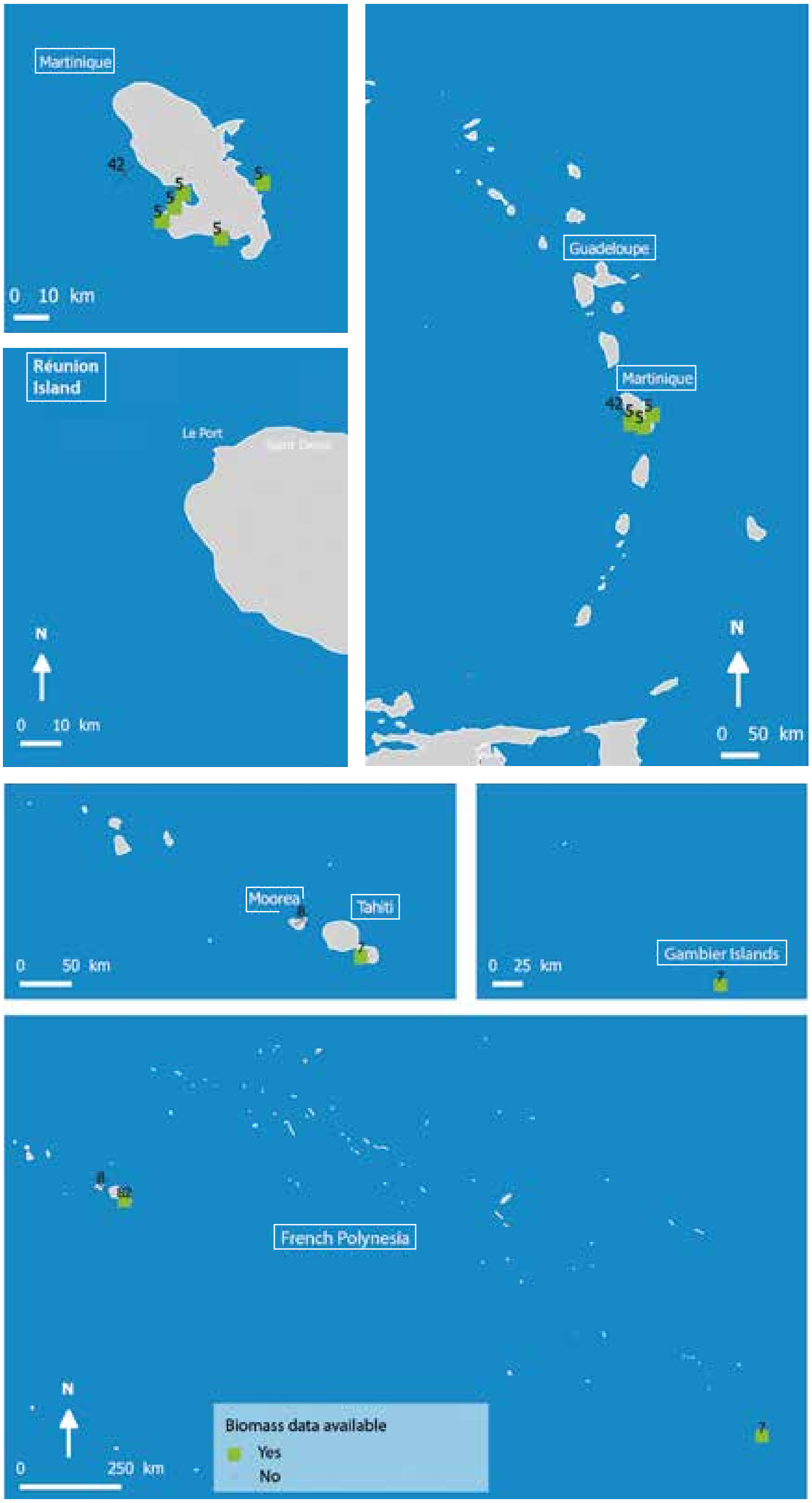
Type of substrate studied at the different sites in overseas France



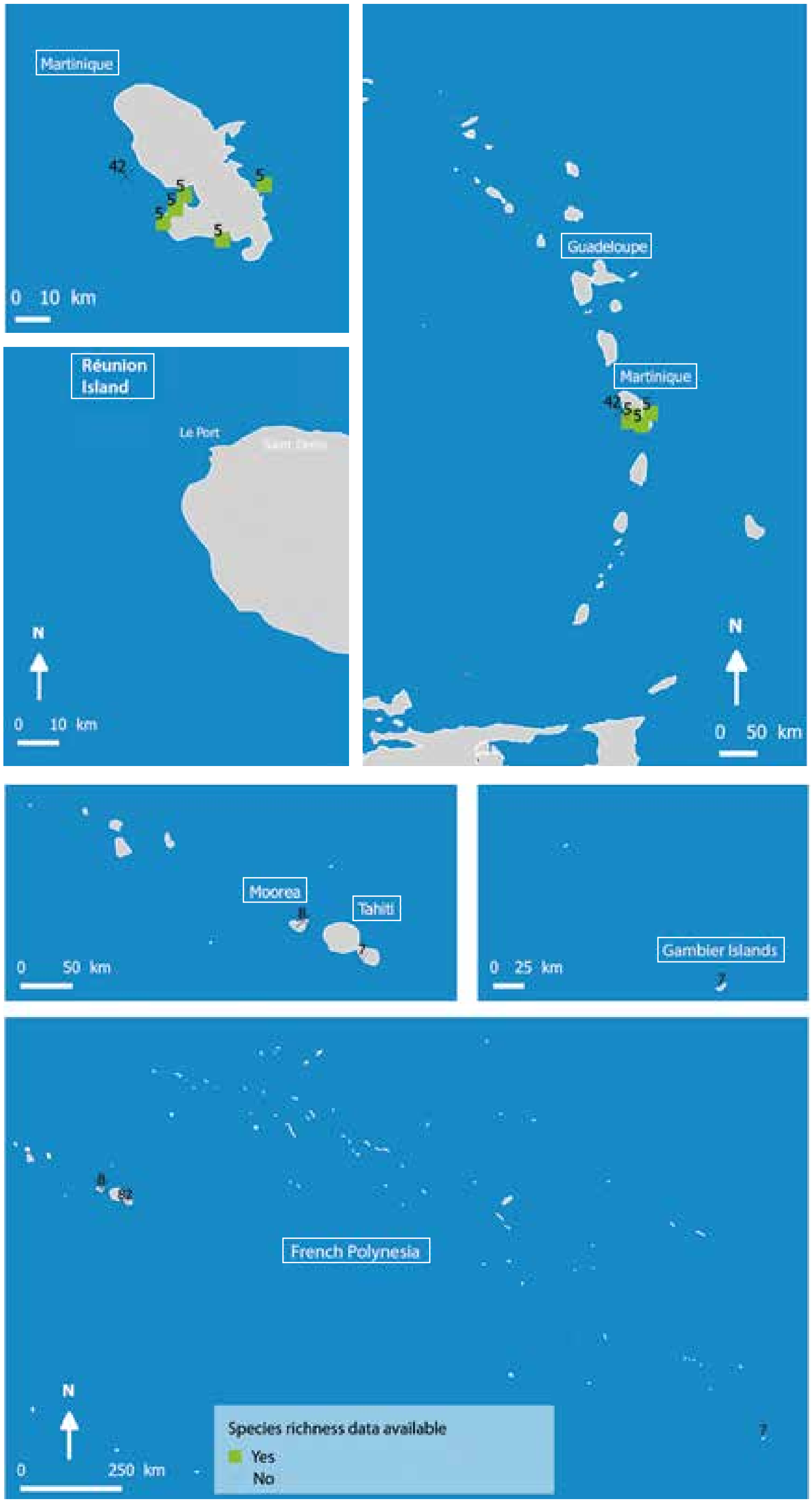
Availability of abundance data for overseas France



Availability of biomass data for overseas France



Availability of species richness data for overseas France



Annotated key references

[5] Desrosiers C. *et al.*, 2014. ***Optimal colonization and growth of marine benthic diatoms on artificial substrata: protocol for a routine use in bioindication.*** Journal of Applied Phycology, vol. 26, 1759-1771. (Caution: monitoring of the early stages of colonisation, macrofouling not studied) **Martinique** at **5 study sites** (Atl1, Car1, Car2, Bay1, Bay2) representative of the hydromorphological & chemical diversity of the area's coastal waters; wave exposure variable according to the site (from none to high, qualitative data only) but same light exposure; **8 weeks** of monitoring in **2011** in **spring** (March, April); **1 sample/week**; 3 types of artificial substrates, of similar roughness **(frosted glass, frosted Plexiglass and enameled tiles)**, as panels positioned ± 3 m deep; aim: to test the development of marine diatoms on different artificial substrates in different environments and to find the asymptote for the stabilisation of the microphytobenthic community; explanatory variables measured: depth, O_2, T°, pH, sal., PO_4, DIN, Chla, turbidity, hydrodynamics (qualitative); response variables measured: **biomass**, **density**, **S**; max. biomass = 11.4 mg/cm^2; S = 45; communities of diatoms dominated by pennate forms; the genus Nitzschia is represented by 31 species, monitoring of Amphora and Mastoglia; 3 key phases of biofilm development: week 1 = biofilm establishment, week 5 = exponential development phase, week 8 = mature biofilm; the sites do not differ significantly in their biogeochemical parameters but vary in their hydrodynamics and habitat type; B of biofilm greater on Plexiglass than glass or tiles in week 5 and B of biofilm lower on glass than 2 other substrates in week 8; but no significant difference in terms of valve density and S; species composition of diatom communities dependent on site and time of development.

[7] Lacoste E. *et al., 2014.* ***Biofouling development and its effect on growth and reproduction of the farmed pearl oyster Pinctada margaritifera.*** Aquaculture, vol. 434, 18-26. **Tahiti** (**Vairao lagoon**) and **Gambier archipelago** (**Mangareva**); study conducted **between 2011 and 2013**, over **21 months**; sampling in all seasons (November 2011 to July 2013) of colonisation by pearl oysters (substrate = **calcium carbonate**) and "kangaroo" nets (substrate = **plastic**); sampling at **7 m** deep; aim: to determine the effects of fouling on i) shell growth rate, ii) flesh weight, and iii) reproduction as well as to define the temporal dynamics of biofouling development in French Polynesia based on the hypothesis that it varies seasonally (focus on 2nd objective for this atlas); explanatory variables measured: T°, Chla; response variables measured: **pres/abs** of groups of fouling organisms, biomass (fresh weight); **minimal biomass** of fouling**: 786 ± 316 g**/group (= mean of 4 nets of 12 oysters); **max. biomass: 1798 g**/group (= mean of 4 nets of 12 oysters); pioneer species: ***Didemnum* sp.**, then development of dominant species belonging to groups: **Ascidiacea**, **Polychaeta**, **Bryozoa** and **Bivalvia**; presence of mobile fauna species: crabs, amphipods and isopods; after 3 to 12 months of immersion, fouling reached a wet weight of 800 to 1,800 g/net of biomass, which represents 75 % of the total weight of the structure (weight of net, oysters and fouling); conclusion relating to article's 1st aim: strong development of biofouling does not affect oyster growth rate.

[8] Gleason M.G. , 1996. ***Coral recruitment in Moorea, French Polynesia: the importance of patch type and temporal variation.*** JEMBE, vol. 207, 79-101. Monitoring in **Moorea** in **1990**, **1991**, **1992**, **1993**; in total, **3 years** of monitoring of **non-enameled ceramic tiles** immersed at depths **1-2 m** and **8-10 m 9x4 mos.**, i.e.: **August-Dec.**, **Dec.-April** (warmest season), **April-August**, each year; aim: to identify coral recruitment patterns of reefs after disturbance; explanatory variables measured: fore- vs back-reef; response variables measured: **A**, **coral diversity**, **hard fouling**; back-reef: avg. 3.5 recruits per tile (i.e. 155.56/m²); fore-reef: 2.4 recruits; dominant species = Pocilloporidae and Poritidae then Acroporidae recruits + recruits from other families; 4-month old recruits: Poritidae = 0.4-3.2 mm, Acroporidae = 0.6-3.5 mm, Pocilloporidae = 0.6-11.7 mm, variable size according to season; coral recruitment patterns in Moorea characterised by the influence of the season during which the colonised structure was immersed and the year of immersion (high annual variability).

[42] Dubois D., 2017. ***Analyses de macrofouling d'éprouvettes immergées en Martinique.*** Confidential internal report, 24pp. **Martinique**; turbulent area, low light levels; installation of test panels made of **different materials** (coated steel, polymer membranes [several types] and unpainted steel) in the natural environment at 8 different depths (**1 m**, **2 m**, **10 m**, **20 m**, **50 m**, **100 m**, **150 m** and **500 m**); monitoring for **5 mos. between Dec. 2015 and April 2016**, 1 sampling date; aim: to assess the biofouling cover of test panels composed of different materials installed at different depths for 5 months; explanatory variables measured: depth, material, coating; response variables measured: **% cover**? (but no data available); dominant species: **hydrozoans, sponges** and **goose barnacles** + a few **red algae**; no fouling at 500 m depth; hydrozoans and sponges are dominant on panels immersed between 10 and 100 m deep with a decreasing density gradient; at 1 m deep, presence of goose barnacles.

[64] Consortium Biopaintrop (MAPIEM/UBS/Hydrô Réunion), 2017. ***Formulations intégrant les extraits actifs tropicaux et tests in situ.*** Confidential report, 30pp. **Réunion Island**, in Le Port (as well as Lorient and Toulon, see atlas sections on Bay of Biscay and the Mediterranean); low hydrodynamics; **2016-2017**; **9 months** of monitoring (June 2016 to March 2017); **monthly** sampling; **PVC** panels (10 x 20 cm); aim: to observe the development of biofouling at 3 contrasting sites and on different coatings (including uncoated surface); explanatory variables measured: latitude, type of coating; response variables measured: **N** (coating effectiveness); **% cover** by functional group; early col. = Ulva (5 %), Phaeophyceae (60 %) and late col. = oysters (100 %); heavy fouling by oysters at Réunion site; this study highlights the importance of testing the spectrum of effectiveness of antifouling paints on different sites.

[82] Faberes D., 1981. ***ETM - étude de site - rapport préliminaire de l'étude du fouling dans le lagon de Vairao.*** CNEXO/Ifremer internal report, 58pp. **Tahiti** (**Vairao lagoon** = sheltered environment) studied in **1980-1981** (**15 mos.**) **monthly/ quarterly** samples; **panels** made of different materials (white **PVC**, black PVC, **stainless steel**, **mild steel**, **AG3**, **AG4**, **concrete**, **titanium**, **aluminium bronze**, **copper-nickel**) installed **2 and 25 m** deep; aim: to identify the effects of marine biofouling on different materials potentially used in the construction of an ocean thermal energy plant, monitoring of colonisation (attachment period & long-term development; explanatory variables measured: T°, sal., dissolved O_2, nitrates, silicates, phytoplankton composition; response variables measured: **faunal composition**, **biomass** (fresh weight), **corrosion**; biomass of fouling on PVC panels at -2 m = 1-1.6 kg/m² (3 mos.), 2-2.6 kg/m² (6 mos.), 3.7 kg/m² (9 mos.); at -25 m = 300 g (3 mos.), 1.3-1.8 kg (6 mos.), 1.2-1.7 kg (9 mos.); dominant species: **ascidians**, and longer term = **coral**; **↗ in biomass** between 3 and 9 mos.: from 1 to 3.7 kg at -2 m and from 300 g to 1.7 kg at -25 m; **attachment period which seems most conducive in the lagoon: April** (greatest attached biomass); **samples at 25 m show half as much fouling as those at 2 m deep**; attachment period not as clear-cut as in temperate environments (although it can be seen that recruitment is higher around April in terms of biomass); predation not studied but an evident factor!; little fouling in the lagoon compared to areas briefly studied outside the lagoon or along the coasts of mainland France; conclusions on materials: see doc.

5 - Biofouling in French waters

Based on the information extracted from the different documents analysed, we are able to present certain **data in graphic form according to depth** (Fig. 20) **and time** (Fig. 21, 22 and 23).

The biomass data presented in Figure 20 represent the total fresh weight (all living organisms considered). The duration of immersion of the substrates studied ranges from 9 months to far longer periods (natural substrate in place). First, across all the zones, we find that **biomass** (only total fresh weight [community level] was considered to produce Fig. 20 and 21) **varies greatly** according to depth (from **20 g/m² to 40 kg/m²**) and in particular in the top ten metres of water (Appendix 2a). These extremely variable values are **consistent with those measured at other sites in Europe,** and in particular off the coasts of Scotland and Sweden (Appendix 2b).

As concerns biomass at community level (i.e. all fouling organisms found on the substrate), the heterogeneity of the available data makes it difficult to compare geographical zones (available data: Overseas France, n = 2; Bay of Biscay, n = 2; Channel, n = 12) and these **data are difficult to compare with those indicated in the standards specifying the critical biofouling densities for offshore structures** expressed in kN/m^3, mass being a volumetric concept. This observation is a key point which should be integrated into new protocols. Indeed areal densities should at least be associated with thickness values in order to determine volumetric data which can be used in engineering studies.

By reviewing this corpus of literature, quantitative data were also able to be extracted at different time steps. Monitoring of biomass variations (fresh weight) is presented in two reports

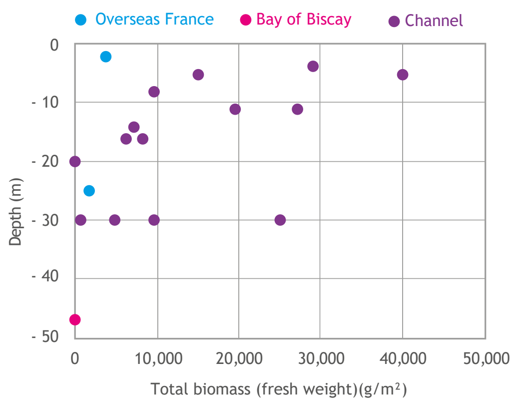


Fig. 20. *Total fresh weight (continuous values) at different depths measured in three geographical zones*

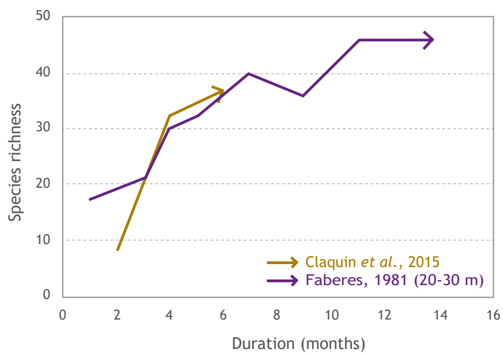


Fig. 22. *Species richness at different stages of fouling*

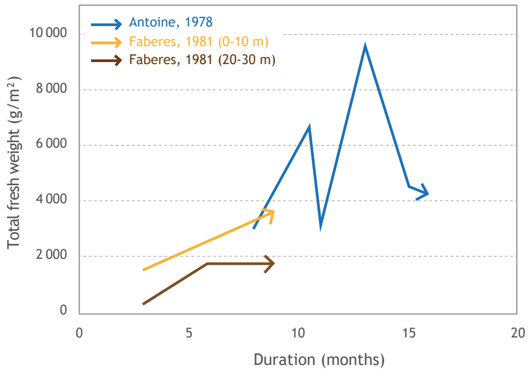


Fig. 21. *Total fresh weight of biofouling recorded during 9- to 16-month measurement cycles*

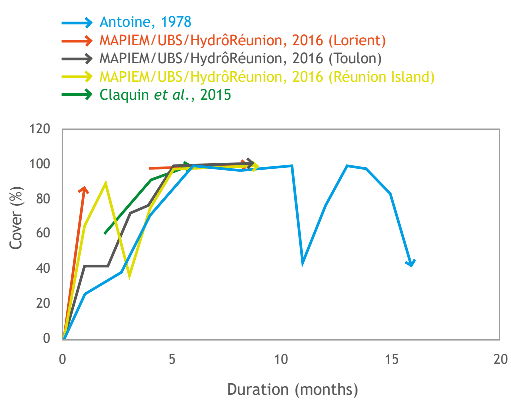


Fig. 23. *Variation in the percentage cover during the colonisation process at 5 sites.*

(Antoine, 1978; Faberes, 1981); by placing these data in the same space-time context (Fig. 18, 21) we find that, **in general, biomass increases overtime, but varies considerably**. Figure 21 also shows that the total weight of fouling varies with depth: the biomass of the fouling community is greater between 0 and 10 metres than between 20 and 30 metres in Tahiti (Faberes, 1981). **Species richness (S)**, measured at different time steps during the two other studies (Claquin *et al.*, 2015; Bellan-Santini, 1970), **tended to increase over time and followed the same pattern** (Fig. 22). Species richness then stabilised at the monitored site for over a year.

The **percentage cover measured** through three studies and **at five different sites shows marked temporal variation** and a rapid increase in the percentage cover for the first month following immersion (Fig. 23). The colonisation rate varies according to the site, and the colonisation sequence shows regressions (sharp drop in cover) over time. **Several natural processes can explain the decrease in cover** at advanced stages of biocolonisation, **primarily predation and climate (storms)**.

This work highlights the great variability in the biofouling process, including in temperate, sheltered environments (e.g. variation in percentage cover measured in Sainte-Anne du Portzic; Antoine, 1978). Given the heterogeneity of the data extracted from the documents analysed, sufficiently robust conclusions cannot be drawn at this stage. This review underscores the importance of performing a quantification of biofouling for the specific area concerned. However, by pooling the results of studies conducted to characterise biofouling (and more generally hard substrate communities), knowledge of this process can be improved. This would also help to exhibit the temporal and spatial colonisation patterns expressed for instance in terms of biomass, biovolume, abundance or geometric characteristics (see *Variables du fouling à mesurer en priorité dans un contexte EMR* in Quillien *et al.*, in prep. *Existing protocols to measure biofouling characteristics: what methodological adaptations are needed within ORE contexts?)*. Furthermore, to more fully understand and predict these variations, it is essential to conduct longer term biofouling monitoring studies and to include the measurement of potential explanatory variables (temperature, currents, predation pressure, etc.).

This work also highlights the **lack of correlation between the data acquired by implementing protocols for ecological studies and those necessary for engineering purposes.** Currently, the comparison of data extracted for this review with existing offshore design standards is not feasible. This is particularly the case of the biomass, volume and functional group (e.g. hard or soft organisms) of dominant species. These variables must be measured simultaneously and be able to be correlated in order to venture beyond areal data and obtain the distribution of biofouling density.

6 - Acronyms and abbreviations

A = Abundance
Abs. = Absence
AFDW = Ash-Free Dry Weight
AR = Artificial Reef
Avg. = Average
B = Biomass
Bathy. = Bathymetric
Bryo = Bryozoans
Chla = Chlorophyll a
Circa = Circalittoral
Com. = Communities
DIN = Dissolved Inorganic Nitrogen
FEM = France Energies Marines
Freq. = Frequency
H' = Shannon Index
Ind = Individuals
Infra = Infralittoral
J' = Pielou's Evenness Index
Med. = Mediterranean
MIS = Matter In Suspension
Mos. = Months
NA = Not Attributed
N° = Number
Phaeo. = Phaeophyceae (brown algae)
POC = Particulate Organic Carbon
PON = Particulate Organic Nitrogen
ppm = Parts Per Million (1 ppm = 1 mg/kg)
Pres. = Presence
Quali. = Qualitative
Quanti. = Quantitative
Rhodo. = Rhodophyceae (red algae)
S = Species richness
Sal. = salinity
SD = Standard Deviation
Subs. = Substrate
T° = Temperature

7 - Bibliographical references

Antoine, E. (1978). *Etude du fouling sur la station d'essais en milieu marin de Sainte-Anne du Portzic (juin 1977 - décembre 1977). 28 pp.*

Benedetti-Cecchi, L. (2000). Predicting direct and indirect interaction during succession in a mid-littoral rocky shore assemblage. *Ecological Monographs*, *70(1)*, 45–72. https://doi.org/10.1890/0012-9615(2000)070[0045:PDAIID]2.0.CO;2

Burrows, M. T. (2012). Influences of wave fetch, tidal flow and ocean colour on subtidal rocky communities. *Marine Ecology Progress Series, 445,* 193–207. https://doi.org/10.3354/meps09422

Canning-Clode, J., & Wahl, M. (2010). Patterns of Fouling on a Global Scale. In *Biofouling* (pp. 73–86). https://doi.org/10.1002/9781444315462.ch5

Castric-Fey, A. (1974). *Les peuplements sessiles du benthos rocheux de l'archipel de Glénan (Sub Bretagne) - Ecologie descriptive et expérimentale. 333 pp.*

Castric-Fey, A. (1988). Les facteurs limitants des peuplements sessiles sublittoraux en Baie de Concarneau (Sud Finistère). Vie Milieu, *38(1)*, 1–18.

Castric-Fey, A., & Chasse, C. (1991). Factorial analysis in the ecology of rocky subtidal areas near Brest (West Brittany, France). *Journal of the Marine Biological Association of the United Kingdom. Plymouth, 71(3)*, 515–536. https://doi.org/10.1017/S0025315400053121

Compère, C. (1999). Biofilms en mileu marin. *Techniques Sciences Méthodes, 11*, 48–54.

Connell, J. H. (1972). Community Interactions on Marine Rocky Intertidal Shores. *Annual Review of Ecology and Systematics, 3*, 169–192.

Connell, J. H., & Slatyer, R. O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist, 111(982)*, 1119–1144.

Damblans, G. (2017). Floating wind turbine power cable: a complex new challenge. 4th Floating Offshore Wind Turbines - FOWT 2017, Marseille, France, 15/03/17 - 16/03/17.

Damblans, G., Berhault, C., Le Cunff, C., Molin ,B., Wiet, P., Cinello, A., Deglaire, T., Legras, JL. (2013). "Investigations on Galloping of Non-Circular Cross Sections". OMAE 2013-10357

DePalma, J. R. (1982). Horizontal and vertical distribution of fouling in the world's oceans. In *Fouling and Corrosion of Metals in Seawater* (pp. 7–14).

Gaurier, B., Germain, G., Facq, J. V, Baudet, L., & Schoefs, F. (2014). Effet des concrétions marines sur le comportement hydrodynamique de structures circulaires. In *Journées de l'Hydrodynamique* (pp. 1–12).

Ghobashy, A. F. A., & El Komy, M. M. (1980). Fouling in the southern region of the Suez Canal. Aquatic Ecology, *14(3)*, 179-185.

Glasby, T. M., & Connell, S. D. (2001). Orientation and position of substrata have large effects on epibiotic assemblages. *Marine Ecology Progress Series, 214*, 127–135. https://doi.org/10.3354/meps214127

Heideman, J. C., & George, R. Y. (1981). Biological and engineering parameters for macrofouling growth. In *MTS/IEEE* (pp. 550–557).

Hiscock, K. & Mitchell R. (1980). The description and the classification of sublittoral epibenthic ecosystems. In: *The Shore Environment Volume 2: Ecosystems* (eds J.H. Price, D.E.G. Irvine & W.F. Farnham) (pp. 323-370) Academic Press, London

Hunsucker, J. T., Hunsucker, K. Z., Gardner, H., & Swain, G. (2016). Influence of hydrodynamic stress on the frictional drag of biofouling communities. *Biofouling, 32(10)*, 1209–1221. https://doi.org/10.1080/08927014.2016.1242724

Langhamer, O. (2012). Artificial reef effect in relation to offshore renewable energy conversion: State of the art. *The Scientific World Journal, 2012, 8p*. https://doi.org/10.1100/2012/386713

Langhamer, O., Wilhelmsson, D., & Engström, J. (2009). Artificial reef effect and fouling impacts on offshore wave power foundations and buoys - a pilot study. *Estuarine, Coastal and Shelf Science, 82(3)*, 426–432. https://doi.org/10.1016/j.ecss.2009.02.009

Lord, J. P. (2017). Temperature, space availability, and species assemblages impact competition in global fouling communities. *Biological Invasions, 19(1)*, 43–55. https://doi.org/10.1007/s10530-016-1262-7

Loxton, J., Macleod, A. K., Nall, C. R., McCollin, T., Machado, I., Simas, T., Vance, T., Kenny, C., Want, A., Miller, R. G. (2017). Setting an agenda for biofouling research for the marine renewable energy industry. *International Journal of Marine Energy, 19*, 292–303. https://doi.org/10.1016/j.ijome.2017.08.006

Macleod, A. K., Stanley, M. S., Day, J. G., & Cook, E. J. (2016). Biofouling community composition across a range of environmental conditions and geographical locations suitable for floating marine renewable energy generation. *Biofouling, 32(3)*, 261–276. https://doi.org/10.1080/08927014.2015.1136822

Noël, L., Griffin, J., Jenkins, S. R., Noël, L. M. J., Griffin, J. N., Moschella, P. S., ... Hawkins, S. J. (2009). Marine Hard Bottom Communities, 206(May). https://doi.org/10.1007/b76710

Osman, R. W., & Whitlatch, R. B. (2004). The control of the development of a marine benthic community by predation on recruits. *Journal of Experimental Marine Biology and Ecology, 311(1)*, 117–145. https://doi.org/10.1016/j.jembe.2004.05.001

Quillien, N., Damblans, G., Boukerma, K., Bressy, C., Briand, J.-F., Compère, C., Dreanno, C., Jacob, D., Leblanc, V., Reynaud, M., Schoefs, F., Lejart, M. In prep. Existing protocols to measure biofouling characteristics: what methodological adaptations are needed within ORE contexts?

Richmond, M. D., & Seed, R. (1991). A review of marine macrofouling communities with special reference to animal fouling. *Biofouling, 3*, 151–168.

Roberts, D., Rittschof, D., Holm, E., & Schmidt, A. R. (1991). Factors influencing initial larval settlement: temporal, spatial and surface molecular components. Journal of Experimental Marine Biology and Ecology, *150(2)*, 203 -221. https://doi.org/10.1016/0022-0981(91)90068-8

Rule, M. J., & Smith, S. D. A. (2007). Depth-associated patterns in the development of benthic assemblages on artificial substrata deployed on shallow, subtropical reefs. *Journal of Experimental Marine Biology and Ecology, 345(1)*, 38–51. https://doi.org/10.1016/j.jembe.2007.01.006

Taormina, B., Bald, J., Want, A., Thouzeau, G., Lejart, M., Desroy, N., & Carlier, A. (2018). A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. *Renewable and Sustainable Energy Reviews, 96*(July), 380–391. https://doi.org/10.1016/J.RSER.2018.07.026

Tiron, R., Pinck, C., Reynaud, E. G., & Dias, F. (2012). Is biofouling a critical issue for wave energy converters? *Proceedings of the International Offshore and Polar Engineering Conference, 4*(May), 669–679. Retrieved from http://www.scopus.com/inward record.ul?eid=2-s2.0-84866110753&partnerID=40&md5=8d41ac429a5d41f62ebaffdc4536c27f

Valiela, I. (1995). *Marine Ecological Processes.* 686p. https://doi.org/10.1007/978-1-4757-4125-4

Vance, T., Lauterbach, L., Lenz, M., Wahl, M., Sanderson, R. A., & Thomason, J. C. (2009). Rapid invasion and ecological interactions of Diplosoma listerianum in the North Sea, UK. *Marine Biodiversity Records, 2*, e59. https://doi.org/10.1017/S1755267209000815

Wahl, M. (1989). Marine epibiosis. I. Fouling and antifouling: some basic aspects. *Marine Ecology Progress Series, 58*, 175–189.

Want, A., Crawford, R., Kakkonen, J., Kiddie, G., Miller, S., Harris, R. E., & Porter, J. S. (2017). Biodiversity characterisation and hydrodynamic consequences of marine fouling communities on marine renewable energy infrastructure in the Orkney Islands Archipelago, Scotland, UK. *Biofouling, 7014*(July), 1–13. https://doi.org/10.1080/08927014.2017.1336229

Want, A., Porter, J., Long, C. (2018) BioFREE: a global study of biofouling impacts on wave and tidal renewable energy technologies. Oral presentation, ICOE conference, Cherbourg.

8 - Appendices

Appendix 1

Table listing the articles analysed which form the basis of the "review" and "mapping" databases for producing the atlas of biofouling in French waters.

Author(s)	Publi.	Title	Ref.	Zone
Antoine	1978	Etude du fouling sur la station d'essais en milieu marin de Sainte-Anne du Portzic	14	Channel
Antoine	1978	Etude du fouling sur la station d'essais en milieu marin de Sainte-Anne du Portzic (Déc 1977-Déc 1978)	83	Channel
Augris, Caill-Milly, de Casamajor	2009	Atlas thématique de l'environnement marin du Pays Basque et du sud des Landes	93	Bay of Biscay
Bellan-Santini	1970	Salissures biologiques de substrats vierges artificiels immergés en eau pure durant 26 mois dans la région de Marseille	69	Mediterranean
Bellan-Santini, Arnaud, Bellan, Harmelin, Le Campion-Alsumard, Leug Tak Kit, Picard, Pouliquen, Zibrowius	1969	Etude qualitative et quantitative des salissures biologiques de plaques expérimentales immergées en pleine eau	95	Mediterranean
Bridier	2016	Dynamique temporelle d'une communauté benthique sur substrat artificiel en rade de Brest	63	Channel
Brown, Eaton, Cragg, Goulleter, Nicolaidou, Bebianno, Icely, Daniel, Nilsson, Pitman, Sawyer	2003	Assessment of effects of chromated copper arsenate (CCA)-treated timber on nontarget epibiota by investigation of fouling community development at seven European sites	15	Bay of Biscay
Castège, Milon, Fourneau, Tauzia	2016	First results of fauna community structure and dynamics on two artificial reefs in the South of the Bay of Biscay	4	Bay of Biscay
Castric-Fey	1988	Les facteurs limitants des peuplements sessiles sublittoraux en Baie de Concarneau (Sud Finistère)	11	Bay of Biscay
Castric-Fey	1974	Les peuplements sessiles du benthos rocheux de l'archipel de Glénan (Sud Bretagne) - Ecologie descriptive et expérimentale	12	Bay of Biscay
Castric-Fey	1996	Richesse et biodiversité en mer mégatidale : communautés sublittorales rocheuses de la région Trébeurden-Ploumanac'h	67	Channel

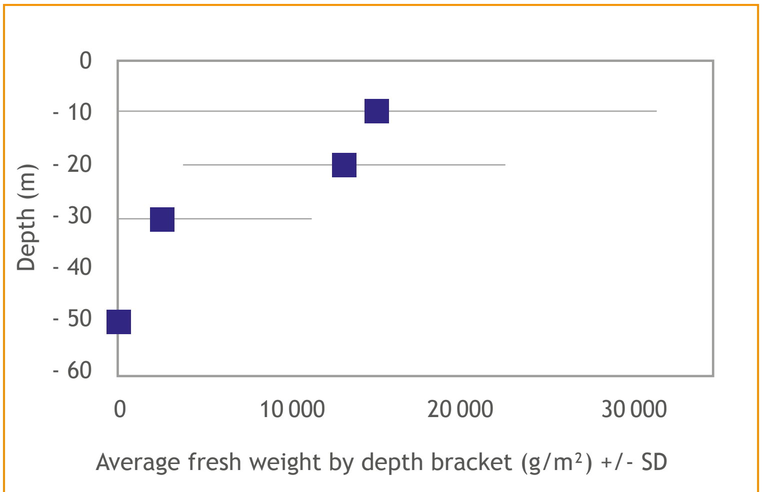
Author(s)	Publi.	Title	Ref.	Zone
Castric-Fey, Chassé	1991	Factorial analysis in the ecology of rocky subtidal areas near Brest	57	Channel
Castric-Fey, Girard-Descatoire, Larfargue, L'Hardy-Halos	1973	Etagement des algues et des invertébrés sessiles dans l'archipel de Glénan - définition biologique des horizons bathymétriques	66	Bay of Biscay
Chassé et al.	1976	Etude écologique d'avant-projet sur le site de Ploumoguer	31	Channel
Chauvaud	2017	Dynamique temporelle d'une communauté benthique sur substrat artificiel en rade de Brest : influence de l'environnement et des interactions spécifiques	58	Channel
Claquin, Lestarquit, Leroy, Rusig, Mussio, Napoléen, Orvain, Foveau, Dauvin, Schlund, Bachelet, Feunteun, Danet, Collins, Mallinson, Jensen, Robinson	2015	Suivis environnementaux : colonisation des matériaux en mésocosmes et *in situ*	76	Channel
Clausade	1969	Peuplement animal sessile des petits substrats solides récoltés dans trois biocenoses des fonds détritiques des parages de Marseille	70	Mediterranean
Consortium Biopaintrop	2017	Formulations intégrant les extraits actifs tropicaux et tests *in situ*	64	Bay of Biscay, Mediterranean, Tropical Indian Ocean
Cudennec	2015	Dynamique de la colonisation benthique sur les substrats artificiels des installations EMR	68	Channel
Dalias, Blouet, Foulquié, Dupuy de la Grandvire, Lenfant	2008	Suivi scientifique des récifs artificiels de Valras-Plage	84	Mediterranean
De Casamajor, Lalanne	2016	Intérêt biogéographique de la côte basque rocheuse	80	Bay of Biscay
De Casamajor, Popovsky, Lissardy	2014	Suivi DCE du paramètre "macroalgues subtidales"	81	Bay of Biscay
Derrien, Catherine	2013	Inventaire vidéo de la biodiversité benthique sur le site hydrolien de Paimpol-Bréhat. Note de synthèse - Données 2012	72	Channel

Author(s)	Publi.	Title	Ref.	Zone
Derrien, Catherine	2015	Inventaire vidéo de la biodiversité benthique sur le site hydrolien de Paimpol-Bréhat. Note de synthèse - Données 2013	73	Channel
Derrien-Courtel, Le Gal, Grall	2013	Regional-scale analysis of subtidal rocky shore community	65	Channel, Bay of Biscay
Desrosiers, Leflive, Eulin, Ten-Hage	2014	Optimal colonization and growth of marine benthic diatoms on artificial substrata: protocol for a routine use in bioindication	5	Tropical Atlantic
Dubois	2017	Analyses de macrofouling d'éprouvettes immergées en Martinique	42	Tropical Atlantic
Duchêne	2014	Evaluation du biofouling sur la machine test OH-OCT-1	41	Channel
Faberes	1981	ETM - étude de site - rapport préliminaire de l'étude du fouling dans le lagon de Vairao	82	Overseas French territories in the Pacific
Faimaili, Ntoumas, Hernandez, Delauney, Sivyer, Karlson, Seppala	2016	Report on JERICO Biofouling Monitoring Program (BMP)	26	Channel
Garrabou, Ballesteros, Zabala	2002	Structure and dynamics of north-western Mediterranean rocky benthic communities along a depth gradient	16	Mediterranean
Gleason	1996	Coral recruitment in Moorea, French Polynesia: the importance of patch type and temporal variation	8	Tropical Pacific
Harmelin, Bellan-Santini, Boudouresque, Le Campion -Alsumard, Leung Tack Kit, Salen	1970	Etude expérimentale de la colonisation des surfaces vierges naturelles en eau pure et en eau polluée dans la région marseillaise (conditions de l'expérience)	71	Mediterranean
Labadie, Dubreuil	2010	Inspection des récifs artificiels des sites expérimentaux de l'Île d'Yeu et du Croisic	54	Bay of Biscay
Laborde	2010	Suivi scientifique des récifs artificiels Capbreton, Soustons/Vieux Boucau, Messanges/Azur/Moliets	56	Bay of Biscay

Author(s)	Publi.	Title	Ref.	Zone
Lacoste, Le Moullac, Levy, Gueguen, Gaertner-Mazouni	2014	Biofouling development and its effect on growth and reproduction of the farmed pearl oyster *Pinctada margaritifera*	7	Tropical Pacific
Lamy	1996	Organisation, structure et dynamique des peuplements macrobenthiques d'une table conchylicole de l'étang de Thau	27	Mediterranean
Mazouni, Gaertner, Deslous-Paoli	2001	Composition of biofouling communities on suspended oyster cultures: an in situ study of their interactions with the water column	6	Mediterranean
Migné	1996	Rôle des organismes suspensivores dans les transferts pelago-benthiques d'une zone de fort hydrodynamisme	78	Channel
Migné, Davoult	1995	Multi-scale heterogeneity in a macrobenthic epifauna community	77	Channel
Prygiel, Davoult, Dewarumez, Glaçon, Richard	1988	Description et richesse des peuplements benthiques de la partie française de la Mer du Nord	79	Channel
Reynaud	2016	Analyse sur le biofouling présent sur SEM-REV	34	Bay of Biscay
Rudeault	2004	Le Wharf de la mine de Dielette - Les récifs artificiels	75	Channel
Ruitton, Francour, Boudouresque	2000	Relationships between algae, benthic herbivorous invertebrates and fishes in rocky sublittoral communities of a temperate sea	9	Mediterranean
Taormina	2015	Inventaire de la faune et flore marine et caractérisation des assemblages benthiques des milieux subtidaux rocheux d'un site remarquable de la région de Roscoff : le Plateau de la Méloine	62	Channel

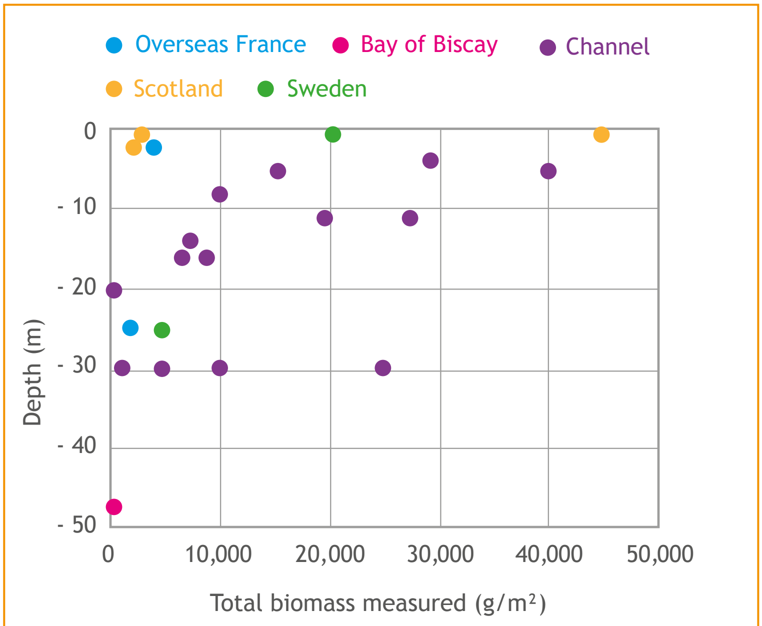
Appendix 2a

Mean total fresh weight (+/- standard deviation) by depth range



Appendix 2b

Comparison of total biomass values measured in different zones: atlas zones as well as Scotland and Sweden



9 - Notes

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