Development and demonstration of an automated, modular and environmentally friendly multi-functional platform for open sea farm installations of the Blue Growth Industry

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CHAPTER 1: INTRODUCTION

The aim of the **Blue Growth Farm project** is to develop and demonstrate an automated, modular and environmentally friendly multi-functional platform for open sea farm installations of the Blue Growth Industry. Therefore, this project can be a driver on designs a system to produce food and energy at the least environmental load.
The BGF platform design is based has the following aims:

1. Ensuring a nominal 2.000t/y fish production, operating with advanced automation and remote control capabilities;

- Avoid or minimize the pollution to the surrounding marine ecosystem, at the same time exploiting the marine natural resources in a sustainable way;
- Maximize the electricity production in the BGF potential installation area, dispatching produced electric energy to the grid and providing a maritime electric station service to shipping.

In particular, WP4 aims to carry out the Environmental Impact Assessment studies for the Blue Growth Farm concept and potential exploitation. In this respect, the present report of the Task 4.1 performs an assessment of all the main environmental components possibly impacted by the BGF installation, as a farm located in open sea. The outcome of this study has to be intended as a decision-making support tool for the development, designing and exploitable phases of the project, aiming at avoiding/reducing/compensating any likely environmental negative effect.

1.1 IDENTIFICATION OF THE DOCUMENT AND ITS STRUCTURE

The present document is a WP4 deliverable of the European Commission funded project The Blue Growth Farm (under Grant Agreement no.774426, in the framework of H2020 programme).
The deliverable D4.1 “Environmental Impact Assessment” is the first step to the assessment of the overall environmental sustainability of the BGF system.

The document is organised in the following chapters:

- Chapter 1 introduce and specifies the structure of the document;
- Chapter 2 describes programmatic framework, starting form the international legal context to the local;
- Chapter 3 describes the environmental characteristic of the selected site;
- Chapter 4 outline the Project and the features of its main operational life;
- Chapter 5 provides the assessment of the impacts on the main components, taking into account the sensitive receptors, and including mitigation measures;
- Chapter 6 reports the final reccomendations
- Chapter 7 is the conclusions of the document;
- Chapter 8 lists the quoted references.

Within this document, the international legal framework and all the methods used to assess the environmental impacts are fully described, therefore avoiding unnecessary repetitions into impact assessment documents of the selected sites of Spain and Scotland.

CHAPTER 2: PROGRAMMATIC FRAMEWORK

2.1 INTERNATIONAL ENVIRONMENTAL POLICY

The overall ocean resources for human exploitation are limited, and a comprehensive and integrated approach is necessary to deal with ocean-based human activities. The marine renewable energy facilities and related large-scale installation at sea represent a development that involves integrated coastal management strategies and marine spatial planning, when located in areas under control of a state authority, although at different level. The development of parks where renewables are exploited within territorial waters may be properly managed by an Integrated Coastal Zone Management (ICZM) approach and by marine spatial planning instruments, where appropriate.

Aiming to increase global production of aquatic products, and at the same time maintaining environmental sustainability, spatial planning for aquaculture is receiving an increased attention globally, due to the need to optimise the use of space in the context of other uses. The EU is particularly concerned with food security, given that 71% of the fish consumed in the EU are imported. Several texts have been developed at international, European and national level as guidelines for the management of the marine area and its uses, as navigation and overflight, exploration and development, and including the exploitation of its resources, the conservation of biological resources, the protection and preservation of the marine environment and the marine scientific research.

The EU Integrated Maritime Policy (IMP) for the European Union clearly states that “all matters relating to Europe's oceans and seas are interlinked, and that sea-related policies must develop in a joined-up way if we are to reap the desired results”. Therefore, a sectoral management is no longer appropriate to reach a proper management of marine resources. The IMP aims to trigger integrated governance, offering the necessary cross-sectoral tools for its implementation.

2.1.1 The Renewables within the International law of the Sea

The United Nations Convention on the Law of the Sea (UNCLOS), signed in 1982 at Montego Bay, codifies the international law of the sea: it has, specifically, established the rules relating to the use of the sea and the exploitation of its resources in the view of ensuring their conservation and preservation for future generations. These rules and the resulting rights and duties of States vary, according to the different maritime areas where the States exercise their legal power.

With regard to internal waters and the territorial sea, State sovereignty has the full right to exploit its energy resources within the territorial sea, extending up to 12 nautical miles from the baselines.

The coastal States have a sovereign right to develop renewable marine energy only in areas close to its coasts (territorial sea) and in area under its national jurisdiction (Exclusive Economic Zone, where it exists) or within its Continental Shelf.

The Article 56.1.a of the Convention describes the sovereign rights of the coastal State in its **Exclusive Economic Zone (EEZ)**, concerning "the production of energy from water, currents and

winds". The EEZ is a space up to 200 miles wide calculated from the baselines of the coastal state. The State is also obliged in ensuring the protection of the environment, and corresponding capabilities can be shared with or transferred to the EU.

The exploitation of the **Continental Shelf,** which is regulated by the Article 77 of the Convention, specifically listing exploitable resources, does not mention the Renewables. In the same way, this Article does not regulate the pelagic compartment and the overlying airspace. Installations at the Shelf level are regulated by the Article 80 that introduces, by the formula *all things being equal,* an extension of the regime applicable in the EEZ (Article 60).

On the **High Seas,** no provision of the Law of the Sea Convention makes any reference to any specific right to operate the Renewables. On the other hand, the exploitation of the seabed and its mineral resources, which have been designated by the international community as "Common Heritage of Humanity", is subject to a regulated regime and supervised by the International Seabed Authority, established under the United Nations Convention for the Law of the Sea (art. 156).

2.1.2 The international regulatory regime of Aquaculture

The regulation of marine aquaculture is not restricted to aquaculture-specific legislation. Where not included in specific legal frameworks, it exists under other regimes. Within international regulations, aquaculture is mainly subjected by two regimes: the law of the sea and the international environmental law.

The International law of the sea is primarily determined by the provisions of the United Nations Convention on the Law of the Sea (UNCLOS) of 1982, effective since 1994. The treaty was aimed to establish “a legal order for the seas and oceans which will facilitate international communication, and will promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment”.

The UNCLOS provisions on the protection and preservation of the oceans are widely acknowledged as a package of generally applicable rules of customary international law. Aquaculture is not mentioned in the convention, since it was not recognised as of international significance at the time of its issue. However, the convention has a global approach when saying in its Preamble ‘that the problems of ocean space are closely interrelated and need to be considered as a whole’ and that it ‘takes into account the interests and needs of mankind as a whole’. Thus, the scope of the convention is sufficiently broad to include several aspects of aquaculture. Regulation of aquaculture in marine waters is applied over the different areas where operations can be run. The convention divides the oceans in several jurisdictional zones, with different legal regimes: the Territorial Sea, the Exclusive Economic Zone, the Continental Shelf and the High Seas.

<u>The Territorial sea</u>

Primarily, marine aquaculture sites are run in coastal regions, thus within the twelve mile zone of the territorial sea where the coastal state has a full legal sovereignty. The legislation concerning

aquaculture is therefore mainly the national law.

Exclusive economic zone

It can be expected in the future that a number of fish farms will be located in offshore waters, at relevant distances from coast and port facilities. The EEZ was originally introduced to manage the increasing claims of exclusive rights in respect of fishery grounds, raised by several states in the second half of the 20th century. The EEZ extends from the outer limit of the territorial sea to a maximum of 200 nautical miles from the territorial sea baseline. The rights of the coastal state in that zone do not include a complete sovereignty, but are limited to control and exploit the natural resources lying in the seabed and in superjacent waters. Thus UNCLOS only gives to the coastal State the jurisdiction and the sovereign rights over the economic activities, marine scientific research and environmental matters in the EEZ.

This includes the right to build, authorize and regulate the construction and operation of, among others:

- Installations and structures for the purposes provided for in article 56 and other economic purposes;
- Installations and structures which may interfere with the exercise of the rights of the coastal State in the zone.

UNCLOS leaves the terms 'installations and structure' undefined. Regarding aquaculture sites as moored ships, it does not incorporate their method of construction and functionality. If we have a look at the meaning of the term 'structure', aquaculture facilities, being constructed as whole units with a significant size, can certainly be qualified as structures.

The installations and structures have to be constructed because of a particular purpose. Additional to 'other economic purposes', Article 60 refers to the purpose defined in Article 56: exploring and exploiting, conserving and managing the natural resources, both living or non living, of the waters superjacent to the seabed and of the seabed and its subsoil. This is intended concerning to the other activities for the economic exploitation and exploration of the zone, as the case of production of energy from the water, currents and winds. Aquaculture is not specifically mentioned as an applicable purpose, nevertheless it is included.

UNCLOS provides no definition of the term 'natural resources'. Aquaculture operations in the oceans include usually cages, nets and moorings. The farmed species, as the energy necessary to grow them, are sourcing elsewhere, so that the only local resource used for farming is the use of space and the seawater. While Article 56 recalls the 'natural resources ... of the waters', as a consequence, aquaculture does not exploit the 'natural resources' of the oceans. However, aquaculture is obviously an economic activity. Therefore, the building of aquaculture installations is covered by Article 60.

As a result, UNCLOS grants States a right to construct aquaculture facilities in their EEZ. Furthermore, the coastal state may ban other states from constructing aquaculture facilities in its EEZ, since aquaculture is not subject to the freedoms 'of navigation and overflight and of the laying of submarine cables and pipelines, and other internationally lawful uses of the sea related to these freedoms'.

Article 60 also specifies some conditions and limitations on the building and operating that are applicable to aquaculture facilities in the EEZ. Around structures, the coastal state may establish reasonable safety zones in which it may take appropriate measures to ensure the safety both of navigation and of the structures. The aquaculture operations have not to interfere with sea-lanes essential to international navigation.

Furthermore, structures have to be removed once they are abandoned or no longer in use. Partial removal is allowable, provided that publicity is given regarding the depth, position and dimensions of any unremoved facilities. This provision has been criticised for being insufficient and requiring a revision in future conventions. Since 1998, the Offshore Installations – Guidelines of the International Maritime Organization require that 'no installations should be placed on any continental shelf or in any EEZ unless the design and construction is such that it makes entire removal upon abandonment or permanent disuse feasible.' However, these guidelines are only recommended for consideration, do not have the status of international law and, therefore, are not binding on states.

Aquaculture facilities are not comparable with oil platforms in size or weigth, thus the removal provisions cannot be applied to them. Therefore, the current legislation needs a revision to better accommodate the specificity of aquaculture operations.

Continental shelf

The continental shelf of a coastal state, according to the principles of the United Nations Convention on the Law of the Sea of 1982, includes the bottom and subsoil of submarine areas that extend beyond its territorial sea through the natural extension of its land territory to the outer edge of the continental margin, or up to a distance of 200 nautical miles from the baselines. However, the external limit of the continental shelf does not exceed the distance of 350 miles from the baselines. The coastal state exercises sovereign rights on the continental shelf in order to explore it and exploit its natural resources, and such activities cannot be undertaken without the express consent of the coastal state. Natural resources are expressly defined as mineral resources and other non-living resources of the seabed and subsoil. The delimitation of the continental shelf between states with opposite or adjacent coasts is established by agreement based on international law, or by mutual agreement in the frame of the UNCLOS.

The extended continental shelf is the zone beyond the 200 nautical mile limit, stretching out to 350 nautical miles of the baseline or 100 nautical miles from the 2500meter isobath. In Mediterranean Sea, the continental shelfs are deriving from mutual agreement between the coastal States, and do not reach such extension.

The exclusive rights to exploit the natural resources in this zone refer solely to 'non-living resources of the seabed and subsoil together with living organisms belonging to sedentary species.'

Thus, beyond the EEZ, the coastal state only has an exclusive right over the resources of the seabed in the area of the Continental Shelf.

When aquaculture takes place in the water bodies above the seabed - as is the common farming method for finfish - a State cannot claim any rights from the provisions regarding the continental shelf. Moreover, the definition of Resources applicable to the Area in Art. 133, refers solely to the seabed, ocean floor and subsoil, and concerning only minerals.

However, Article 80 of UNCLOS provides that 'Article 60 applies *mutatis mutandis* to ... installations and structures on the continental shelf'. This formula, to be intended 'with the necessary changes', imply that the provisions on the continental shelf are of major relevance if a state has not established an EEZ. In that case, it can basically exercise the same rights concerning artificial structures and operations on its continental shelf.

The question is: are the 'necessary changes' enabling the rights relating to aquaculture in the EEZ to apply to the continental shelf as well? There has been no discussion of this subject in literature so far; in practice the problem has not occurred yet. When determining the UNCLOS regime of the continental shelf, the answer is negative. Article 78 determines that:

The rights of the coastal State over the continental shelf do not affect the legal status of the superjacent waters or of the air space above those waters.

In light of the fact that aquaculture operations are not taking place in or on the seabed but rather in the waterbodies above, the rights of other States aiming to construct aquaculture facilities seem not to be restricted. Moreover, the exclusive right to construct installations on the continental shelf derives from the background of oil platforms. Unlike oil drilling, aquaculture does not require any resources of the sea or seabed itself. In this respect, mariculture can be compared to facilities producing energy from the water. However, in contrast to the provisions applying to the EEZ, the Articles on the continental shelf do not provide the specific sovereign right 'for the purpose of ... production of energy from the water'. This aspect is confirmative to the view that a state cannot claim an exclusive jurisdiction on aquaculture sites over the continental shelf.

In conclusion, the coastal state is not granted the exclusive right to build structures in its continental shelf zone, and has no dedicated exclusive jurisdiction. Other states may erect aquaculture sites without the coastal states consent.

High seas

The term 'High Seas' applies to all parts of the sea which are not included in the internal waters, the territorial sea or in the EEZ of a state. In this area, the 'freedom of the high seas' can be exploited. This concept is found in Article 87 of UNCLOS:

The High Seas are open to all States, whether coastal or land-locked. (...) It comprises, inter alia, both for coastal and land-locked States:

- Freedom to construct artificial islands and other installations permitted under international law, subject to Part VI.

Thus, the construction of installations such as aquaculture sites constitutes a part of the freedom of the high seas. However, it does not in any way subject the used part of the seas (where the farm is located) to state sovereignty.

This freedom, however, must comply with the requirement of Article 116 that "*due regard shall be paid to the interest of other states".* Moreover, Articles 117 determines:

"All States have the duty to take, or to cooperate with other States in taking, such measures for their respective nationals as may be necessary for the conservation of the living resources of the high seas."

Considering marine aquaculture, this provision can be interpreted such that operations in the high seas have to be carried out without harming wild stocks.

Environmental control under UNCLOS provisions

UNCLOS also addresses aspects related to environmental law, which are of concern to mariculture. It is intended to conserve the seas as a source of food and to secure them from pollution. With the adoption of UNCLOS, the freedom of polluting the oceans has expired.

Article 118 provide that the States have to ensure that their farming practices do not threaten wild stocks or interfere with their conservation.

The main chapter dealing with issues of the marine environment is Part XII of the convention. The provisions addressing the marine environment contain preventive and oppressive measures, arranged in seven subsections, referring to global and regional cooperation, monitoring and environmental assessment, legislation, enforcement, and safeguards. The subject of protection is the marine environment including "*rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life".* This statement has been interpreted as being an allusion to the precautionary principle, which is based on the assumption that scientific uncertainty should not be used as an excuse for not taking conservation and management measures.

Article 192 imposes an obligation on the parties to protect and preserve the marine environment. Signatory countries are committed to the task of taking all measures necessary to prevent, reduce, and control pollution of the marine environment, using the best techniques necessary within their capabilities. Thus, the convention demands not the same level of measures to be taken by all states.

In respect of the diminished economic and technical possibilities of developing states, it does not request the same efforts as from developed states.

The term 'pollution of the marine environment' is defined in Article 1(4) as:

The introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.

Regarding the impacts of aquaculture, aquaculture operations are able to cause pollution. Thus, the environmental controls of Part XII of UNCLOS require the states to consider the environmental impact of aquaculture operations on the marine environment.

The actions that states shall take must deal with all sources of pollution. Pollution from mariculture sites is not directly addressed in Article 194 since mariculture pollution is not caused by land-based sources or through the atmosphere, and not produced by vessels or by the installations and devices of the nature referred to in Article 194(3)(c) and (d). Aquaculture is also not an activity that falls in the category of 'dumping' as defined in the convention:

(a) *'dumping' means:*
(i) any deliberate disposal of wastes or other matter from ... platforms or other man-madestructures at sea;
(ii) any deliberate disposal of ... platforms or other man-made structures at sea;
(b) 'dumping' does not include:
(i) the disposal of wastes or other matter incidental to, or derived from the normal operations of ... platforms or other man-made structures at sea and their equipment.

Chemical and biological substances that are introduced to waterbodies by aquaculture operations cannot be described as deliberate disposal. In fact, the pollution results principally from feeding, medication, maintaining facilities, excretion of aquaculture organisms and escaping of alien species into habitats, thus incidental during the normal operation of aquaculture sites as stated Article 1(5b)(i).

Cooperation of States in the conservation and management of living resources: *"States shall cooperate with each other in the conservation and management of living resources in the areas of the high seas. States, whose nationals exploit identical living resources, or different living resources in the same area, shall enter into negotiations with a view to taking the measures necessary for the conservation of the living resources concerned. "* However, the enumeration of sources of pollution is not exclusive, and because of the fact that the implementation of offshore aquaculture was not foreseen at the time of the convention's consultation, pollution from installations such as aquaculture operations may be included in the scope of marine environment

protection. Article 196(1) report clearly that: *"states shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto."*

Offshore aquaculture can be considered as a recent technology, so that this provision can be interpreted in a way that states are required to prevent the negative ecological impacts of aquaculture.

According to Article 193, signatory states maintain the sovereign right to exploit their natural resources but they have to do this in a way conform to their environmental policy and their duty to protect the marine environment. The convention recognizes the significance of national environmental policies in the exploitation of natural resources.

Articles 207-213 UNCLOS provide a catalogue of requirements for states to adopt laws and regulations relating to the pollution of the marine environment. The measures are classified according to the different sources of pollution. Article 218 is the sole provision that can be applied to aquaculture.

Article 218: Pollution from seabed activities subject to national jurisdiction:

- *Coastal States shall adopt laws and regulations to prevent, reduce and control pollution of the marine environment arising ... and from artificial islands, installations and structures under their jurisdiction, pursuant to articles 60 and 80*
- *States shall take other measures as may be necessary to prevent, reduce and control such pollution.*
- *Such laws, regulations and measures shall be no less effective than international rules, standards and recommended practices and procedures.*
- *States, acting especially through competent international organizations or diplomatic conference, shall establish global and regional rules, standards and recommended practices and procedures to prevent, reduce and control pollution of the marine ...*

The Article's superscription is misleading when referring only to seabed activities. The diction, however, makes it clear that pollution from aquaculture sites is included in the scope of the provision.

The last paragraph of Article 218 is linked to Articles 197-203, which require states to seek cooperation on a global or regional basis directly or through competent international organisations. The cooperation shall include setting regulatory standards, notification in case of pollution, contingency plans, research and technical assistance to developing states.

Article 214 states that signatory countries shall enforce the laws adopted in accordance with Article 208 and take all the measures necessary to implement the legislation addressing

environment protection. To safeguard the obligations that the convention imposes relating to the preservation of the marine environment, several provisions regarding liability have been adopted. According to Articles 235 and 304, states are 'responsible for the fulfillment of their international obligations' and 'shall be liable in accordance with international law'.

Articles 204-206 deal with the monitoring and environmental assessment of the risks. In particular, states shall keep under surveillance the effects of any activities which they permit, or in which they engage, in order to determine whether these activities are likely to pollute the marine environment.

Conclusions

UNCLOS has been described as being of constitutional character and as a major contribution to the establishment of a legal framework for the protection and preservation of the marine environment. However, several developments since its enactment have not been acknowledged by revision of its provisions. The unforeseen enhancements in science and technology have revealed gaps in that legal regime. The convention is not comprehensive and flexible enough to meet the new challenges raised by mariculture. It focuses on territorial sovereignty, but the sea is an ecosystem that is not delineated by international borders. Thus, the necessity for a more precise and detailed regulation in this respect remains urgent.

Generally, the requirements set by UNCLOS can be described as being often weak and lacking in comprehensive protection of the marine environment. The provisions frequently use terms such as 'shall endeavour', 'promote', or 'in accordance with their capabilities' that leave a wide scope for interpretation and thus do not impose strict obligations, but merely express vague efforts.

Especially when it comes to monitoring and environmental assessment, the convention leaves legislative gaps, when saying that states 'shall ... endeavour, as far as practicable, to observe ... the risks or effects of pollution of the marine environment.' This provision does not address the worries marine aquaculture raises. Offshore aquaculture is a recent development that needs research and monitoring comprehensively. Using new techniques such as genetically modified organisms or introducing unknown problems to the oceans, such as vast amounts of faecal waste resulting from high density of stock, aquaculture requires close and widespread observation and control, a responsibility from which states cannot abdicate. In general, regulatory regimes on monitoring are one of the key issues for international environmental treaties that can display their full potential for ocean conservation. For developing states which are not able to accomplish that task, competent international bodies must be created and granted the respective rights.

2.1.3 Other international Environmental Agreement

Although it is a rather new discipline, having arisen only in the last 100 years, international environmental law now covers a vast range of issues. Treaties dealing with the exploitation of deep sea bed resources to space exploration have been arranged to avert, alleviate or compensate for all matters of environmental mischief.

International environmental law is generally weak in respect to impacts generated at sea by activities as mariculture. The provisions are composed fairly broadly, are unspecific, and do not recognise the special requirements which are necessary to prevent pollution of marine aquaculture, mainly referring to the release of organic matters or chemicals into marine waters. The growing significance of the precautionary principle in international environmental law can be appreciated since this approach perfectly fits mariculture, a development that is too new to predict all its ecological impacts in detail and with scientific proof, but where harm to the oceans due to current production methods seems most likely.

On the other hand, the complex pattern or inter-related impacts of the renewables, ranging from space occupation to energy emissions in waters, are not sufficiently addressed by the international environmental legal framework. The only effective regulation possibility remains connected to the State environmental law application, with regard to its own installations at sea.

The oceans have been described as 'the only truly 'international' area on the planet, representing an expanse beyond the territorial boundaries of all nations'. Thus, it is not surprising that the protection of the seas is a key issue in international environmental law.

A variety of regulatory frameworks concerning aquaculture have been adopted throughout the world. Many countries manage the aquaculture sector through some form of national regulation (eg licensing associated with design, geographic or operational conditions). However, the regulation has been criticised as being often only ad hoc, as an answer to specific problems or concerns, or not being comprehensive enough and neglecting sustainability aspects.

A comprehensive framework which provides security for farmers as well as the tools for aquaculture development and considers other stakeholders' interests sufficiently has not even been achieved in the most developed countries. Considering this, international legislation and its enforcement cannot be overrated. Moreover, international bodies not only play a significant role in enforcement of law but also in its creation. Many treaties have been initiated by the work of international organisations. Because aquaculture is a global issue, a supranational environmental agreement is desirable. Regulation should be carried out at the global level rather than at a regional level to provide the essential consistency of law. States are required to evaluate development strategies consistent with principles of environmental responsibility by raising such issues in international forums. Successful aquaculture regulation involves reconciling the interests of aquaculture participants, the communities in which they are based, and the consumers. Without policy and legal coherence, the development of aquaculture will be thwarted and cannot reach its full potential.

The international environmental treaties have been criticised for generally being unable to provide the necessary monitoring and enforcement tools in practice. International bodies that are assigned that task are incapable of performing it, since they frequently lack a sufficient budget; their duties are not precisely defined. Further, many treaties are not self-executing and thus they depend on the assistance of the parties themselves. However, developing countries are often not equipped

with the technological or financial capacity to successfully enforce environmental regulation by themselves. International organisations are an important factor in filling that gap.

The Stockholm Declaration

The 1972 Declaration of the United Nations Conference on the Human Environment – better known as the Stockholm Declaration121 – states the objectives that environmental law has to cope with:
"States have ... the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

This provision is considered the 'cornerstone of international environmental law'.

Environmental law before the Stockholm Declaration left unprotected gaps: for example, protection of the high seas presented a special problem. Since the high seas are not the territory of any state, harming them did not mean a breach of state responsibility.

The Rio Declaration

The Rio Declaration on Environment and Development of 1992, produced at the 1992 United Nations 'Earth Summit' comprises of 27 principles intended to promote sustainable development around the world. It expressly adopts the precautionary principle and includes the customary obligation not to cause transboundary harm.

Moreover, at the Earth Summit, the Convention on Biological Diversity (CBD) evolved. This is a legally binding instrument committing governments to protecting the earth's biological resources and it affects some elements of aquaculture relating to introductions of alien species and other externalities. As part of its implementation, the Jakarta Mandate of 1995 calls for sustainable mariculture operations and emphasises the importance of incorporating community-based coastal resources management. The recommendations include installing a monitoring programme and preferring local rather than alien species in farming.

Intergovernmental organisations addressing aquaculture

Supranational legal regimes directly addressing the issues related to aquaculture have only be raised in the last 20 years. Since then, the international recognition of the role of institutions and legal systems in controlling, enabling, and encouraging responsible aquaculture has steadily been increasing. Marine aquaculture faces the problem that states have not created an international body or mandated an existing organisation to monitor operations and enforce international environmental

law. Since a large proportion of aquaculture activity takes place in developing countries, an international observation of marine environmental issues becomes even more important.

FAO - The Code of Conduct

The duty to cooperate on a global basis in formulating international rules and standards established by Articles 197-201 in the UNCLOS motivated the creation of the Code of Conduct for Responsible Fisheries (the Code) by the Food and Agriculture Organization of the United Nations (FAO), which was unanimously adopted on 31 October 1995. The Code presents a framework for the regulation of all living aquatic resources. It is voluntary and does not create in itself any legal obligations. In 1997, it was expanded and contains now a section on aquaculture that aims to provide principles and standards applicable to the conservation, management and development of aquaculture activities.

The Code stresses on the precautionary approach in the marine environment and emphasises the growing importance of aquaculture for economies and food security when calling on states to 'consider aquaculture ... as a means to promote diversification of income and diet'. The provisions compel states to promote responsible aquaculture through control and regulatory actions. The Code requires that aquaculture is based on the best scientific information and ecologically sustainable plans that allow the rational use of resources shared by aquaculture and other activities. Specific provisions of the Code address the issue of genetic resources used in aquaculture and requests states to minimise the effects of escaped farmed fish on wild stocks.

In addition to the Code, the FAO has drafted guidelines for aquaculture development. These guidelines have no formal legal status but include suggestions on how to implement Article 9 of the Code in national legislation.

The Code addresses more issues concerning aquaculture than UNCLOS, and in more detail. It deals with a wide range of impacts of aquaculture, including environmental, social and human health aspects. However, the regulation has some gaps. For example, a requirement to monitor genetically modified fish more closely and to notify other states when those species are used in open waters, where the danger of escape is significant, is desirable. Moreover, the Code is mainly concerned with aquaculture in areas under national jurisdiction. Operations in the high seas are thus excluded.

Furthermore, the Code's weakness lies in the fact that it only provides soft law. Since it is not mandatory, the Code is often criticised as being less effective than binding international law. Moreover, the language of the Code is vague and extensive. It is formulated too generally, without providing precise assistance for the implementation into national law.

However, the intention behind the Code was to create a document that can serve as a template for domestic regulation. Especially in countries where environmental legislation is underdeveloped, stakeholders require a starting point to be able to generate local regulations on aquaculture. The

Code acts as a guideline for creating legislation while leaving the freedom which is necessary for implementation in differing ecological, social and economic backgrounds.

Therefore, even if the Code is voluntary, its existence may result in an improvement of quality control in aquaculture operations, since it is 'a powerful motivational force linked to necessity to gain competitive advantage, one form of which resides in product quality assurance'.

Maritime organisations

Several international maritime bodies have initiated frameworks such as codes of practice or resolutions relating to marine aquaculture. The International Maritime Organization (IMO), however, which is a United Nations body acting globally, has not yet implemented legal instruments that deal exclusively with aquaculture. Most intergovernmental organisations concerned with marine jurisdiction are limited to particular regions or subjects.

Regional Fisheries Bodies (RFBs) play an important role in regulating the seas. Some have real management powers and make decisions on allowable catches and technical management measures whereas others have a purely advisory role and promote the collection of statistics, information exchange and scientific analysis. Not all of these organisations have put responsible aquaculture on their agenda, but some attempt to govern their member states' aquaculture activities.

OSPAR

A legislative instrument regulating international cooperation on environmental protection is the Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention), comprising of fifteen signatory nations. The most important measure initiated by OSPAR affecting marine aquaculture is known as PARCOM Recommendation 94/6 on 'Best Environmental Practice for the Reduction of Inputs of Potentially Toxic Chemicals from Aquaculture Use'. Its provisions are generally targeted at measures to reduce the use of toxic substances and chemicals in fish farming, and to limit the disposal of toxic antifoulants to the sea. In 2000, an OSPAR study revealed that these recommendations have not been adopted very successfully. However, in its recent report, the OSPAR Commission reaches the conclusion that there is no need for the development of additional programmes and measures since it regards the marine aquaculture industry as too diverse to apply anything but a case-by-case approach. Thus, OSPAR gives the impression that it has resigned from further promoting the sustainable development of aquaculture.

The Barcelona Convention

Aquaculture is not expressly mentioned within the Barcelona Convention text, and it is not recalled clearly in its Protocols. Nevertheless, being a polluting activity, aquaculture is regulated within the general provision of the Convention, while is not expressly mentioned in the Offshore Protocol, especially addressed to Oil and Gas activities. The most part of Mediterranean Sea is divided, basing on mutual agreement between adjacent coastal States, into areas of Continental

Shelf. In those case, it may be argued that the provisions of art. 80 of the UNCLOS apply, giving to States the right to exploit space and waters for renewables and aquaculture. The ICZM protocol, that should address more specifically the themes of sustainable development and spatial planning in costal areas, is not yet ratified nor in force.

Eco-labelling

Another scheme of implementing, monitoring and enforcing marine environmental regulation is utilising the assistance of non-governmental organizations. NGOs habitually have the ability to focus and direct pressure onto states. They certainly provide a rather cost-effective way of enforcement to the international community. A particularly persuasive method to promote and enforce sustainable aquaculture operations could be eco-labelling.

Eco-labelling means placing a label on a product to inform consumers that the product is less environmentally harmful than similar products, either based on the actual product characteristics, the production and process method used in its manufacture, or both. To be awarded an eco-label, the producer must abide by the respective certification scheme, which usually comprises detailed rules and principles that take into account best farming techniques, optimal feeding regimes, environmental sustainability, welfare of the fish and other issues related to aquaculture.

Such certification of aquaculture products has the potential to significantly improve the sustainability of production practices. Eco-labels are a powerful tool in controlling buyers' demand. There is an increased awareness of sustainability issues among consumers that influences purchase decisions. Certified producers can mark their products with the label, signifying that the products meet the production standards laid down in the certification guidelines. Both fish farmers and the environment can profit from labelling. Producers gain better access to markets and receive price premiums for labelled products whilst incentives for adoption of improved environmental production methods are provided.

Friend of the Sea (FOTS), a small NGO based in Italy, runs a certification programme for sustainable aquaculture. Naturland is a major certifying organisation for organic agriculture and also has a certification scheme for organic aquaculture. The Soil Association is a UK-based organization which campaigns for and certifies organic agriculture. Other certification methods have not adopted sustainability as the baseline but best practices in general. The Global Aquaculture Alliance (GAA) is the primary global trade association that certifies aquaculture production and processing facilities with the label 'The Best Aquaculture Practices Certified (BAP Certified)'.

However, these schemes can only be seen as a starting point since they require improved elaboration to meet all concerns related to the negative impacts of aquaculture. They are merely representing particular stakeholder interests, lack in transparency and propose weak ecological and socioeconomic standards. Furthermore, they usually focus on particular species, leaving consumers confused.

The World Wildlife Fund (WWF) launched The Aquaculture Stewardship Council (ASC) in 2011, which has created an eco-label for farmed seafood as well. Its aim is to draft standards for responsible, sustainable aquaculture for twelve aquaculture species. With over 2000 participants in the Aquaculture Dialogues, ranging from scientists to governments and NGOs, it ensures the best possible stakeholder participation. Thus, the eco-label has the potential to be applied and accepted by both producers and consumers of aquaculture products.

Conclusion

The consensus is that aquaculture is an activity with a remarkable potential for human benefit. However, a healthy environment is essential to the wellbeing of the human population. With 71 percent of the earth covered by oceans, it is obvious that preserving the seas is vital to achieve that goal. Therefore, instruments have to be found to facilitate aquaculture development in a way that respects the competing concerns. There are no perfect solutions to the tensions surrounding aquaculture. Since aquaculture operations occur in diverse modes, that creates particular difficulties when drafting regulations or guidelines which meet the requirements of all the stakeholders. A regime is required that allows the industry to prosper and, at the same time, safeguards the wild stocks in order to preserve the social and economic benefits. The aim is finding a balance between aquaculture development and environmental protection. Adequate legal and policy frameworks on an international level are an effective ingredient to act as a compass in aquaculture development. Certainly, that is not an easy task, but if it is done well, it could help to safeguard marine resources for future generations.

2.1.4 European legislation

The EU environmental assessment legislation describes the minimum requirements that a Member State must meet when drawing up a plan or program, and may require to a developer within the entire life cycle of a project. The information that must be provided is determined precisely by the national laws and the conventions that the country has signed.

The EU has several relevant Directives concerning:

- European Framework Directive Marine Strategy (MSFD)– EU Directive n ° 2008/56 / EC, to achieve the good ecological status of all marine waters by 2020.
- Habitats Directive n ° 92/43 / EEC; Bird Directive n. 147/2004, for the conservation of nature and the protection of specific species and habitats.
- The Environmental Strategic Assessments / SEAs Directive 2001/42 / EC. This Directive requires the authorities that draw up a plan or program to draw up an environmental impact report (indicating the likely significant environmental effects and reasonable substitutes) and to hold consultations. (The public, environmental authorities and other Member States in cases of significant transboundary impacts). The Environmental Impact Report and the results of the consultations are taken into account before the adoption of the plan or program. Once adopted, the environmental authorities, the public and any Member State consulted shall be informed and the relevant information made available to them.
- The Environmental impact assessments / EIA Directive 85/337 / EEC, repealed and replaced

by EU Directive 2011/92 of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment. This directive provides in particular that projects likely to have significant effects on the environment, in particular by reason of their nature, size or location, shall be subject to an application procedure for self- and an assessment of their impact ". This Community legislation is transposed in France through the provisions of the Environmental Code relating to impact studies. In order to determine the anticipated adverse effects as early as possible and to evaluate the intensity of the expected effects, it is necessary to monitor the significant environmental impact at all scales.

- The amended Environmental Impact Assessment (EIA) Directive (2014/52/EU) entered into force on 15 May 2014, at the aim to simplify the rules for assessing the potential effects of projects on the environment. Being in line with the drive for smarter regulation, it reduces the administrative burden, and also improves the level of environmental protection, with a view to making business decisions on public and private investments more sound, more predictable and sustainable in the longer term. The new approach pays greater attention to threats and challenges that have emerged since the original rules came into force some 25 years ago, in areas like resource efficiency, climate change and disaster prevention, now better reflected in the assessment process. The main amendments are as follows:

1. Member States now have to simplify their different environmental assessment procedures.
2. Timeframes for the different stages of environmental assessments. Screening decisions within 90 days and public consultations not less than 30 days.
3. The screening procedure is simplified
4. EIA reports to be produced more understandable for the public, especially as regards assessments of the current state of the environment and alternatives to the proposal.
5. The quality and the content of the reports will be improved.
6. The grounds for development consent decisions must be clear and more transparent for the public.

In case projects can have significant adverse effects, developers will be obliged to do the necessary to avoid, prevent or reduce such effects. Projects have to be monitored, and existing monitoring arrangements may be used to avoid duplication of monitoring and unnecessary costs.

2.1.4.1 The ecosystem approach within European policy

At EU level, while the Treaties governing the establishment and functioning of the EU do not explicitly mention the ecosystem approach, it is referred to implicitly and can be implemented through a number of policies and legal instruments. At policy level, for example, this includes the Integrated Marine Policy (IMP), where the Commission has recommended that national policies should be guided by the principles of subsidiarity, competitiveness, sustainable economic development, stakeholder participation, and the ecosystems approach (COM (2008) 395 final). Legally the ecosystems approach finds its basis in both the MSFD and the CFP.

The MSFD seeks to implement the environmental aspects of the IMP and consequently a key focus of that legislation is to manage human activities that impact upon marine ecosystem, to protect and conserve biodiversity and ensure sustainable development of marine resources. The

MSFD also refers to adaptive management to facilitate a more flexible approach to managing activities that may impact on the quality of the marine environment and growing evidence from both science and impacts experienced. In practice, and according to the Preamble of the Directive, this means by applying an ecosystem-based approach, priority should be given to "achieving or maintaining good environmental status in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration" (Recital 8). Article 1(3) reiterates this by providing that the marine strategies put forward by Member States will apply an ecosystem-based approach to the management of human activities, "ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status." This links to Annex VI of the MSFD and specifically the spatial and temporal distribution controls, to be included in Member States' programme of measures, that influence where and when an activity is allowed to occur. Other EU legal instruments, in particular the nature conservation legislation (i.e. the Birds and Habitats Directives), that enable the creation of protected sites will also contribute to implementing the ecosystems approach as envisaged by the MSFD.

In the context of the Common Fishery Policy, in 2008 the Commission published a Communication on the role of the CFP in implementing an ecosystem approach to marine management (COM (2008) 187). This does not mention aquaculture explicitly, but the Communication explains the Commission's position in relation to the ecosystem approach by stating that it seeks to ensure goods and services from living aquatic resources for present and future generations within meaningful ecological boundaries (EC, 2008b: 3). This means in practice that aquaculture, and fisheries management should not be detrimental to future functioning, diversity and integrity of marine ecosystems.

The Communication stresses that an ecosystem approach to managing marine waters "cannot and should not be implemented in a specific sector alone, but must be cross-sectoral", referring to the aforementioned instruments (IMP, MSFD, Habitats Directive) in assisting with implementation. Reform of the CFP aims to ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food and focuses on four policy areas: fisheries management, international policy, market and trade policy; and funding of the policy through the EMFF, (Regulation (EU) No 508/2014). Each of these policy areas can contribute to the implementation of an ecosystem approach. Fisheries management measures, for example, deal with catch limits between 2015 and 2020 and aim to sustain fish stocks in the long term. This also contains measures relating to making fishing fleets more selective in what they catch and to phase out the practice of discarding unwanted fish and in that way recognises the impact of fishing activity on all components of the ecosystem. In an aquaculture context, explicit responses to the ecosystem approach are not so clear-cut, but are implied by the application of EIA, for example. Under EIA applicants for an aquaculture site licence should undergo a process of investigation and data collection to determine possible environmental (and social) risks associated with the aquaculture development (including local cumulative effects), and provide mitigation or means to offset possible impacts, prior to an application being approved. There is consideration of local ecosystems on a site-by-site basis (or perhaps within a small-scale area) but at present little

over-arching strategy that promotes integrated thinking at the zonal or area management scale that is fundamental to the ecosystem approach.

2.1.4.2 Integrated Maritime Policy and Sea-basin strategies

In 2007, the EC published an Integrated Maritime Policy (IMP) for the European Union (COM (2007) 575). This explicitly recognises that "all matters relating to Europe's oceans and seas are interlinked, and that sea-related policies must develop in a joined-up way if we are to reap the desired results" (EC, 2007: 2). In light of this, sectoral management is no longer appropriate. The IMP sought to instigate more integrated maritime governance with the necessary cross-sectoral tools for implementation. The IMP concentrated on:

- Maximising the sustainable use of the oceans and seas;
- Building a knowledge and innovation base for the maritime policy;
- Delivering the highest quality of life in coastal regions;
- Promoting Europe's leadership in international maritime affairs; and
- Raising the visibility of maritime Europe.

Subsequent actions at EC level have tended to focus on the above themes. The IMP also has a number of cross-cutting policies within it including those on integrated maritime surveillance; marine data and knowledge; sea basin strategies and Blue Growth. To date six-sea basin strategies have been developed, covering the Baltic Sea, Black Sea, Mediterranean Sea, North Sea, the Atlantic and the Arctic Ocean. These specific strategies exploit the strengths and address the weaknesses of each large sea region in the EU. In the Atlantic Area, for example, the Strategy (COM (2011) 782) grouped the challenges and opportunities into five themes: implementation of the ecosystem approach; reduction of Europe's carbon footprint; sustainable exploitation of seafloor natural resources; emergency response; and socially inclusive growth (EC, 2011). A subsequent Action Plan was adopted in May 2013 (COM (2013) 279) which seeks to deliver the over-arching objectives of the strategy as well as contribute to Blue Growth in France, Ireland, Portugal, Spain and the United Kingdom. This has four priority areas: promote entrepreneurship and innovation; protect, secure and develop the potential of the Atlantic marine and coastal environment; improve accessibility and connectivity; and create a socially inclusive and sustainable model of regional development (EC, 2013d). The Action Plan recognises aquaculture under priority 1 in relation to improving skills in the industry and supporting the reform of the CFP, which was underway at that time.

2.1.4.3 MSFD Application

Background to the Marine Strategy Framework Directive (MSFD)

The MSFD was developed in response to concerns that although existing legislation protected the sea from some specific impacts, it was largely sectoral and fragmented. There was also recognition that since some of the activities that impact on the marine environment are managed at a European or international level (e.g. fisheries and shipping) and other impacts can cross national boundaries (e.g. litter, eutrophication, noise), national action to protect the marine environment

needs to be supported by a framework to ensure action is taken across Europe.

The MSFD requires Member States to put in place the necessary management measures to achieve GES (good ecological status) in their marine waters by 2020. GES involves protecting the marine environment, preventing its deterioration and restoring it where practical, while using marine resources sustainably. The Directive is wide-ranging and sets out 11 descriptors of GES.

MSDF descriptors of GES

7. Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions ("Descriptor 1" or "D1").
8. Non-indigenous species (NIS) introduced by human activities are at levels that do not adversely alter the ecosystems ("Descriptor 2" or "D2").
9. Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock ("Descriptor 3" or "D3").
10. All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity ("Descriptor 4" or "D4").
11. Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters ("Descriptor 5" or "D5").
12. Sea floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected ("Descriptor 6" or "D6").
13. Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems ("Descriptor 7" or "D7").
14. Concentrations of contaminants are at levels not giving rise to pollution effects ("Descriptor 8" or "D8").
15. Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards ("Descriptor 9" or "D9").
16. Properties and quantities of marine litter do not cause harm to the coastal and marine environment ("Descriptor 10" or "D10").
17. Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment ("Descriptor 11" or "D11").

Aims of the Directive

The overarching aim of the Directive is for Member States to put in place measures to achieve Good Environmental Status (GES) in their marine waters by 2020. Member States must develop Marine Strategies for their waters consisting of: an initial assessment of their marine waters; characteristics, targets and indicators of GES; monitoring programmes for measuring progress towards GES, and; programmes of measures to achieve or maintain GES.

The Directive came into force on 15 July 2008 and was transposed into UK law by the Marine

Strategy Regulations 2010.

MSFD, 2008/56/EC Article 3(5) – Good Environmental Status means the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations. A fuller description is set out at MSFD, 2008/56/EC Article 3(5).

The aims of the Directive are to:

1- Protect and preserve the marine environment prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected;

2- Prevent and reduce inputs in the marine environment, with a view to phasing out pollution, so as to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea.

Member States must apply an ecosystem-based approach to the management of human activities. In this context this means ensuring that the collective pressure of human activities is kept within the levels compatible with the achievement of GES, ensuring that the capacity of the marine ecosystem to respond to human-induced changes is not compromised, whilst enabling the sustainable use of the marine environment now and in the future.

The aims of the Directive are to be delivered through the development of marine strategies covering the following elements (Figure 1):

a) An Initial Assessment of marine waters analysing the essential features, characteristics and environmental status of those waters (by July 2012, with subsequent assessments carried out on a six-yearly basis);
b) Determination of a set of characteristics for GES, based on the 11 GES Descriptors set out below (by July 2012, reviewed on a six-yearly basis);
c) Establishment of comprehensive environmental targets and indicators to guide progress towards achieving GES (by July 2012, reviewed on a six-yearly basis);
d) Establishment and implementation of a coordinated monitoring programme for the ongoing assessment of GES (by July 2014, reviewed on a six-yearly basis);
e) Development of a programme of measures designed to achieve GES by 2020 (by Dec 2015, reviewed and revised on a six-yearly basis);
f) Implementation of the programme of measures described above (by Dec 2016, reviewed on a six-yearly basis).

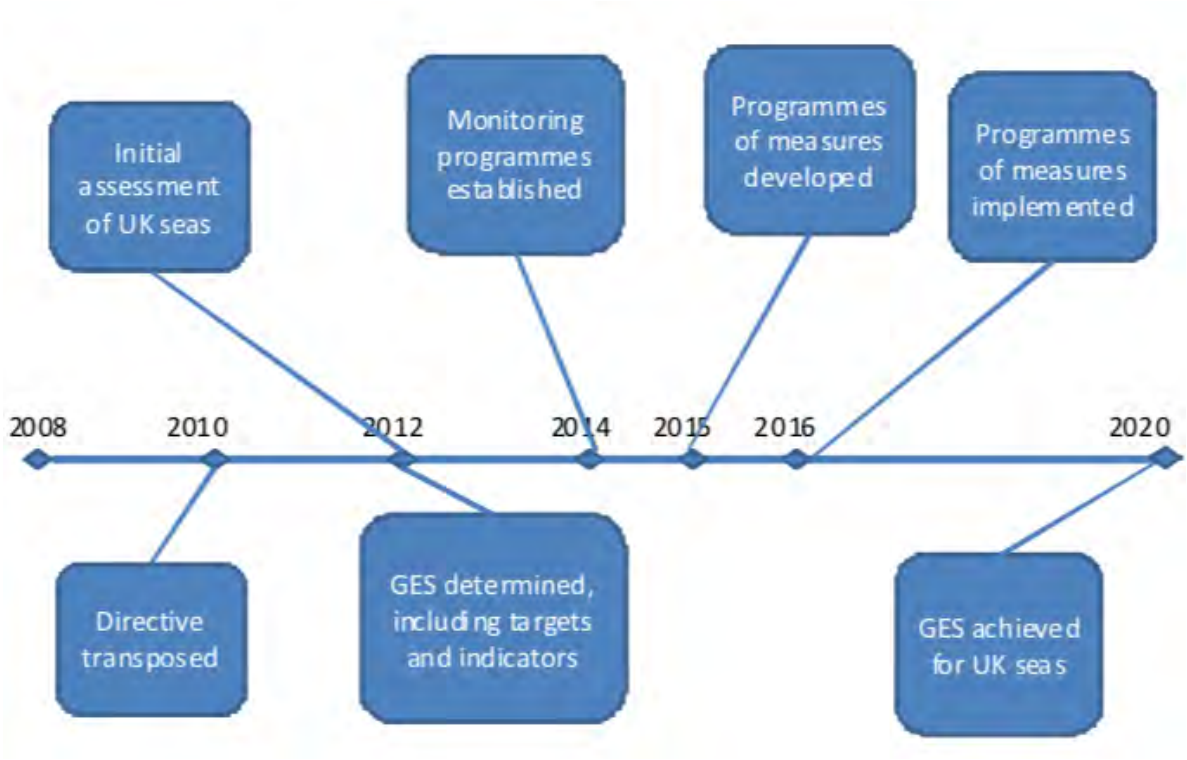


Figure 1: Key stages in MSFD implementation process

Each stage of the marine strategy must be reviewed every six years and revised if necessary. The monitoring programmes presented in this strategy are for the first period from 2014 to 2020. Where appropriate, they will be updated to take account of new developments and knowledge.

GES is defined in the Directive as follows: 'Good Environmental Status means the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations.

2.1.4.4 Aquaculture

In February 2013, the plenary session of the European Parliament approved the Commission proposal of 2011 on the Reform of the Common Fisheries Policy, the Regulation being approved in December of the same year. On April 29, 2013, the Commission Communication was published containing the Strategic Guidelines for the Sustainable Development of Aquaculture of the European Union, which were written based on the outcome of the consultations with interested parties. The guidelines are organized around four priority axes: i) simplification of administrative procedures; ii) coordinated spatial planning; iii) strengthening competitiveness and iv) promoting fair competition conditions.

As reflected in the Strategic Guidelines for the Sustainable Development of Aquaculture of the European Union (hereinafter, the guidelines), aquaculture is one of the pillars of the EU strategy on

blue growth and contributes to the achievement of the Strategy Europe 2020, in terms of smart, sustainable and inclusive growth precepts.

On the other hand, the Integrated Marine Policy (IMP) was created with the intention of coordinating sectoral policies in the marine-maritime field: i) blue growth; ii) knowledge and data of the sea; iii) maritime space management; iv) integrated maritime surveillance and v) maritime basin strategies.

Following the approval of the proposal for the reform of the Common Fisheries Policy in December 2013, the Commission proposed a new fund for maritime and fisheries policies in the 2014-2020 period: the European Maritime and Fisheries Fund (FEMP), which After numerous modifications it was approved by Parliament in April 2014 and published on May 20. For the purpose of greater coordination, the Commission asks the Member States to prepare the respective Multi-Annual National Strategic Plans (PENP) based on the proposed guidelines. PENPs must be sent no later than the National Operational Programs. The Common Strategic Framework (MEC) is the legal framework that establishes common provisions for the use of these European funds designed for the development of the Europe 2020 Strategy in the 2014-2020 period, including the FEMP.

2.1.4.5 Guidelines on environmental impact

Several documents have been produced by governments, providing specific information on assessment processes and methods for monitoring environmental impacts. Here are some examples:

- UN Environment (2018). Assessing Environmental Impacts- A Global Review of Legislation, Nairobi, Kenya.
- Guidelines for the conservation of nature in the development of offshore wind farms - United Kingdom - DEFRA 2005
- Consolidated guidance on environmental considerations for the development of offshore wind farms - OSPAR 2008
- Guidelines on wind energy development and the requirements of nature conservation in the EU - European Commission 2010
- Guidance document on aquaculture activities in the Natura 2000 Network -European Commission, 2012

2.1.4.6 The european strategy on energy

European energy policy has been shaped through different directives that affect the improvement of energy efficiency and specifically, energy efficiency in buildings, the promotion of renewable energy and the reduction of greenhouse gas emissions.

The renewable energy objectives were defined in Directive 2009/28 / EC10 concerning the promotion of the use of energy from renewable sources.

This Directive aims to establish a common framework for the production and promotion of energy from renewable sources. It sets, for each Member State, an objective relating to the share of energy obtained from renewable sources in gross final energy consumption by 2020. This objective is in line with the EU's '20-20-20' overall objective.

On the other hand, before 2020, the share of energy from renewable sources in the transport sector must reach at least 10% of the final energy consumption in this sector. Likewise, sustainability criteria are established for biofuels to account for the objective of 10% renewable in transport.

The Directive also provides that the Member States must establish a national action plan for 2020 that determines the share of energy from renewable sources consumed in transport, electricity and heat production. These plans of action should take into account the effects of other measures related to energy efficiency in final energy consumption (the most important is the reduction of energy consumption). These plans must establish modalities to reform planning and charging regulations, as well as access to electricity networks, in favour of energies generated from renewable sources.

2.1.4.7 European Landscape Convention

The European Landscape Convention was opened for signature in Florence, Italy, on 20 October 2000 in the framework of the Council of Europe Campaign "Europe, a common heritage". It was written by a Group of Experts in which the main international governmental and non-governmental organisations concerned were involved; the Committee of Ministers of the Council of Europe adopted the final text of the Convention on 19 July 2000.

The Convention's purpose is to promote landscape protection, management and planning of European landscapes and to organize European co-operation on landscape issues.

It represents the first international treaty to be exclusively concerned with protection, management and enhancement of European landcape.

It is extremely wide in scope: the Convention applies to the Parties 'entire territory and covers natural, rural, urban and peri-urban areas, which include land, inland water and marine areas.

It deals with everyday or degraded landscapes as well as those that can be considered outstanding. In other words, it recounts the importance of all landscapes, and not just of exceptional landscapes, as having a crucial bearing on quality of life and as deserving attention in landscape policy.

A key aspect of the Convention is the active role it assigns the public as regards perception and evaluation of landscape. Awareness raising is therefore crucial in order to involve the public in decisions affecting the landscape in which they live.

<u>International cooperation</u>

The Contracting Parties undertake to engage in European cooperation on the consideration of the landscape dimension of international policies and programs, and to recommend, where relevant, the inclusion in them of landscape considerations. They also undertake to cooperate in technical and scientific matters, to exchange landscape specialists for information or training purposes and to exchange information on all matters covered by the Convention.

There is a provision on border landscapes. The Contracting Parties undertakes to encourage transfrontier cooperation on local and regional level and, wherever necessary, to prepare and implement joint landscape programs.

National measures

In accepting the Convention's principles and objectives, the Contracting Parties, respecting the principle of subsidiarity, undertakes to protect, manage and / or plan their landscapes by adopting a range of general and special measures. This entails promoting participation of communities and public authorities in decisions affecting the landscape of the region or locality.

General measures

1. Recognition of landscapes in law as an essential component of people's surroundings, an expression of the diversity of their shared cultural and natural heritage, and a foundation of their identity.
2. Establishment and implementation of landscape policies aimed at landscape protection, management and planning.
3. Establishment of procedures for participation by the general public, local and regional authorities and other parties with an interest in the definition and implementation of landscape policies.
4. Integration of landscape into regional and town planning policies, and in its cultural, environmental, agricultural, social and economic policies, as well as in any other policies with possible direct or indirect impact on landscape.

Specific measures

1. Alerting civil society, private organizations and public authorities to the value of landscapes, their role and changes in them.
2. Promoting training for specialists in landscape appraisal and operations, multidisciplinary training programs in landscape policy, protection, management and planning for professionals in the private and public sectors and for associations concerned, and school and university courses which, in the relevant subject areas, address the values attaching to landscapes and the issues raised by their protection, management and planning.
3. Enlisting the help of all interested parties to improve knowledge of landscapes and to ensure that identification and assessment procedures are guided by exchange of experience and methodology between the Contracting Parties at European level.
4. Defining quality objectives for the landscapes identified and assessed, after public consultation.
5. Putting landscape policies into effect by introducing instruments aimed at protecting, managing and / or planning the landscape.

2.2 ENVIRONMENTAL LEGAL FRAMEWORK

France is an EU Member State having a coastline on the Atlantic Ocean, Channel, North Sea and the Mediterranean Sea basin, for a total extension of 8411 km. When the overseas territories are included, its Exclusive Economic Zone extends 11 million square kilometers, making it the second largest Exclusive Economic Zone in the world.

For the implementation of relevant EU legislation, maritime regions have been organised as follows:

- East Channel-North Sea: includes the coastal areas of regions Haut-de-France and Normandy and the maritime areas under French sovereignty and jurisdiction bordering these regions;
- North Atlantic-West Channel: includes the coastal areas of regions Pays de la Loire, Brittany and the maritime areas under French sovereignty and jurisdiction bordering these regions;
- South Atlantic: includes the coastal areas of Nouvelle-Aquitaine and the maritime areas under French sovereignty and jurisdiction bordering this region;
- Mediterranean: includes the coastal areas of Occitanie, Provence-Alpes-Côte d'Azur, Corsica and the maritime areas under French sovereignty and jurisdiction bordering this region.

Figure 2: France maritime regions

2.2.1 The national strategy for the sea and the coastal - application of the Directive "MSFD"

The transposition of the "MSFD" Directive into French law is carried out by the establishment of Marine Environment Action Plans (PAMM) (art L 219-9 of the Environment Code introduced by the law of 12 July 2010), which is the environmental component of future strategic front-line documents created by art. L 219-3 of the same code and which, on the scale of each Façade, decrees the objectives of the National Strategy for the Sea and the Littoral (art L 219-1).

Developed under the responsibility of the maritime and regional Prefects, these action plans for the marine environment must include the following elements: (i) an initial assessment of the state of the marine subregion, (ii) a definition of the good ecological status of the subregion, to be achieved by 2020, (iii) the setting of environmental objectives, (iv) a monitoring program and a program of measures.

These Marine Environment Action Plans (PAMM) include:

- an analysis of the specificities and characteristics essential characteristics and of the ecology of these waters,
- an analysis of the main impacts and pressures, particularly due to human activity, on the ecological status of these waters,
- An economic and social analysis of the use of these waters and the cost of degradation of the marine environment.

The PAMM must be developed on the basis of broad consultations with maritime and coastal stakeholders. This concertation is carried out in particular within the Maritime Council of the Façade (CMF), which also integrates the public institutions in charge of the sea and the coast, the nature protection associations and the users of the environments. It is followed by a public consultation, in which every citizen can participate.

The law of 12 July 2010 provides an integrated national strategy for the sea and coastline (SNML). This document is intended to federate sectoral policies in the fields of fisheries, environment, industry, energy and transport. Maritime Façade will break down this strategy through a strategic front-end document (DSF). The prefect of the Provence-Alpes-Côte d'Azur region and the maritime prefect of the Mediterranean are jointly responsible for ensuring the development, adoption and implementation, in consultation with the Counseil Maritime de Façade.

All the components of the PAMM of the Western Mediterranean Marine Subregion have been completed and approved:

- Inter-prefectoral decrees approving elements 1 (initial assessment) and 3 (environmental objectives) were taken on 21 December 2012;
- The definition of good ecological status was developed at the national level and approved by the ministerial decree of 17 December 2012;
- The inter-prefectoral decree approving the monitoring program of the PAMM was taken on June

3, 2015;
- The inter-prefectoral decree approving the program of measures of the PAMM was taken on April 8, 2016.

The environmental objectives are intended to establish the necessary conditions and to guide efforts to achieve or maintain the good ecological status of the waters of the Mediterranean Marine Subregion. They are included in the program of measures which was approved on April 8, 2016.

The environmental objectives of the PAMM of the "Western Mediterranean" Marine sub-region are structured by the eleven descriptors of good ecological status specified in Annex I of the MSFD.

They are divided into 13 general environmental objectives, divided into 3 categories:

- Objectives related to ecological status;
- Objectives related to the reduction of pressures on the marine environment;
- Cross-cutting objectives, necessary for the full achievement of several objectives or meeting.

2.2.2 Application of the Strategic Environmental Assessment (SEA) Directive

The Directive has been transposed into French law in various codes: for the environment, Articles L. 122-4 to L. 122-11 and R. 122-17 to R. 122-24 of the Environment Code; for urban planning, Articles L. 121-12 to L. 121-15 and R. 121-14 to R. 121-17 of the Town Planning Code, L. 4424-13, L. 4433- 7, R. 4424-6-1, R. 4433-1 and R. 4433-1-1 of the general code of territorial collectivities.

The environmental assessment of plans or programs includes an environmental report which, under the terms of Article L. 122-6 of the Environmental Code identifies, describes and evaluates the significant effects that the implementation of the plan may have. This report presents the measures planned to reduce and, to the extent possible, offset the significant negative impacts that the implementation of the plan may have on the environment. It sets out the alternative solutions envisaged and the reasons why, in particular from the point of view of environmental protection, the project has been selected.

The development of marine renewable energies has been the subject of two calls for tenders by the “Commission pour la Regulation de l’Energie (CRE)” for offshore wind energy (launched under the Energy Code), coupled with calls for expressions of interest for offshore wind turbines. The tenders have not been submitted to the Strategic Environmental Assessment required for national plans and programs. Initial assessments under the MSFD were not available at the time of the launch of the first two wind tenders. In the future, the linkage between these strategic documents and the development of renewable energies at sea is called for to be strengthened.

2.2.3 Application of the Environmental Impact Assessment (EIA) Directive

This Directive is transposed into French law in Article R122-2 of the Environment Code created by Decree No. 2011-2019 of 29 December 2011, which specifies that any project belonging to the

category of installations and works on "Energy" and sub-category No. 27 "Offshore installations for the production of energy" is subject to an impact study.

In the case of significant negative impacts on marine biodiversity, IUCN France reiterates the importance of respecting the "avoid / reduce / compensate" sequence, in order to design projects that have the least impact on the environment. The implementation of the sequence is hierarchical: priority is given to avoiding impacts; if they cannot be avoided, measures are taken to reduce them; Lastly, any significant residual impacts that could not be avoided or reduced must be compensated (as a last resort).

The "avoid / reduce / compensate" sequence is described in the EIA Directive, which requires developers to describe the measures envisioned to avoid, reduce and, if possible, offset the significant adverse environmental effects of the project. The environmental impact assessment of the project (in the Environmental Impact Assessment report, for example).

The Ministry of Ecology also published guidelines in October 2013 to clarify the application of the "avoid / reduce / compensate" sequence.

In France, several supporting documents have also been issued:

1) MEDDE (DGEC) published in 2012, is a methodological study on the environmental and socio-economic impacts of renewable marine energies.
2) France Energies Marines is coordinating an environmental impact assessment guide for marine tidal technologies (GHYDRO project)
3) The MERiFIC Project has produced a documentary synthesis of the environmental impacts of renewable marine energies, September 2012
4) Ifremer has published a protocol for carrying out impact studies and monitoring projects for sites for implementing renewable energy at sea, with numerous recommendations
5) The EU Project “Atlantic Power Cluster” brings together players from Ireland, Spain, France, Portugal and the United Kingdom and aims to sustainably develop the renewable energy potential of the coastal and marine environment in these regions.
6) CEREMA, 2018 - Évaluation environnementale - Guide d’aide à la définition des mesures ERC.
7) MEEM, « Guide d’évaluation des impacts sur l’environnement des parcs éoliens en mer », Direction Générale de l’Energie et du Climat (DGEC), 2017.
8) MEDDE, 2017 - Évaluation environnementale - Guide de lecture de la nomenclature des études d’impact (R.122-2)

2.2.4 Application of the Habitats and Bird Directive

The Natura 2000 network consists of designated sites for the conservation of certain bird species (1979 "Birds Directives") and the conservation of natural habitats and other species ("Habitat" Directives of 1992). The French Natura 2000 offshore network currently covers an area of 4.1 million hectares with 207 sites (148 mixed and 59 fully marine). It aims to build a coherent network

with regard to the challenges of safeguarding the region's biodiversity, as required by European legislation. It must be completed in particular by designations of further offshore sites.

2.2.5 The Law of the Coast

According to Articles L.321-2 and R.321-1 of the French Environment Code, "coastal municipalities and overseas departments bordering the seas and oceans are considered coastal municipalities", as well bordering salt ponds, inland water bodies with a surface area greater than 1,000 hectares', but also those set out in Article R.321-1 of the Code.

Faced with the increasing concentration of activities and the urban development of coastal regions, the Littoral law (1986) sets four objectives:

- Preserve rare, sensitive spaces and maintain ecological balances;
- Economically manage the consumption of space due to urbanization and tourism development;
- Open the shoreline wider to the public;
- To give priority to coastal activities that are linked to the sea.

2.2.6 The development of renewable energy

In line with the European energy policy, France has launched a program to combat climate change.

The law n ° 2009-967 of August 3rd, 2009, relative to the implementation of the Grenelle of the environment (Grenelle I), envisaged in its article 2 that France carries "the share of the renewable energies to at least 23% of its final energy consumption by 2020 ". Recently, Law No. 2015-992 of 17 August 2015 on the Energy Transition for Green Growth has set the following objectives:

- Reduce greenhouse gas emissions by 40% between 1990 and 2030 and divide by four by 2050 (factor 4);
- Reduce final energy consumption by 50% in 2050 compared to 2012 and bring the annual rate of decline in energy intensity to 2.5% by 2030;
- Increase the share of renewable energies to 23% of gross final energy consumption in 2020 and 32% of this consumption in 2030; on this date, to achieve this objective, renewable energies must represent 40% of electricity production, 38% of final heat consumption, 15% of final fuel consumption and 10% of gas consumption. (Article L.100-4 4 ° of the Energy Code);
- Reduce fossil fuel consumption by 30% in 2030 compared to 2012.

This law defines the energy needs of France in the medium and long term, as well as the necessary means of energy production. It foresees that these needs will be included in the Multiannual Energy Program (EPP), adopted by decree.

Decree No. 2016-1442 of 27 October 2016 on multiannual energy programming sets 2023

objectives for marine renewable energies, with 3100 MW of installed capacity and 700 to 8000 MW of allocated projects. more. Within this objective, the floating wind turbine and the tidal turbine must represent 100 MW of installed power and between 200 and 2000 MW of projects allocated in addition, according to the feedback of the pilot parks and under price conditions.

In 2017, four development Project on Floating Wind Farms have been allocated, for a total capacity of 24 MW:

- "Provence Grand Large", composed by 3 wind turbines of 8 MW each. Project is developed by EDF EN, using Siemens wind turbines and a floating structure developed by SBM/IFPEN. The site is at Faraman, Mediterranean Sea.
- "Eolienne Flottantes Golfe du Lion", composed by 4 wind turbines of 6 MW. The project is developed by Engie/EDPR/CDC, using GE turbines and a floating structure by Eiffage/PPI. It is located at Leucate, Mediterraean Sea.
- "Eolienne Flottantes de Groix", located at Groix, Brittany. Developed by Eolfi/CGN, with turbines manufactured by GE and a floating structure developed by DNCS and VINCI.
- "Eolmed", located at Gruissan, Mediterraean Sea. The Project is developed by Quadran, using Senvion wind turbines and a floating structure developed by Bouygues Travaux Publics and Ideol.

2.2.7 The development of aquaculture

The implementation of regional schemes for the development of marine aquaculture (SRDAM) is carried out in application of article L 923-1-1 of the rural and sea fishing code, introduced by the law of modernization of the 27 July 2010. This article provides that, in each region of the metropolitan littoral, existing sites and sites favourable to the development of marine aquaculture (shellfish farming, marine finfish farming and other marine culture) should be identified.

The expected objective of the approach is to enable the development of sectors that are currently hampered in their development and in difficult economic situations. This development is intended to be based on the identification of suitable areas, based on a minimum consensus between all the stakeholders concerned.

These schemes, once approved by order of the regional prefect, must be taken into account during the appraisal of management acts relating to authorizations for the exploitation of marine crops by the Departmental Direction of the Territories and the Sea (DDTM). They are also intended to be taken into account when preparing the Facade Strategic Document (FSD), a tool for implementing the national integrated maritime policy.

The Interregional Directorate for the Sea (DIRM) Mediterranean is in charge, under the authority of each prefect of coastal region, of the development and updating of the three regional schemes concerning the Mediterranean.

In application of the aforementioned law, the development of SRDAM must be based on consultation with elected representatives of local authorities, representatives of public institutions and professionals concerned, as well as qualified personalities chosen because of their expertise in environment protection and use and development of the sea and coastline.

Regional scheme for the development of marine aquaculture in Provence-Alpes-Côte d'Azur

The regional development plan for marine aquaculture in Provence-Alpes-Côte d'Azur was validated on December 10, 2015 by order of the prefect of the Provence-Alpes-Côte d'Azur region.

This scheme will have to be taken into account during the appraisal of the management acts relating to authorizations for the exploitation of marine crops by the departmental directorates of the territories and the sea. It is also intended to be taken into account when drawing up the Facade Strategic Document, a tool for implementing the National Integrated Maritime Policy.

The method adopted for the elaboration of the three regional drafts Mediterranean plans (Provence-Alpes-Cote d'Azur, Languedoc-Roussillon and Corsica) was based on six successive phases, prior to their adoption by the regional prefect:

- Collection of information and data from state services (existing sites) and professionals (proposals for suitable sites);
- Elaboration of a project for a directory of existing sites and a project of a directory of suitable sites;
- Regional meetings of work between departments of the State, professionals or their representatives, local authority regional;
- Consultation of services, public institutions, professionals and local authorities;
- Consultation meeting with stakeholders (local authorities, public institutions, professionals, civil society);
- Aassage in maritime board of facade and making available to the public

For the Provence-Alpes-Côte d'Azur region, in addition to the working meetings and the written consultation phases, consultation meetings were organized at the end of 2014 and the beginning of 2015 in each of the three coastal departments, involving municipalities, public institutions inter-municipal co-operation and main concerned managers, the County Councils, the Regional Council, the public services and establishments of the State as well as the representatives of the professionals of the fishing and the aquaculture.

These meetings made it possible to better take into account certain stakes or uses expressed by the actors. In particular, several sites favorable to the development of aquaculture have been modified or removed following these meetings.

The draft scheme, updated following these departmental meetings, received a favorable opinion from the Maritime Facade Council of the Mediterranean, meeting on 9 July 2015.

Pursuant to Decree No. 2012-616 of May 2, 2012 concerning the evaluation of certain plans and documents having an impact on the environment, the project, accompanied by its environmental report, has been submitted to the opinion of the environmental authority during the year 2015.

Before validation by order of the Regional Prefect and in application of Article L923-1-1 of the Rural and Sea Fisheries Code, the draft regional scheme for the development of marine aquaculture in Provence-Alpes-Côte d'Azur, have finally been made available to the public, from October 5, 2015 to November 8, 2015.

All areas confirmed or selected as suitable for marine aquaculture are located in coastal zone, therefore the BGF selected area do not fit the present aquaculture development scheme.

2.2.8 Protected areas

Protected areas are an essential element of biodiversity, geodiversity and landscape conservation strategies. Born to preserve a remarkable natural heritage, they also contribute to the good ecological quality of the environments and territories that surround them, and help maintain the ecosystem services to the people. Conscious of these multiple benefits, the Parties to the Convention on Biological Diversity have committed by 2020 to protect 17% of terrestrial areas and 10% of marine and coastal areas, through a network of ecologically protected areas. In France the protected areas, regardless of their status, now cover nearly 20% of the land space and involve several institutional actors. France aims to have at least 2% of its metropolitan land area under a protection regime, and to protect 20% of its whole maritime domain by 2020.

Development of the law of nature protection

It was essentially after the Second World War that French law for the protection of nature developed, in connection with the birth of environmental concerns on an international scale. Most of the regulatory tools for the protection of natural areas were issued during this period, particularly concerning nature reserves (1957) and national parks (1960).

The legislator also innovated by creating the regional natural parks (1967), which precede the notion of sustainable development, and the Conservatoire du Littoral (1975), an original institution dedicated to the acquisition of coastal sites. The law of 10 July 1976 summarizes these legal developments, proclaiming in the general interest the protection of species, environments and landscapes.

The emergence of biodiversity and sustainable development

France has gradually integrated the guidelines of international conventions and EC Directives into a broader vision of territorial planning, which links environmental protection and development. Following the Rio Convention in 1992 and with the establishment of the European Natura 2000 network, it has developed on a large scale a policy of contractual management of biodiversity, involving more local actors. The decentralization process initiated in the 1980s has contributed to this development: the Law on Local Democracy (2002) provides for a closer involvement of local authorities in the management of protected areas and empowers regions in creating natural reserves. This was reinforced by the law of 14 April 2006, which opens the governance of national parks to local authorities. It also creates a new protection status, the Marine Nature Park, whose management involves all users of the sea.

Strategies for terrestrial and Marine Protected Areas creation

More recently, France has set up a national consultation process on environmental issues - called Grenelle Environnement and Grenelle de la Mer - which have enabled national commitments to protect biodiversity. In this context, it has set out an ambitious strategy to develop an ecologically representative and coherent network of protected areas, which aims to:

- place at least 2% of the metropolitan land area under strong protection by 2020;
- conserve 20% of marine waters under national jurisdiction by 2020, half of which is in fish stocks.

The implementation of these strategies will enable France to surpass the objectives set out by the Convention on Biological Diversity, which aim to protect at least 17% of terrestrial areas and 10% of marine and coastal areas by 2020. These goals are complementary to the establishment of the national ecological network called "Green and Blue weave", which aims to restore ecological continuity between natural environments.

The main protection modalities

There are three legal ways in France to protect natural areas:

Land ownership, consisting of acquiring land to ensure the permanent protection of a remarkable natural area. This approach is favored in areas threatened by urbanization or, conversely, marked by the abandonment of agricultural and pastoral practices favorable to biodiversity;

Framing or prohibiting human activities that can affect natural environments. It results in the implementation of strict regulations on the management of wildlife and ecosystems;

Contractual protection, by of delegating to a third party, for a specified period, the management of a natural area within the framework of a usage control agreement.

To these protection systems can be added international labeling, which aims to protect and enhance exceptional species, environments and landscapes in accordance with criteria defined worldwide.

These different modalities are complementary, they can be superimposed to reinforce the level of protection. A tool can also come from two different approaches. This is the case for example when a protected natural area is created by decree (regulatory protection) and its management is based on the establishment of contracts with local actors (contractual protection).

The organization of the state for the protection of natural areas

The central State has set up a specific organization for the management of the status of protected areas under its jurisdiction. The central administration (Ministry in charge of the ecology, in link for certain duties with the Ministry of Agriculture) assumes direct responsibility for most protection statuses. It is represented in the regions by regional directorates for the environment, planning and housing (DREAl) and by the prefects.

Several public institutions have been created to manage specific protection statuses. Depending on the case, they can perform management missions, pooling resources and external communication.

Advisory bodies are responsible for advising on legislative and regulatory projects, as well as on the creation of protected areas (the National Nature Conservation Council, and in the regions, the Regional Natural Heritage Scientific Councils)

Actors involved in management

The management of protected areas is ensured by a large number of institutional actors, even if most statutes are the direct responsibility of the State or local authorities. This is particularly the case for national parks, which are exclusively administered by public institutions under the supervision of the Ministry of Ecology. But the management of certain tools, such as nature reserves, can also be delegated to a third party with a private status (association, foundation, owner).

To carry out their mission, protected area management bodies rely on scientific and technical institutions, which intervene in fields as varied as naturalistic expertise, the sharing of data on biodiversity, and the dissemination of knowledge to the public and the training of professionals:

- The Technical Workshop of Natural Spaces is an inter-network organization whose mission is the professionalization of the managers of all natural areas. It operates in France (mainland France and overseas), in Europe and internationally by offering continuous training programs, management methods and tools, and by facilitating technical exchanges between managers;
- the National Botanical Conservatories are responsible for conducting inventories of the wild ore and natural habitats;
- The National Museum of Natural History (Natural Heritage Service) provides a mission of general expertise on all biodiversity, and manages the National Inventory of Natural Heritage (INPN) including the reference base on protected areas.

Participation of local actors

According to the statutes, the creation of a protected area can be the subject of a consultation process with local actors, and be subject to a public inquiry intended to inform the population and to gather its opinion on the project. This is the case for the development of national park and regional nature park charters, as for the creation of marine natural parks.

French nature conservation law has developed several protected area governance mechanisms open to local stakeholders. For example, the advisory committee of a nature reserve constitutes a true local parliament, bringing together all the actors concerned and expresses its opinion on any decision relating to the reserve. Local elected representatives are also represented in the board of

directors of a national park and in the board of management of a marine natural park. In each Natura 2000 site is designated a local consultation body, the Steering Committee (Copil), responsible for the planning and monitoring of management actions.

Internationally protected areas

France is a signatory of international conventions and takes part in multilateral networks and programs aimed at protecting exceptional landscapes, environments and species in accordance with worldwide defined criteria, having both binding legal significance or simply constitute international recognition. In all cases, all or parts of the areas they target are protected by regulatory and / or conventional tools. The "Convention Concerning the Protection of the Cultural and Natural Heritage" was adopted in Paris in 1972 by the UNESCO General Conference to help States to identify, preserve and promote natural and cultural sites recognized for their exceptional universal value.

To be on the World Heritage List, a property must meet at least one of the ten criteria defined by the Convention (4 natural and 6 cultural), be in a good state of conservation (condition of integrity), and benefit from protection and management measures. Nominations are evaluated by IUCN and considered in session of the World Heritage Committee. Each site must have sufficient long-term protection and a suitable and effective management plan. A buffer zone must be defined in the immediate environment of the property to ensure its good conservation. The management of a World Heritage property is primarily the responsibility of the State.

France is a signatory to the main global agreements for the conservation of biodiversity (Convention on Biological Diversity), specific ecosystems (Ramsar Convention on Wetlands) and species (Convention on International Trade in Wild Fauna and Wildlife, International Whaling Convention, Convention on Migratory Species). Its actions to protect natural areas are part of its international commitments and EU community policies.

Because of its territorial presence in several continents and seas, it also engages its responsibility in numerous regional agreements for the protection of terrestrial biodiversity (Bern Convention, Alpine Convention) and marine (Regional Seas Conventions). France is also involved in multilateral programs for the protection of natural heritage, such as the International Coral Reef Initiative (ICRI), and is involved in the main European networks of protected area managers. Finally, France has maritime and land borders with 35 countries in the world, and several border-protected areas are engaged in cooperative actions, resulting in the gradual establishment of transboundary-protected areas.

2.2.9 Biosphere reserve

A biosphere reserve is a terrestrial or marine area established within the framework of the UNESCO Man and the Biosphere Program (MAB), which aims to promote a balanced relationship between man and nature. It performs three mutually reinforcing core functions: biodiversity

conservation, economic development, and research support. As real areas for experimenting with sustainable development, biosphere reserves contribute in particular to the Millennium Development Goals, Agenda 21, and the Convention on Biological Diversity.

Biosphere reserves are created on the initiative of the States, in accordance with the criteria of a statutory framework approved by the General Conference of UNESCO in 1995. They form an international network representing the main ecosystems of the planet.

A biosphere reserve is subdivided into three interdependent zones that make it possible to spatially organize the management objectives (central area, buffer zone, transition area). In France, biosphere reserves do not have a specific legal status, but they overlap in part or totally with protected areas recognized in national law.

Each biosphere reserve constitutes a specific territorial consultation framework. In France, animation can be provided by a mixed union, by the administration of a national park, or by a management committee, which involves the actors of the territory.

2.2.10 RAMSAR sites

A RAMSAR site is a designated area under the Convention on Wetlands of International Importance (1971), the purpose of which is to promote the conservation and wise use of wetlands. Convention States Parties voluntarily designate wetlands for inclusion in the List of Wetlands of International Importance. To be registered, a site must meet at least one of the five ecological criteria defined by the Convention. The inclusion of wetlands under the Convention is an international label that rewards and values the sustainable management actions of these environments, commits and encourages those who implement them to pursue them. For any registration, the State retains priority sites that are already subject to management measures, a charter or a management plan. For each site, it is recommended to identify a monitoring committee, a coordinating body and a site correspondent. France has been a signatory to the Convention since 1986 and currently has 42 sites spread throughout its territory in mainland France and overseas.

Wetlands occupy a large part of the area of Fos and its surroundings, mostly marshes and ponds that extend over almost the entire maritime border of the department. Added to this are large areas of salt marshes.

The territory of the Camargue Regional Nature Park is a Ramsar site. It is therefore a wetland of international importance for which the French State signed the Ramsar International Convention on 1 October 1986. The State then undertook to maintain the ecological character of this wetland of international importance. to plan "wise use" or sustainable use of all wetlands on this site.

It should also be noted that the "Petite Camargue" Ramsar site, a wetland of international importance, is located on the western edge of the study area. It is characterized by a great diversity of environments, largely influenced by strong salinity gradients, and by the presence of exceptional habitats (no less than 7 priority habitats of the Habitats Directive), flora and fauna. a remarkable fauna (bird life, fish fauna, amphibians, reptiles or chiroptera).

2.2.11 Marine mammals sanctuary

A Marine Mammal Sanctuary is a category of *sui generis* marine protected area that aims to protect targeted species and their habitats from any human disturbance (fishing, pollution, by-catch, disturbance) in an extended marine area.

The instrument of creation is tuned on the specific case, and a sanctuary can be instituted by a decree in Council of State or result from an international agreement.

The management of a sanctuary is based on an integrated approach between the development of socio-economic activities and the protection of habitats and marine mammals. In the Mediterranean, the Pelagos Sanctuary has a management plan that includes a wide range of actions, including awareness raising, monitoring human activities and promoting scientific programs. When it comes from an international agreement (Pelagos), a sanctuary is a framework for cooperation between signatory states to harmonize protection actions for targeted species.

Each State is responsible for the implementation of protective measures. Management is based on a process of consultation between all the actors of the sea (administrations, elected representatives, socio-professionals, scientists, nature protection associations).

2.2.12 The BARCELONA Convention

Several regional seas conventions provide, through specific protocols, for the establishment of protected areas to restore, preserve or maintain natural resources that provide socio-economic benefits, habitats of endangered or endemic species, and ecosystems.

The initiative of creation belongs to the States Parties. Protected areas are created on the basis of common criteria defined in each convention.

Protection and management measures are defined in the nominations. According to the conventions, it may be to regulate trade in species and human activities, and in some cases to restrict access to the protected area.

The State is responsible for the implementation of protection and management measures, in consultation with local actors.

Several French marine protected areas have been recognized under regional seas conventions, in particular three Specially Protected Areas of Mediterranean Interest (SPAMIs) from the Barcelona Convention.

2.2.13 Nature conservation at EU level

The European level is an important intervention framework to protect a coherent network and representative of natural habitats and remarkable species, regardless of national boundaries. France is contributing to the establishment of the two main European protection systems for natural areas, the Natura 2000 network under the responsibility of the European Union and the network of biogenetic reserves of the Council of Europe.

Natura 2000 Network

Natura 2000 is Europe's leading ecological network and the largest network of protected areas in the world. It aims to conserve or restore natural and semi-natural habitats and species with high conservation stakes in Europe, while taking into account the economic and social requirements of the territories concerned.

The Natura 2000 sites are designated by ministerial decree, in application of two European Directives (Birds and Habitats-Fauna-Flora) which define in their appendices the most remarkable species and environments threatened worth to be protected. The network includes Special Protection Areas (SPAs) for the conservation of wild bird species listed in Annex I of the Birds Directive, and Special Areas of Conservation (SACs) for the conservation of species and habitats listed in Annexes I and II of the Habitats Directive. A Natura 2000 site may be superimposed with another protected area of a regulatory or conventional nature.

The classification of a site implies obligations for the Member State which must put in place a management plan and measures to avoid the deterioration of habitats.

Site projects and procedures differ according to the Directives:

- ZPS (Special Protection Areas), under the Birds Directive (Directive 79/409 / EEC as amended): they are first designated by national law in a ministerial order and then notified to the European Commission;
- ZSCs (Special Areas of Conservation), under the Habitats, Fauna and Flora Directive (Directive 92/43 / EEC as amended): they are designated after several stages: proposal of SIC (Site of Community Interest), publication of the CIS and designation of CIS in national law under the status of SAC.

On each site, a document of objectives (DOCOB) is elaborated. It is a policy and management document developed under the responsibility of the State, in partnership with all stakeholders and via a steering committee.

Biogenetic reserves

Established in 1973 by the Council of Europe, the network of biogenetic reserves aims to conserve representative examples of wildlife and natural areas of Europe.

Each State designates on its territory biogenetic reserves, which must satisfy at least one of the four criteria set by a Council of Europe Resolution (typical, unique, rare, endangered). If natural areas are already protected at national level, they are directly integrated into the network.

A biogenetic reserve must have a legal status ensuring the effective and long-term protection of habitats, biocenoses or ecosystems. The modalities of protection may be different, but any intervention that may degrade the environment should be avoided. The management of the biogenetic reserves is the responsibility of the State which has designated it. The 35 biogenetic reserves designated in France all correspond to national nature reserves.

Protected Areas at national level

In France, the Ministry in charge of ecology is the main actor in the creation of protected areas. It assumes responsibility for the management of most regulatory protection tools, through its public institutions or related management associations.

National parks

A national park aims to protect large sets of terrestrial and marine ecosystems, and also an exceptional cultural and landscape heritage. Each national park is made up of two sectors with separate regulations: a central area called the heart zone, where the state provides maximum protection for the natural heritage and strictly regulates human activities; a peripheral zone known as the "adhesion area", where a sustainable development policy is established on a voluntary base, in support of protecting the heart of the national park. Integral reserves can be established in the heart zone to strictly protect wildlife and the sea for scientific purposes.

The classification of a national park intervenes by decree in Council of State. The main management document is the charter, developed in partnership between the State and local actors for a maximum of 15 years. The management of a national park is confined to a state public institution, which has its own regulatory power. Its governance gives a large place to local actors, and in particular to the elected representatives of the territorial communities, majority in the board of directors. France has 10 national parks, covering about 8% of the territory (metropolitan France and overseas departments).

National natural reserves

The aim of a national nature reserve is to preserve, in the long term, exceptional, functional and ecologically representative natural environments, as well as species with strong heritage value, geological or paleontological heritage.

The classification in national nature reserve intervenes by decree (simple or Council of State). The creation or revision decree may provide for the establishment of a protection perimeter around the reserve.

The management plan of the reserve determines the necessary interventions to ensure the conservation, the maintenance and even the reconstitution of the natural heritage. Interventions that compromise the integrity of the environment are strictly prohibited.

The sites are managed by a local organization in consultation with the actors of the territory. In particular, it is responsible for developing and implementing the management plan. The management is carried out under the responsibility of the prefect.

The 165 national nature reserves are home to a large part of rare and endangered environments and species in France. The largest national nature reserve covers 22,700 km2 in the French Southern Territories.

Marine national parks

A marine natural park aims to protect a vast marine area of special interest for biodiversity, to develop knowledge of the marine environment and to ensure sustainable management of natural resources.

The creation and the delimitation of a marine natural park intervene by decree after a public inquiry on the territory of the littoral communes concerned by the project.

The management of a marine natural park is based on the principles of the ecosystem approach. The creation decree defines general guidelines, among which the promotion of human activities compatible with the preservation of biodiversity and the good state of the natural environment.

The management is placed under the responsibility of a public institution, the Marine Protected Areas Agency, in consultation with all users of the sea. Each marine natural park has a management

council, governance body and of consultation composed of representatives of the State, local authorities, associations, experts and professional organizations. It decides on any question concerning the park and draws up the management plan.

France has established five marine natural parks and several projects are currently under study on all French maritime facades.

Biological reserves

A biological reserve protects species or habitats that are considered to be remarkable or representative in forest or forest-associated environments such as peat bogs, coastal dunes and heaths.

The classification is pronounced by order of the Ministries in charge of Environment and Agriculture for an unlimited duration.

According to the management objectives and the type of environment, there are the integral biological reserves (RBI), where the forest is left free to evolve, and the controlled biological reserves (RBD) where is established an active conservation management of the ecosystems. There are also mixed biological reserves, which combine an integral part and a directed part.

This regulatory protection tool applies to public forests and its management falls exclusively within the competence of the National Forest Office. More than 200 sites are preserved under this status, in metropolitan France and in the overseas departments.

Coastal conservational sites

Since 1975, the public establishment has been acquiring fragile and endangered areas on the shoreline and lakeshores in order to ensure their permanent protection. This land policy aims to safeguard the natural coastal and lacustrine areas of ecological and landscape interest, while ensuring their access to the public. The land is acquired amicably, by pre-emption and exceptionally by expropriation.

Once integrated into the public domain, they become almost inalienable. Numerous development operations intended for the reception of the public and the daily interventions of the managers make it possible to restore the often-degraded ecosystems and to control the frequentation of the public. Adapted from the British National Trust, the Conservatoire implements partnership management of the land in priority with local authorities to achieve local ownership of site management.

Today, nearly 12% of the French coastline is protected under this status. The ambition is to preserve by 2050 a third of the coast of metropolitan France and overseas, which includes, in addition to the sites of the Conservatory, the coastline protected by national parks, nature reserves, classified sites, forests “domaniales” and sensitive natural areas

Scientific inventories

There are two types of heritage biological inventories. These inventories have no regulatory value. They are tools for knowledge and expertise of biodiversity.

- **ZNIEFF**

The inventory of Natural Areas of Ecological, Fauna and Floristic Interest (ZNIEFF) is a program initiated by the Ministry in charge of the environment and launched in 1982 by the National Museum of Natural History (MNHN). It lists the remarkable terrestrial natural spaces in France.
There are two types of ZNIEFF:

- Type I ZNIEFFs cover areas corresponding to one or more homogeneous ecological units containing at least one remarkable or rare characteristic species or habitat, which has a higher heritage value than that of the surrounding environment. These are areas characterized by their remarkable biological interest, they can be constraining vis-à-vis properties development;
- Type II ZNIEFFs are large, or poorly modified, natural ensembles with significant biological potential. These are generally quite large sectors, of more diffuse wealth than ZNIEFFs of type I, and therefore less sensitive. Type II ZNIEFFs may include Type I ZNIEFFs. They have a functional role as well as ecological and landscape coherence.

- **IBA**

Areas of Importance for Bird Conservation (IBA) refer to a scientific inventory prepared under an international Birdlife International program to identify the most favorable areas for wild bird conservation.

The IBA inventory is a source of information on the status of heritage species, the habitats they occupy and the conservation measures that are applied. To this end, it plays a key role in the framework of a national observatory of threatened birds and is the reference for any new designation of SPAs within the framework of Natura 2000 sites.
Two IBAs are listed near the study area, confirming the major avifaunistic interest of the surrounding wetlands (see location of IBAs on the previous map):

1. Camargue on the right bank of the Grand Rhône (PAC02),
2. Marsh between Crau and Grand-Rhône: Meyranne, Chanoine, Plan du Bourg and Salins du Caban.

<u>Regional level</u>

The Regions are responsible for several regulatory and contractual tools for the protection of natural areas, which give them the capacity to implement a real nature protection policy, in consultation with local stakeholders. They establish Regional Biodiversity Strategies and Regional Ecological Consistency Plans (SRCEs), to identify elements of the national Green and Blue weave.

- **Regional natural parks**

A regional natural park is a rural or peri-urban area whose natural, cultural and landscape heritage represents a remarkable and coherent, but fragile and endangered ensemble, and where local actors commit themselves to a project to reconcile protection and heritage development with local development. The classification of a regional natural park intervenes by decree of the Prime Minister on proposal of the Minister in charge of the ecology.

The guidelines and management measures are set out in a contractual document called "charter", which commits all the signatories for a period of 12 years, and to which the planning documents must be compatible.

The management is ensured by a mixed union, which implements the charter and coordinates the actions carried out by the actors of the territory in domains such as town planning, regional planning, agriculture, the management of natural environments, environmental pedagogy, water resource management, energy and tourism.

The 48 regional natural parks are inhabited areas with more than 4,000 municipalities and 3.5 million inhabitants. They are distributed homogeneously over approximately 14% of the metropolitan territory as well as in some overseas departments (Martinique, French Guiana).

The Regional Park covers 3 municipalities: Arles, Port-Saint-Louis-du-Rhône and Saintes-Maries-de-la-Mer. It extends over more than 100,000 hectares and 75 km of coastline.

For the marine side of the 3 nautical miles, in accordance with the new regulations in force, the territory of the Park will stop at the "coastline". However, given the particular importance of the interaction between marine and freshwaters and the problem of marine erosion, a management agreement must be signed between the State authorities and the Park to enable the latter to continue its interventions on the zone of 3 nautical miles as well as on the 12 miles of the Natura 2000 site.

The natural environments of Port-Saint-Louis concerned are identified as priority protection zones, major wetlands, forested forest areas and wooded complexes to maintain and enhance or sensitive areas to accompany and restore. The Napoléon beach is listed as a sector of tourism and seaside activities.

Any development within the perimeter of the park requires an advisory opinion from the PNRC.

- **Regional natural reserve of Corse**

A regional nature reserve or Corse meets the same objectives and characteristics as a national reserve. Its mission is to preserve exceptional, functional and ecologically representative natural environments in the long term, as well as species with high heritage value.

The classification in natural reserve intervenes by a deliberation of the Regional Council or the Territorial Collective in the specific case of the Corsican region. The classification decision may provide for the establishment of a protection perimeter around the reserve.

The management plan of the reserve determines the necessary interventions to ensure the conservation, the maintenance and even the reconstitution of the natural heritage. Interventions that compromise the integrity of the environment are strictly prohibited.

The nature reserves are under the exclusive responsibility of the Regions (Regional Councils or Corsican Territorial Collectivity) but third parties can decide their management by convention.
Corsica currently has 6 nature reserves established on a total area of 834 km2.

List of Offices and Agencies involved in nature protection

- **Ministère en charge de l'écologie** | www.developpement-durable.gouv.fr
- **Ministère en charge de l'agriculture** | www.agriculture.gouv.fr

18. **Conservatoire du littoral et des rivages lacustres** | www.conservatoire-du-littoral.fr
19. **Rivages de France** | www.rivagesdefrance.org

20. **Office National des Forêts** | www.onf.fr
21. **Agence des Aires Marines Protégées** | www.aires-marines.fr
22. **Office National de la Chasse et de la faune sauvage** | www.oncfs.gouv.fr
23. **Parcs Nationaux de France** | www.parcsnationaux.fr
24. **Fédération nationale des Parcs Naturels Régionaux de France** | www.parcs-naturels-regionaux.tm.fr
25. **Réserves Naturelles de France** | www.reserves-naturelles.org
26. **Fédération des Conservatoires d'Espaces Naturels de France** | www.reseau-cen.org
27. **Réseau des Grands sites de France** | www.grandsitedefrance.com
28. **Atelier Technique des Espaces Naturels** | www.espaces-naturels.fr
29. **Forum des gestionnaires d'aires marines protégées** | www.forum-aires-marines.fr
30. **Muséum National d'Histoire Naturelle - Service du Patrimoine Naturel** www.mnhn.fr/spn - http://inpn.mnhn.fr
31. **Fédération des Conservatoires Botaniques Nationaux** | www.fcbn.fr

2.3 LANDSCAPE LEGAL FRAMEWORK

2.3.1 Monuments

The issuance of a building permit for the installation of buildings that enter the field of view of a listed or inscribed monument is subject to the agreement of the Architect of Buildings of France. The compatibility of the project with the preservation of historical monuments must be demonstrated in the context of the impact study in agreement with the Architect of Buildings of France.

2.3.2 Archaeological heritage - Marine part

In case the installation area of the BGF fall within an area of high archaeological sensitivity, the DRASSM would recommend to carry out a geophysical survey on project areas (no preventive archaeological procedure), in order to clarify the possible interference of the project with cultural maritime properties. The Developer must then declare any discovery within 48 hours to the Departmental Direction of the Territories and the Sea in accordance with Article L532-3 of the Heritage Code and not to undermine it.

According to the national archaeological map dated 04/11/2011, no known archaeological entity however concerns the project area.

2.3.3 Classified sites and registered sites

The classified sites are places whose exceptional character justifies a protection of national level: remarkable elements, places of which one wishes to preserve the vestiges or the memory for the events which took place there, etc.

Classification under the 1930 Act entails the need for a careful landscape integration study of development projects. Projects subject to a building permit located in a classified site are subject to

an authorization issued by the Minister in charge of the sites, after opinion of the CDNPS (Commission Departmental Nature Landscapes and Sites) and, at the discretion of the Minister, a subsequent opinion of the Superior Commission of Sites, Perspectives and Landscapes (CSSPP).

For their part, projects subject to building permits in a registered site must be submitted to the prefectural authority four months before their commencement and to the opinion of the Architect of the buildings of France.

These protective provisions are codified in Articles L. 341-1 to 22 of the Environmental Code (MEDDE).

2.3.4 Wrecks

Several archaeological sites are listed off the Rhone delta and the Gulf of Fos (figure 3). Dozens of wrecks are present off the coast of the study area. Some of them are concentrated at the eastern end of the They de la Gracieuse. Archaeological sites are also identified near the BGF area. The location of these wrecks is shown on the following map.

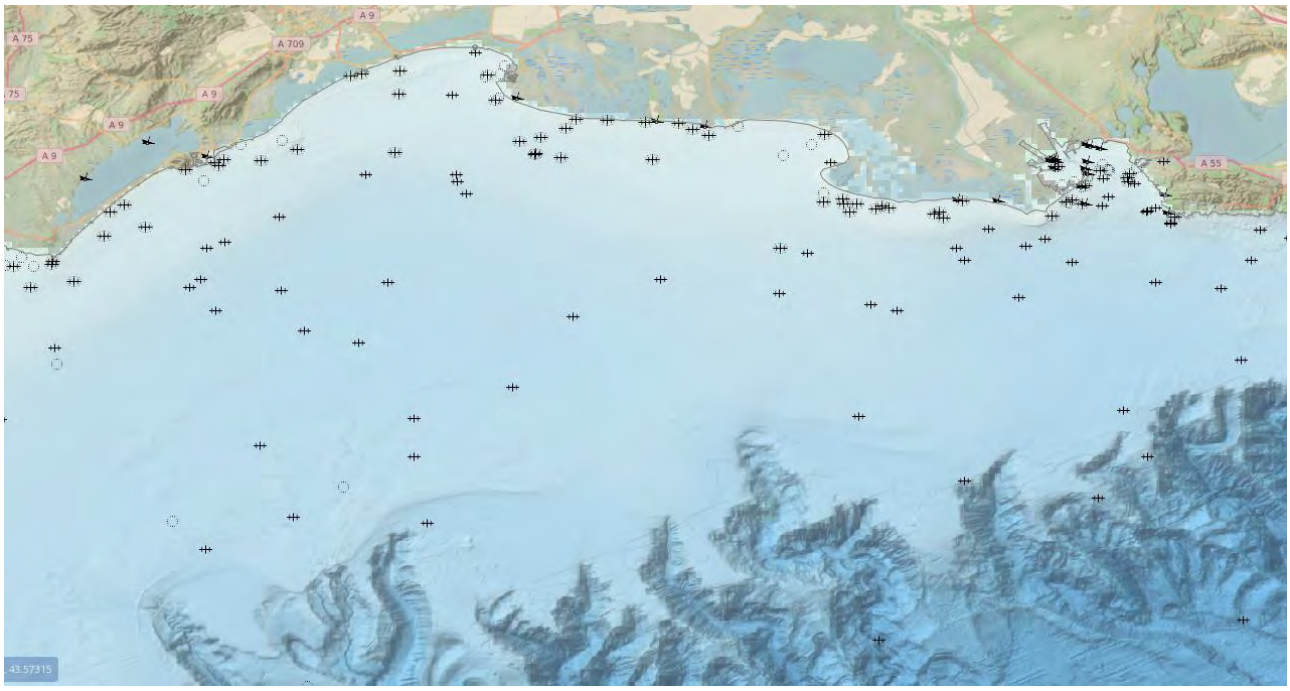


Figure 3: Archaeological sites in the Rhone delta and in the Gulf of Fos, wreck position (*Source: EMODNET, www.emodnet.eu*)

2.3.5 Landscape units at the project area level

The area facing the BGF selected installation site presents contrasting landscapes characterized by two landscape units:

- **Landscape unit of the Camargue**

This landscape unit regards the municipalities of Port-Saint-Louis du Rhone, Arles and Saintes-Maries-de-la-Mer and covers 107,000 ha.

It is composed of 9 sub-landscape units, 1 of which related to the study area: Le Plan du Bourg. This sub-unit is intermediate between the Camargue delta and Crau neighbour. Rice fields, field crops, manades and oak groves form a landscape mosaic. Towards the South along the Rhone, marshes and salt flats follow one another until Port-Saint-Louis-du-Rhône.

- **Landscape unit of the Gulf of Fos**

This landscape unit concerns the municipalities of Fos-sur-Mer and Port-Saint-Louis du Rhône and covers an area of approximately 324 km2.

It is composed of 5 sub-landscape units, 2 of which are included in the study area, which are: Port-Saint-Louis-du-Rhône, Theys and the mouth of the Rhone.

Classified sites and registered sites

Landscapes, intertwined with natural and agrarian landscapes, gives to the Camargue, which extends to the entire Rhône delta originality and a strong identity. They are particularly vulnerable to the effects of peri-urban and diffuse urbanization, as well as to the consequences of heavy traffic associated with tourism and recreation. They are very dependent on the maintenance of ecological balances.

Outstanding areas of the coast

A possible export cable would cross a remarkable area of the coast of the municipality of Port-Saint-Louis-du-Rhône.

The issues related to this space are as follows:

- Preserve the natural areas of Napoléon Point, manage their attendance and existing facilities;
- Rehabilitate and requalify brownfields, developed or artificialized areas around the central basin, the canal and in the Mazet sector; meet the needs of housing and services, in particular to support the development of the industrial-port area, in a context of necessary recomposition of the urban center;
- Increase the capacity for pleasure boating and sea-related activities;
- Industrial wastelands, developed and artificialized spaces, rehabilitation operations and extension of urbanization will take into account the notion of limited extension of urbanization in areas close to the shore as follows:

- agglomerations, located on both sides of the Canal Saint-Louis, may be the subject of a extension or densification in very limited proportions. The character of the constructions must be maintained;

- the unbuilt area, which separates these agglomerations from the first buildings used for activity must be preserved. It can only receive light fittings or intended to restore the naturalness,
- Extensions of urbanization can be planned along the Saint-Louis canal and the basin of the Tellines, by favoring a positioning of the densest developments in the West of the zone.

CHAPTER 3: ENVIRONMENTAL BASELINE

3.1. PHYSICAL ENVIRONMENT

3.1.1 Geology

The Gulf of Lions is a continental margin extending from Cap de Creus in Spain to Toulon in France. It has a broad continental shelf, unusual for the Mediterranean basin, reaching a width of up to 72 km. Its shelf break is well defined between 100-200 m depth and signed by a complex network of submarine canyons, which converge towards the base of the slope, with tributaries of several orders reaching depths of almost 2000 m.

Some of these canyons can be found relatively close to the shore, just a few kilometers from land (for example Cap de Creus canyon in the western part of the gulf), while others relatively far offshore (e.g. Grand and Petit Rhône canyons in the eastern part of the gulf), due to differences in shelf width along the continental margin. The whole set of submarine canyon has a recent origin, being developed during the Quaternary period.

The current morphology of the whole margin resulted from interactions between sediment supply, especially from the Rhône River, eustatic oscillations, destabilization and remobilization of accumulated sediments and geodynamic evolution of the basin during the Plio-Quaternary. On the other hand, Cap de Creus and the Petit Rhône canyons are of tectonic origin.

The whole network of submarine canyons plays an important role in the dynamics of the continental margin. Canyon heads represent nearly 30% of the 120 m depth shelf break area and almost half of the slope surface can be attributed to canyon walls. The continental slope gradient ranges from 10° at its shallower part, down to 2° at the deeper ends close to 2000 m. The slope reaches the flat areas of the Balearic Basin plain at depths close to 2500 m.

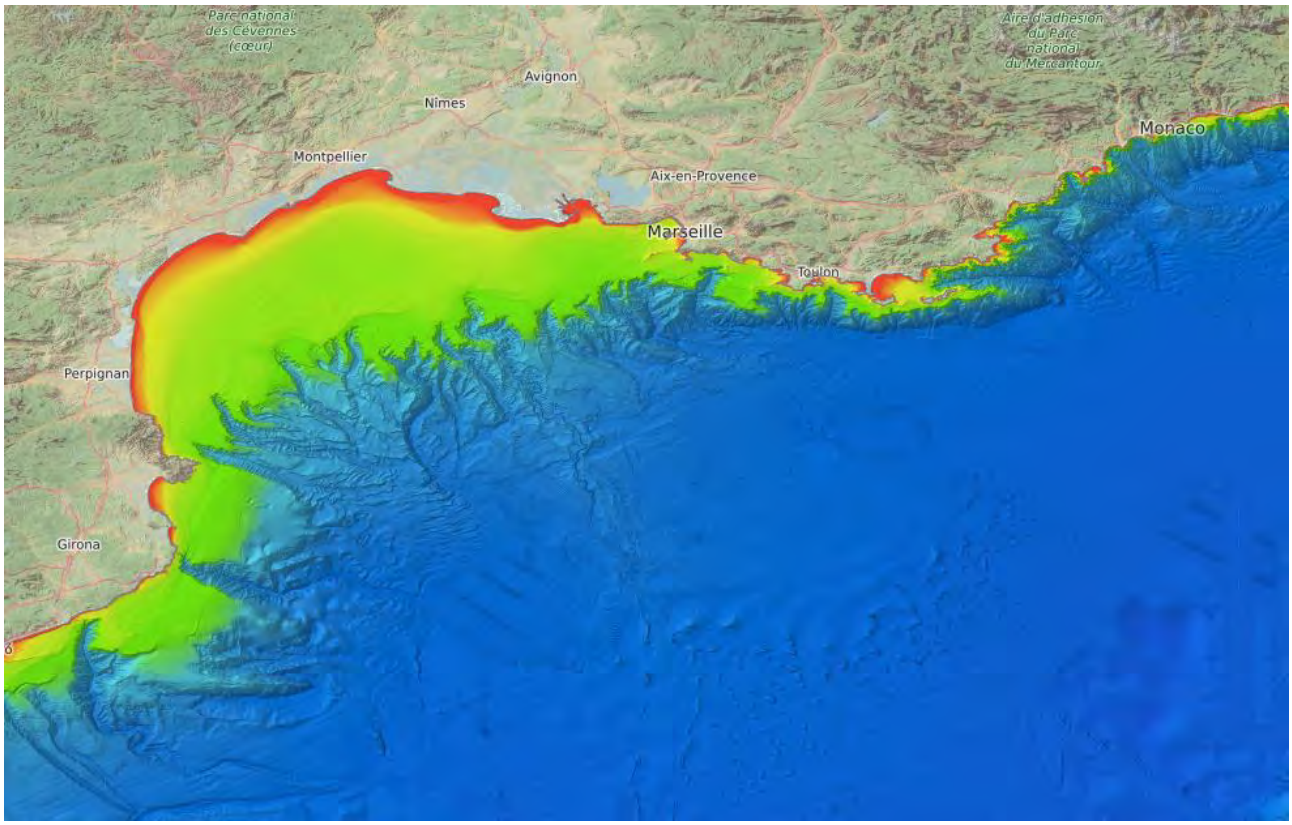


Figure 4: Seabed general features (*Source: EMODNET, www.emodnet.eu*)

Figure 5: Marine canyon network at continental margin (*Source:* UNEP-MAP-RAC/SPA, 2013)

Continental margin and shelf

The Gulf of Lions continental margin is formed by complex pressure deformation structures covered by a relatively thin Holocene sediment layer, irregularly distributed over the entire basin.

This layer is formed by terrigenous muds deposited during the last sea level rise, approximately 18,000 years from present, and made of acoustically transparent sediments. These are composed by alternating silty/clayey and sandy deposits, mainly found on inner- and mid-shelf regions (Got and Aloisi, 1990). Its thickest part can be located next to the Rhône River mouth (approximately 50 m), becoming thinner to the west. It is less than 10 m thick close to the Roussillon shelf and does not exceed 1 m off Cap de Creus, allowing rocky formations to be visible on the inner part of the shelf (Durrieu de Madron et al., 2008). These sediments settle at different rates over the shelf, ranging from 10 to 60 cm per 100 years.

The highest deposition rate is found close to the Rhône River mouth, where it ranges from 30 to 50 g $cm^{-2}y^{-1}$, to decrease rapidly seaward and along-shore. The average accumulation rate on the shelf is 0.20-0.30 g $cm^{-2}y^{-1}$ (Zuo et *al*., 1997). The terrigenous sediment input of the Rhône River is distributed over the continental shelf by the dominant currents up to the Cap de Creus area (Canals

and Got, 1986).

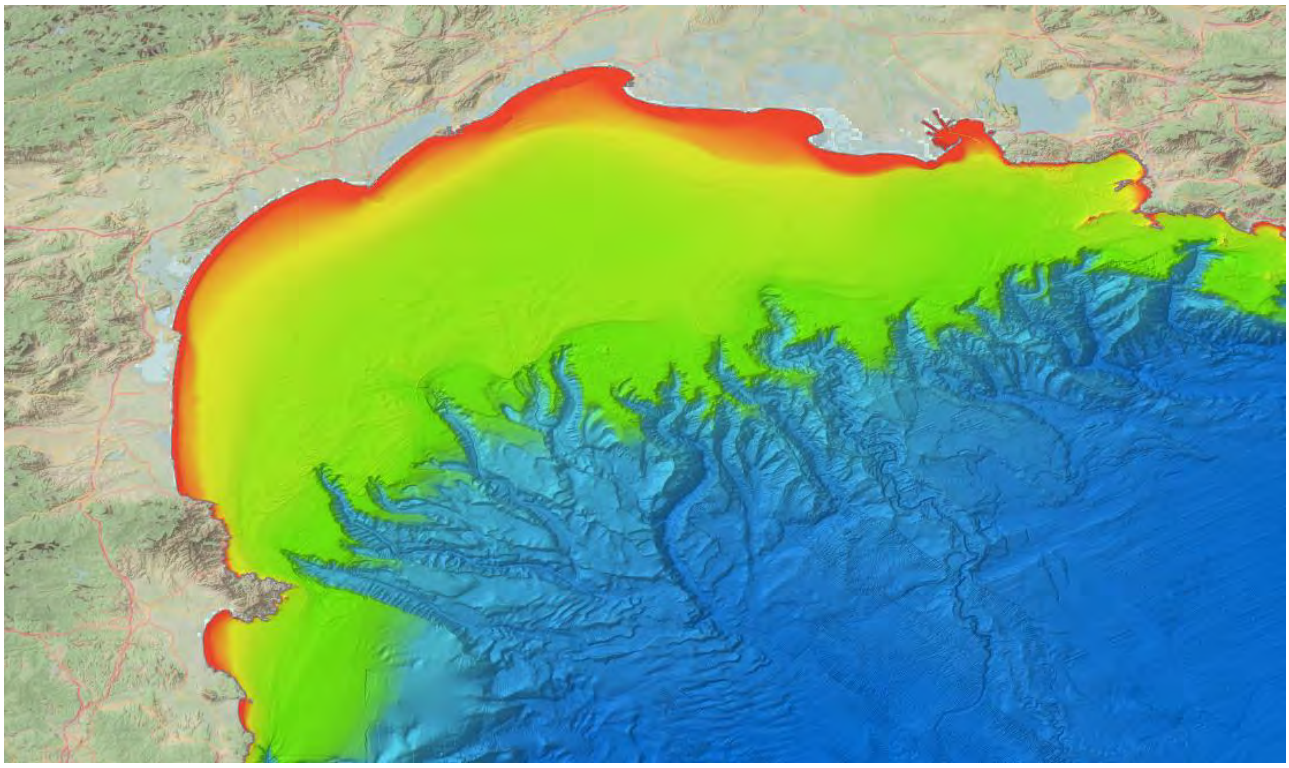


Figure 6: Seabed detail for the Gulf of Lions (*Source: EMODNET, www.emodnet.eu*)

Continental slope

The complex network of submarine canyons greatly influences sediment dispersal and accumulation. Differences in slope morphology and hydrodynamics affect the displacement to the large of the terrigenous materials. Sedimentary conditions on the continental slope are highly unstable, and reworking and erosion result in a complex margin morphology (Got and Aloisi, 1990). In general, recent deposits are thin on the slope, with 1-2 m average sediment thickness on canyon bases and 0.5 m on intercanyon highs and deep-sea fans (Got and Aloisi, 1990). The sediment thickness is also reduced and even be totally lacking due to erosion on canyon walls. The sedimentation rates on the slope decrease with depth, with an average of 0.09 g $cm^{-2}y^{-1}$ for the upper slope and 0.03 g $cm^{-2}y^{-1}$ for the deeper part (Zuo et *al*., 1997).

The Sardo-Balear Abyssal plain

The Sardo-Balear Abyssal plain shows a very flat morphology and presents very low sedimentation rates (Canals and Got, 1986). Submarine canyons seem to play an important role in the formation of Holocene deposits, mainly due to downslope sediment transport, which is believed have been more active during low-sea level stages. The sedimentation processes are more intense close to the major river sources, such as the Rhône River, and in some areas, as Lacaze-Duthiers Canyon, where a deep-sea fan is formed (Got and Aloisi, 1990). Several sedimentary bodies can be

found on the abyssal plain, which seem to be in relation to the submarine canyons activities. These bodies can be interpreted as sandy-clay deposits.

Figure 7: Canyon slope (*Source:* UNEP-MAP-RAC/SPA, 2013)

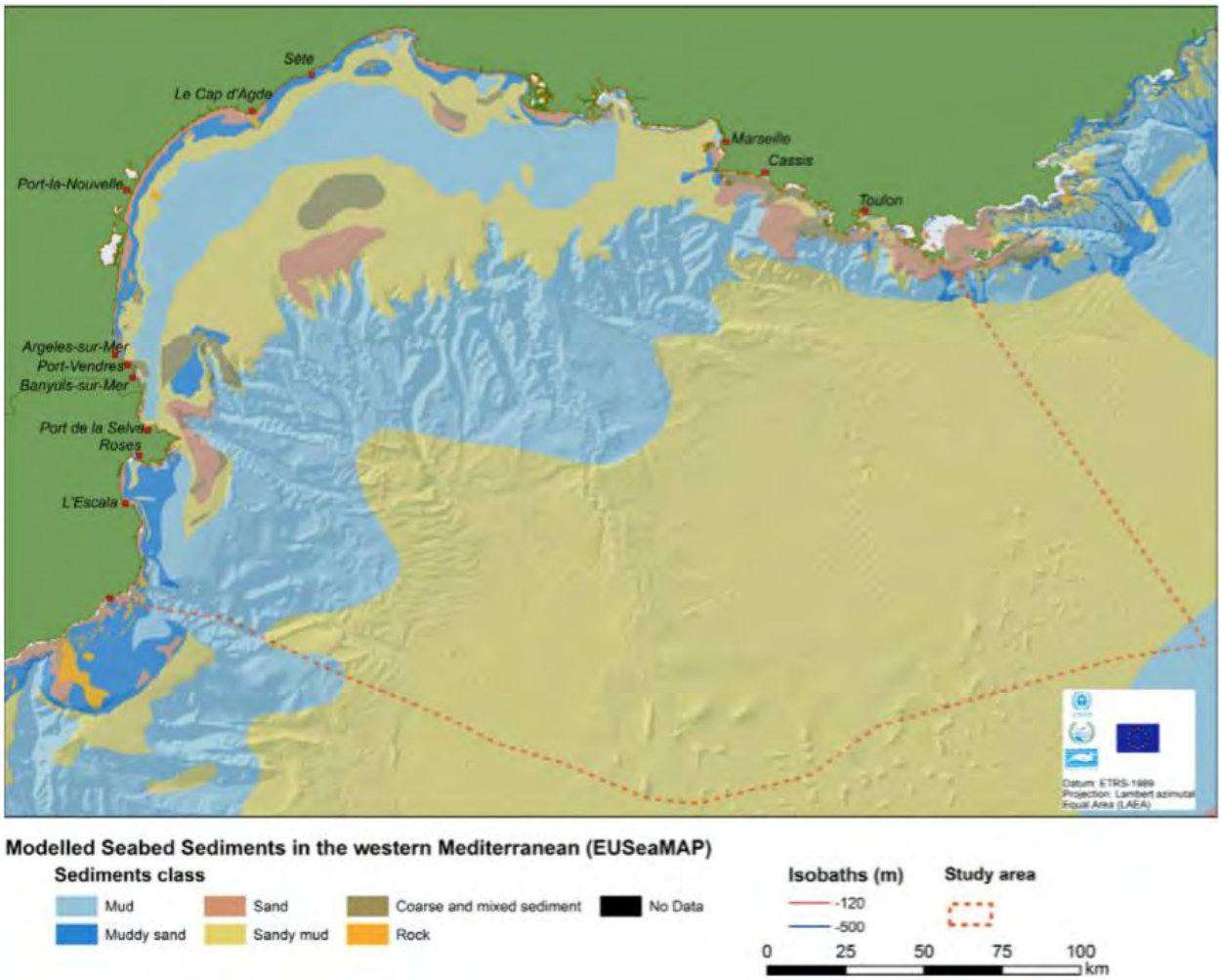


Figure 8: Sediment broad distribution (*Source: EUSeaMap 2011*)

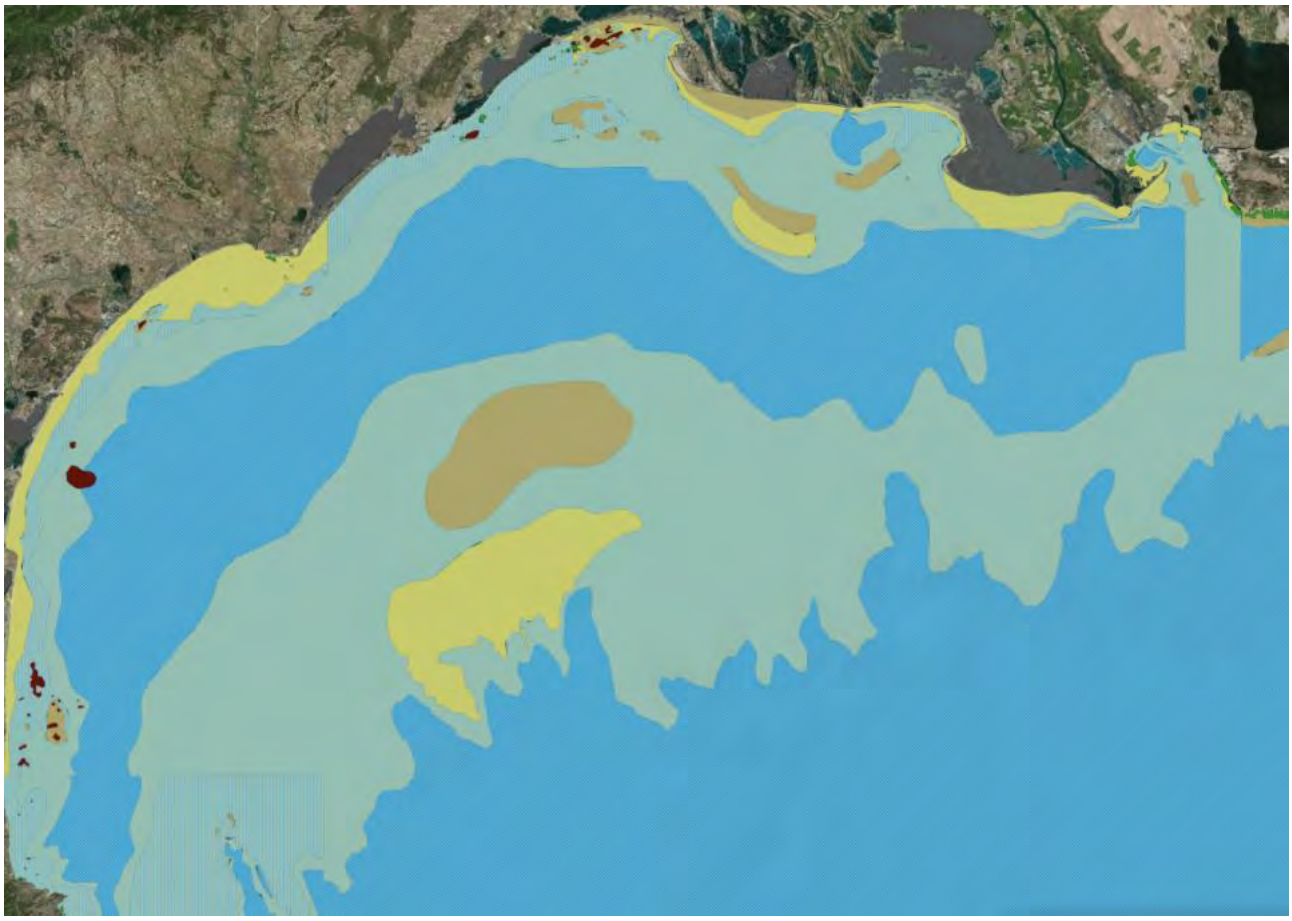


Figure 9: Sedimentary feature in the Gulf of Lions (*Source: EMODNET, www.emodnet.eu*)

3.1.2 Currents

The northern part of the Western Mediterranean Sea is formed by the Ligurian Sea and the Gulf of Lions. The basin's eastern boundary is defined by the Corsica Channel, separating the Ligurian Basin from the Tyrrhenian Sea. West of Sardinia Island, the basin boundary is not clear but is usually defined south of the Balearic Front, whose position undergoes significant changes from winter to summer.

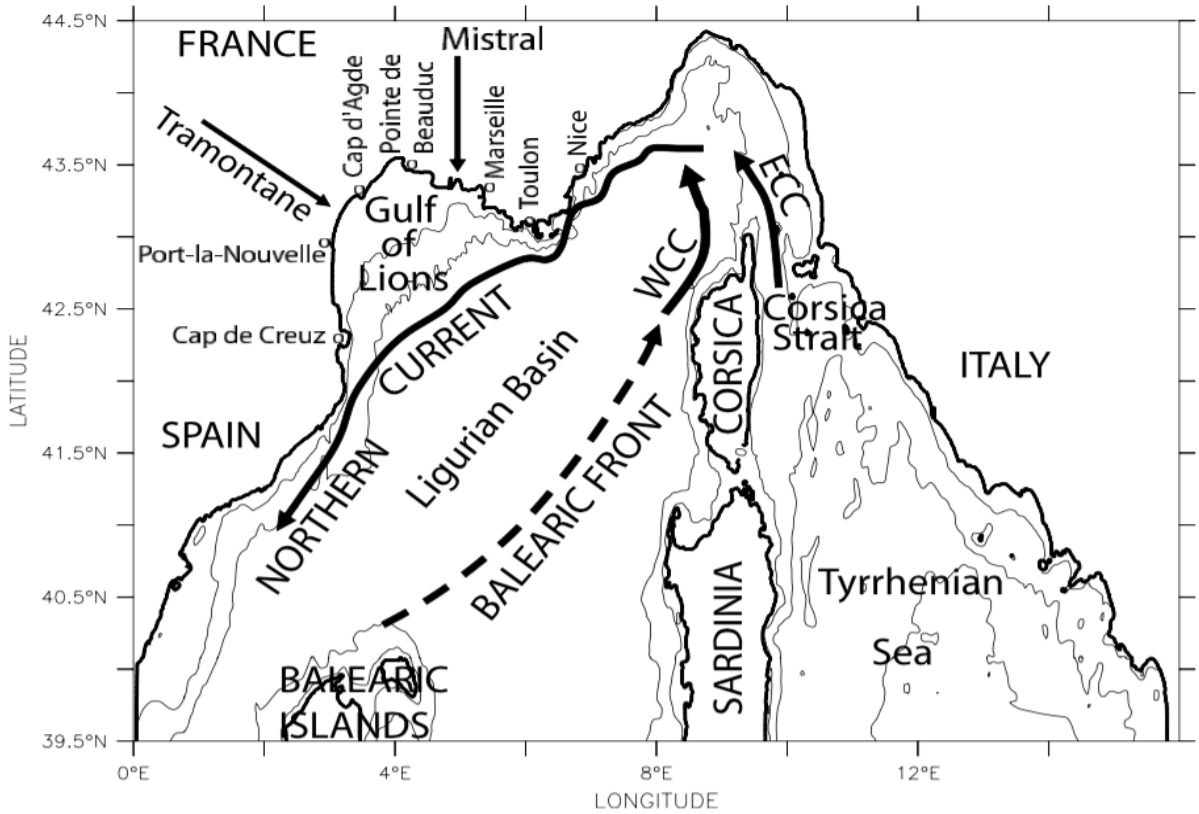


Figure 10: The Norther Current (NC) pattern ***(Source: Andre et al., 2005, mod.)***

In the Ligurian-Provençal Basin, the well-defined cyclonic circulation involves all water masses: in the surface layers, the Modified Atlantic Water (MAW), below, the Winter Intermediate Water (WIW) and the Levantine Intermediate Water (LIW), and in deep layers, the Western Mediterranean Deep Water (WMDW), (Conan and Millot, 1995). This cyclonic circulation is fed by two principal currents flowing northwards along each side of Corsica Island: on the western side, the Western Corsican Current (WCC) and on the eastern side, the Eastern Corsican Current (ECC) which intrudes into the Ligurian- Provençal Basin through the Corsica Channel. North of the Island, the two currents merge to form the more generally called Northern Current (NC) (Millot, 1999).

The Gulf of Lions (GoL), located in the northwestern Mediterranean Sea, is a microtidal area in which the coastal circulation is influenced by the general circulation, in particular the Northern Current, and is also subjected to a large variety of atmospheric forcings. The Rhône River is the main frewater source discharging in this area. Its freshwater river plume has a strong influence on the thermohaline characteristics of the shelf waters.

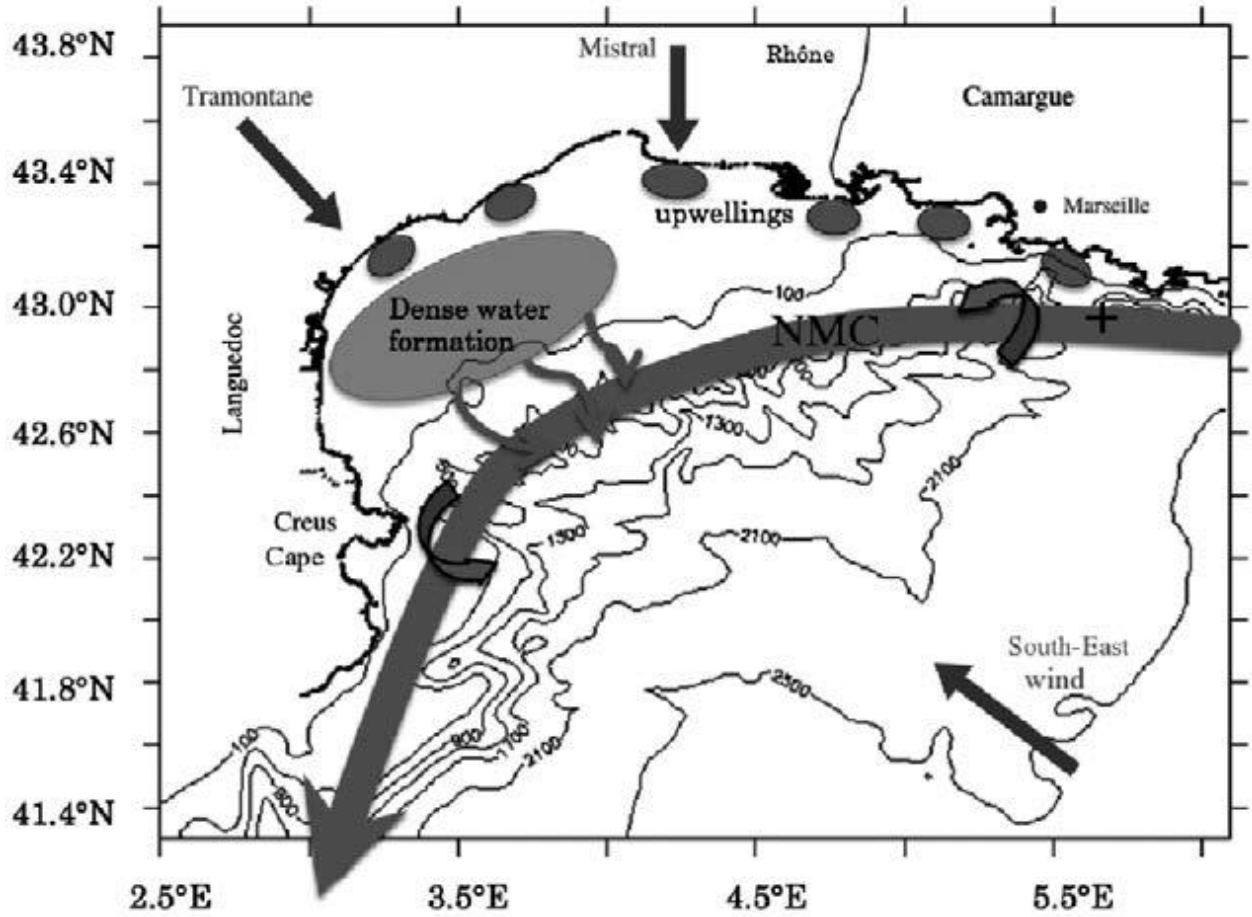


Figure 11: Bathymetry, and main forcings and physical processes of the Gulf of Lions. Two continental winds (the Mistral and the Tramon- tane) and an oceanic wind, mainly blowing from the southeast, are represented. The Rhône River is the main river discharging in the Gulf of Lions. The large curved arrow represents the NC flowing near the coast from the Ligurian Sea to the Balearic Sea. Mesoscale activity of the NC, upwellings and dense water formation and cascading are also represented *(Source: Duchez et al., 2012)*

In addition, winds have an important impact on the dynamics of this coastal area. Continental orography of the south of France makes winds to blow in two main directions: the Tramontane from the west/northwest and the Mistral from the north. In addition, southeast wind can also blow over this area, mainly in autumn and spring (Figure 11).

Numerous physical processes characterize the ocean circulation in the GoL, such as coastal up- and downwellings (Johns et *al*., 1992), winter dense water forming and cascading down the shelf break (Dufau-Julliand et *al*., 2004), local shelf circulation patterns (Petrenko et *al*., 2005) and inertial and diurnal motions (Millot et *al*., 1981).

The Northern Current (NC) is a coastal current constituting the north branch of the global cyclonic circulation of the north- western Mediterranean Sea. This cyclonic loop is generated by the Atlantic water entering the Mediterranean Sea through the Gibraltar Strait and is reinforced by the wind stress curl over the Liguro-Provencal Basin. This current is formed in the Ligurian Sea, and is

composed of equal proportions of the East and West Corsica Currents (Millot, 1990). It then flows westward along the Provencal coast until it reaches the continental bank of the GoL and then flows into the Balearic Basin.

The numerous irregular canyons across the shelf edge have an impact on the path of the NC, which is known to be significantly guided by the bathymetry (Echevin et al. 2003). This current has a clear seasonal variability (Albérola et *al*., 1995). During the winter, the NC has a low width (<30 km while it is be- tween 40 and 60 km wide during the summer), deep depth (>250 m compared to a depth lower than 200 m during the summer), intensity (flux about 1.5-2 Sv, Petrenko 2003) and trajectory, which remain close to the continental slope.

The NC flows southwestwards throughout the year along the continental slope as far as the Gulf of Lions and the Catalan Sea; it then circles the central zone of the basin where dense water formation of WMDW occurs in winter. All along its journey, the Northern Current is recognized as separate current with a flux of the same order (1-2 Sv) as the incoming and outgoing fluxes through the Strait of Gibraltar (Béthoux et *al*., 1982).

During winter, when the current is strongly influenced by the bathymetry, turbulent activity is enhanced and the NC generates 10-20 km amplitude meanders with wave lengths from around ten to one hundred kilometers as well as detaching eddies. This mesoscale activity is observed during the whole year by satellite imagery, although more eddies are frequent during the winter (Hu et *al*., 2009). After wind bursts, the NC can penetrate over the shelf: its variability, as well as the meanders and eddies that are associated with this current are responsible for a large part of the exchanges between the open ocean and the coastal waters (Albérola et *al*., 1995).

At seasonal time-scales, the geostrophic flux of the Northern Current is higher in autumn- winter (1.6 Sv between 0 and 300 m) and tends slowly to decrease until late summer. These seasonal changes of the Northern Current intensity seem not to be directly linked to the wind, but may result from different seasonal changes in the Eastern Corsican Current (0.8-1 Sv) and Western Corsican Current (0.8-1 Sv). The Eastern Corsican Current flux is at a maximum in winter and is thought to be driven by the different thermohaline conditions between the Liguro-Provençal Basin and the Tyrrhenian Sea. The Western Corsican Current reaches its maximum several months later, after geostrophic adjustment to the winter dense water formation. The resulting transport of the Northern Current is thus expected to be large during a relatively long winter period. From a dynamic point of view, the seasonal variability is mainly depicted as a well-defined episode of narrowing, deepening and shoreward shift of the Northern Current from late January to mid-March, following by a period of a generally wide and shallow Northern Current in summer-autumn.

The NC transports up to about 2 Sv ($2x10^6$ m^3/sec) of sea water between the coast and 33 km offshore (Béthoux et *al*., 1988). Speeds in the NC can be as large as 1 m/s at the surface and about 5 cm/s at depth of 400 m, with a decrease in summer. Its core is narrow and centered at 20 km or less from the shore in spring-summer, whereas it is broader and more distant from the coast in autumn. Béthoux et *al*. (1988) showed that the NC seasonal variability is related to the local river runoffs and to the winter deep-water formation processes. There are marked seasonal variations in the

mesoscale activity with a maximum in winter when the NC is deeper, stronger and narrower, closer to the coast and instability processes generate mesoscale structures.

In addition to the seasonal variability, the Northern Current displays an intense mesoscale variability that mainly appears mainly through meanders. These meanders have a relatively wide range of wavelengths (a few 10-100 km) and phase speeds (10-20 km/day), while their amplitude can be as large as the width of the current, i.e. a few tens of kilometers. Along the slope of the narrow shelf of the Catalan Sea, surveys with CTD, surface drifters and infrared imagery have revealed the occurrence of energetic mesoscale eddies and filaments in the frontal area. Current-meter records disclose the presence of seasonal and shorter period changes that are not directly related to local winds. Mesoscale activity increases from autumn to mid-winter, suddenly falls in late winter and continuously decreases afterwards until summer.

While the main branch of the Northern Current follows its route westwards along the continental rise that separates the Gulf of Lions from the open ocean, part of the current can intrude into the shelf and act as a forcing for the Gulf of Lions dynamics. Over this shallow shelf, wind forcing and buoyancy forcing are the other intense coexisting forcing. Strong northerly and northwesterly continental winds, respectively named Mistral and Tramontane frequently blow over the gulf for a few days and sometimes weeks. These cold and dry winds are constrained by the orography and can be intense. They induce upwelling in the eastern part of the gulf cooling of the surface waters, and dense water formation in winter. In autumn and spring, less frequent southeasterly wind events can occur and produce an intensive westward current along the coasts of the gulf. In the Gulf of Lions, buoyancy effects are related to the Rhône fresh water discharges. The Rhône River is the dominant runoff of the Western Mediterranean Sea; its plume extends occasionally over hundreds of kilometers.

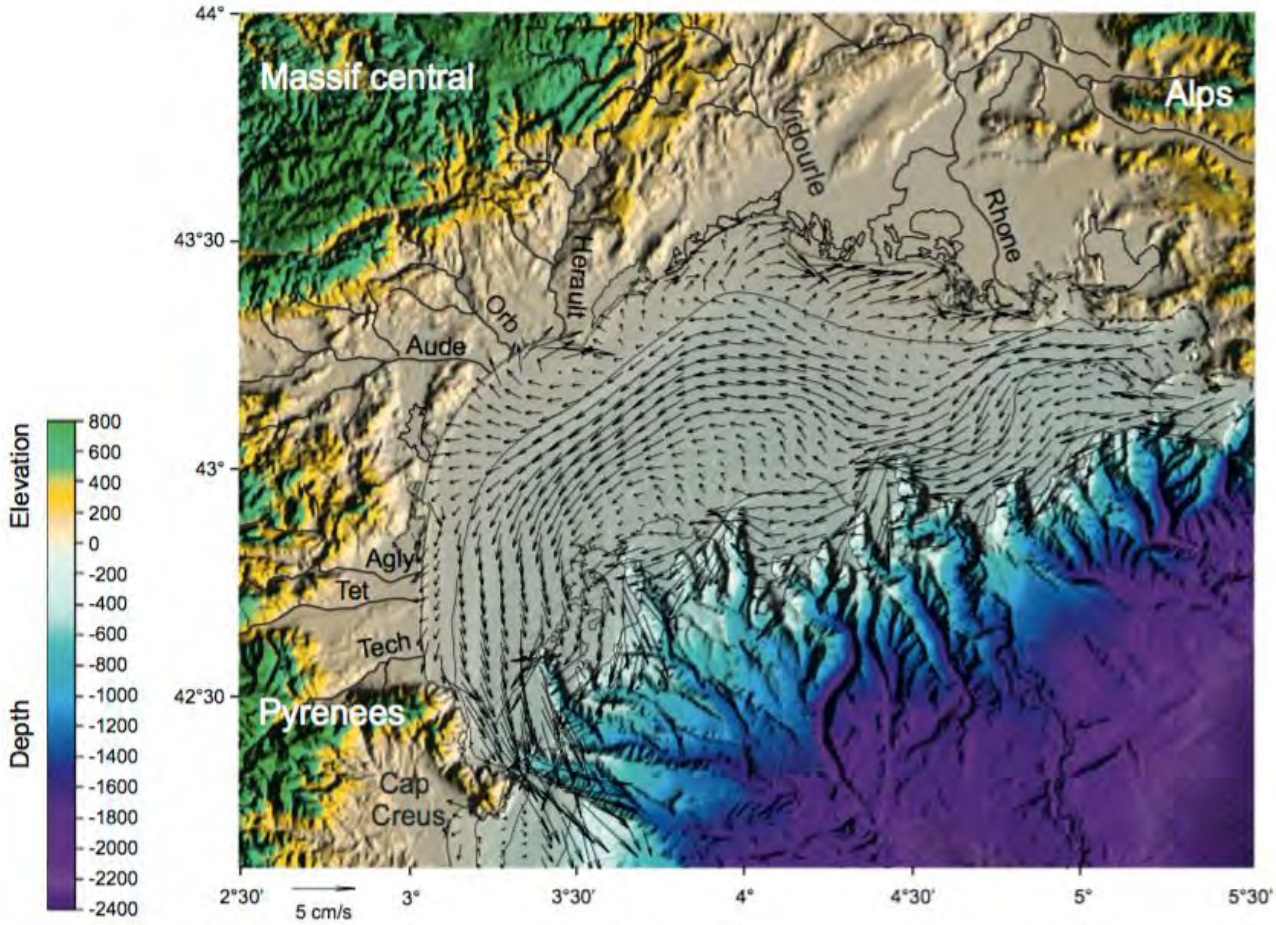


Figure 12: Bottom currents pattern (*Source: Durrier de Madron et al., 2008*)

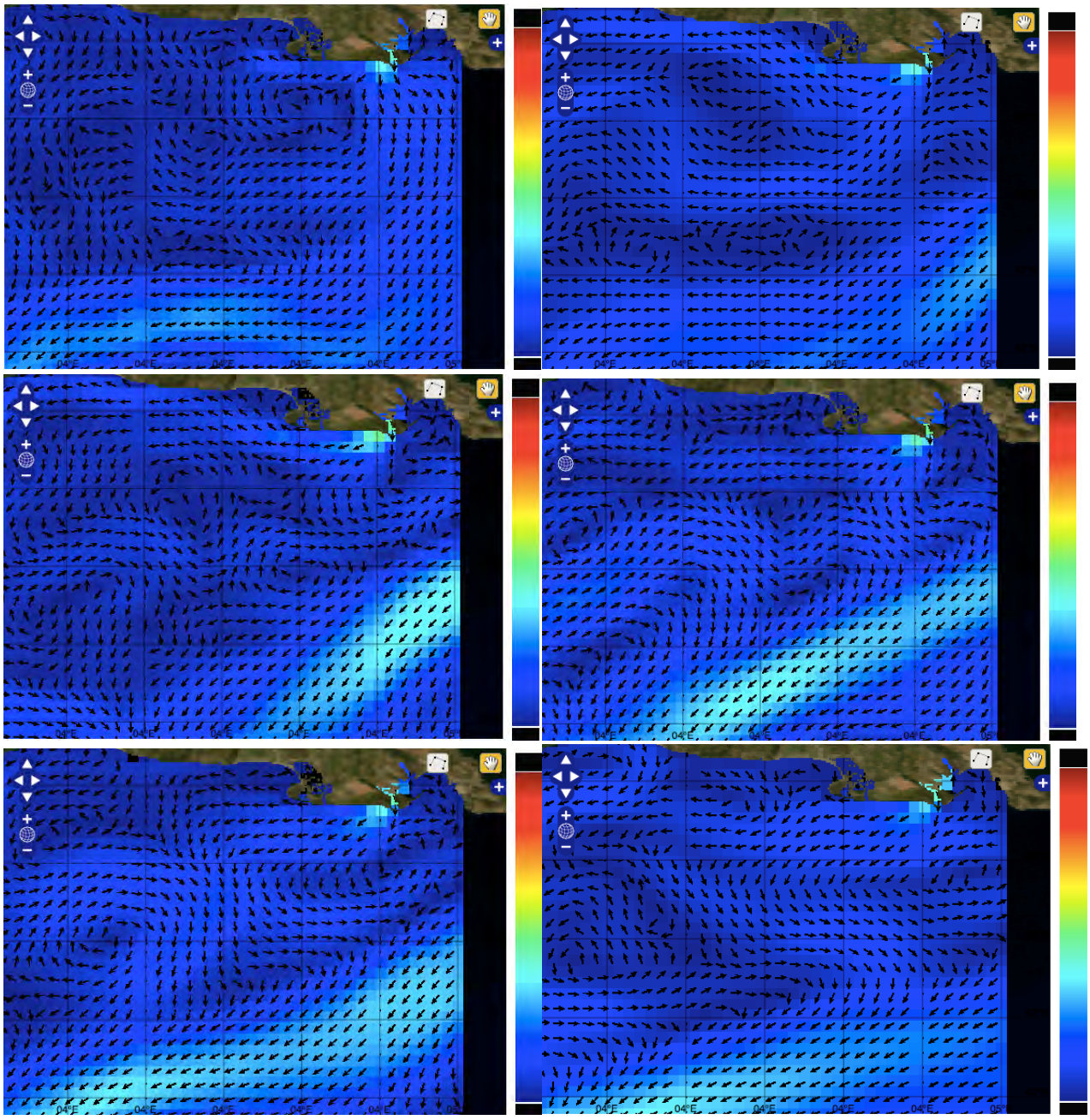


Figure 13: Monthly mean current pattern, surface values. Scale: 0-1 m/sec (*Source: CMEMS, product IBI ANALYSIS FORECAST PHYS 005 001*)

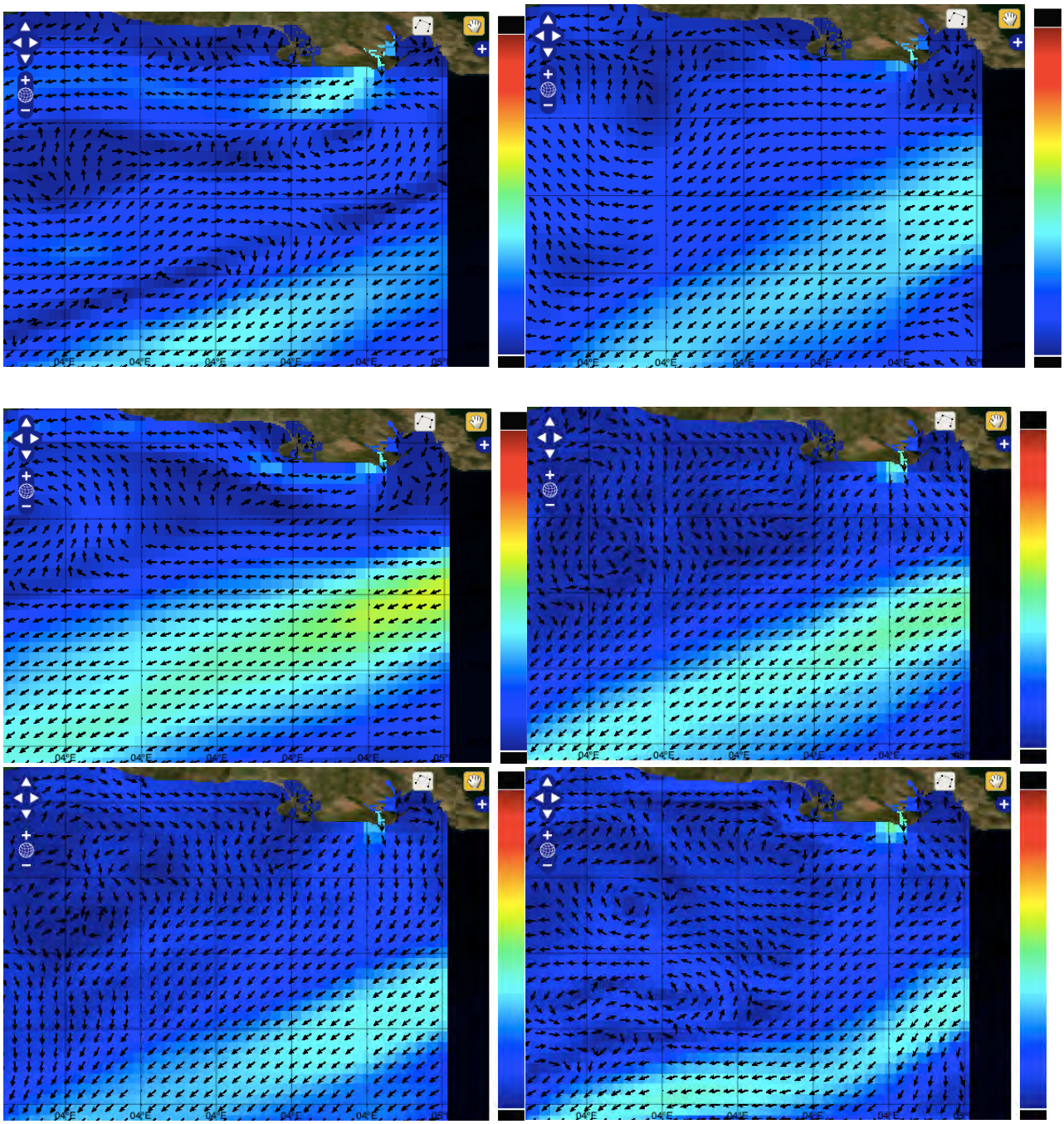


Figure 13, continue.

3.1.3 Waves

In the Gulf of Lions, the northerly waves prevail over the entire year, showing a very small heights in summer. The second dominant direction in the area is the southerly to southeasterly waves having larger heights than the northerly waves.

Sea state is generally quiet in this area but seasonality is marked and highly energetic waves (heights of more than 5 m) can be observed from October to March. Waves with heights above 3 m

are more frequent on the Languedoc coast than on the Roussillon coast but extreme waves reach greater heights in Banyuls than in Sète. These large waves come either from the south to impact the Languedoc coast or from the east to impact the Roussillon coast.

Annual statistics for the significant height and mean spectral period in Banyuls and Sète showed that overall wave conditions in the Gulf of Lions were not very energetic. More than 80 % of the waves had heights lower than 1.5 m and periods less than 5 s. Thus, the annual average of wave height is below 1 m at both sites.

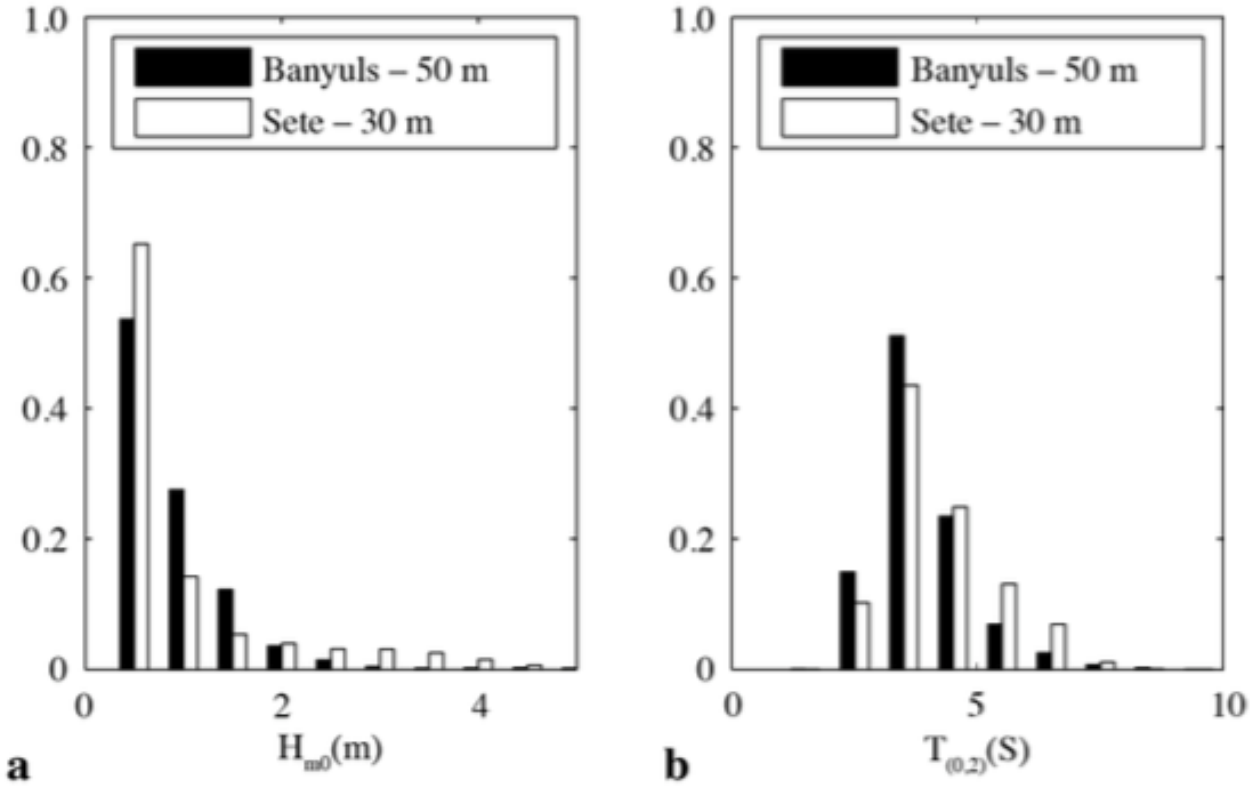


Figure 14: Waves heights and periods in Sète and in Banyuls *(Source: Guizien, 2009)*

In Sète, wave heights larger than 3 m are five times more frequent than in Banyuls. Wave periods are longer in Sète than in Banyuls on average because intermediate waves (wave periods between 5 and 7 s) are twice as frequent in Sète. The same difference between Sète and Banyuls was observed in the proportion of wave heights smaller than 3 m and wave periods shorter than 7 s.

Wave conditions in autumn and winter were more energetic than in summer and spring at both sites, with larger significant heights and mean spectral periods. This is due to the occurrence of energetic wave events during those seasons, even if their overall frequency remained low: less than 2.5 % of waves have a period longer than 7 s at both sites. At both Banyuls and Sète, waves can be highly energetic, with heights larger than 5 m and periods longer than 9 s (observed in autumn and winter). At Sète, two extreme wave events were observed over the periods 1988-2001 and 2003-2006: the significant height reached 6.1 m on 02/21/2004, and 7.36 m on 12/16/1997. Based on a

Gumbel law fit these heights would have return periods of 10.5 and 21 years, respectively. These return periods are either within or close to the overall data collection duration of 16 years at Sète. At Banyuls, three extreme wave events were observed during the 2002-2005 period which lies outside the 80 % confidence interval around the Gumbel fit law: the significant height reached 6.25 m on 10/17/2003, 6.8 m on 02/21/2004 and 8.03 m on 12/4/2003. Return periods for these heights were also estimated using the Gumbel law fit, giving 3, 5 and 10 years, respectively.

Directional histograms for Sète and Banyuls show the differences in wave conditions along the Gulf of Lions coastline. While southerly waves reached Sète, they were not observed in Banyuls. Conversely, northerly waves are only observed in Banyuls. At Banyuls, easterly waves are more frequent and tend to have a larger height compared to those observed in Sète, while this was found to be the opposite for southeasterly waves. Nevertheless, two propagation directions dominated: 33 % of waves originated from the East to South-East (90 to 150 degrees from true North) and 25 % of waves came from the North to North-East (330 to 30 degrees from true North). No wave coming from the South to West was recorded.

Waves with periods longer than 7 s only came from the East to South-East quadrants and this sector also corresponded to the highest waves. The longest wave period (10 s) and greatest height (8.03 m) were observed for a southeasterly wave. Northerly wave heights and periods remained lower than 3 m and 6 s, respectively. In contrast, during the same time period, northwesterly winds (300 to 360 degrees from true North) displayed a larger intensity (13.4 $m.s^{-1}$ on average, 34 $m.s^{-1}$ at the maximum) compared to southeasterly winds (8.3 $m.s^{-1}$ on average, 28 $m.s^{-1}$ at the maximum). Moreover, northwesterly winds clearly dominated (66 % of the time) with speeds larger than 10 $m.s^{-1}$ during more than 30 % of the time and greater than 20 $m.s^{-1}$ during more than 10 % of the time. Southeasterly winds accounted for 25 % of duration. Other wind sectors were only marginally present in the area. Wind and wave directions were poorly correlated, whatever the direction (R^2 = 0.3, $p < 0.01$). The correlation between wind intensity and wave height is slightly larger (R^2 = 0.55, $p < 0.01$), and increased further when restricted to northerly winds and waves (R^2 = 0.71, $p < 0.01$). Wave period and wind intensity were poorly correlated, whatever the direction ($R^2 < 0.3$, $p < 0.01$).

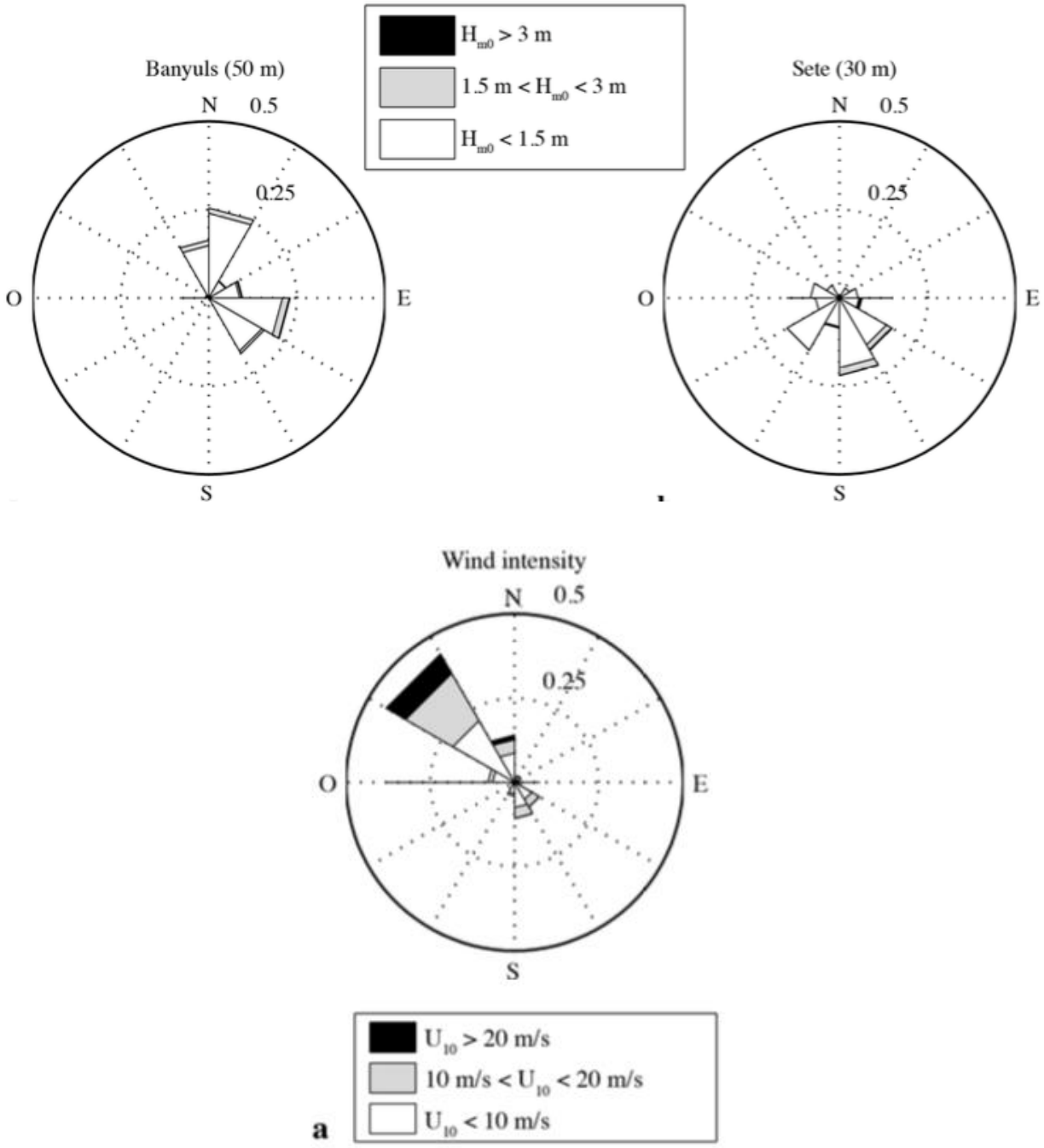


Figure 15: Windroses in Banyuls and Sete *(Source: Guizien, 2009)*

The wave climate spatial variability along the Gulf of Lions can be attributed to the coastline orientation which changes from North-South in the Roussillon to East-West in the Languedoc region. Indeed, in the latter region, northerly waves are absent due to the very short fetch (distance over which the wind blows) for northerly winds. In the Roussillon, the Cape Creus promontory filters out southerly waves.

The change in coastline orientation also partly explains the difference in the wave ages observed at both sites. At Banyuls, the development of northerly waves is limited by a northern fetch of about

100 km long. As a result, northerly waves are less energetic (height lower than 3 m) than southeasterly or easterly ones, and still under wind action when they reach Banyuls (good correlation between wind and wave direction). For the Banyuls site, wind fetch is at a maximum towards the east (800 km) and limited towards the south.

In Sète, it is at a maximum towards the south (1500 km) and limited towards the east. Only the southeast direction offers a similar fetch distance for both sites. For Banyuls, extremely energetic waves were observed coming from the east or from the southeast. Still, these waves were not fully established, although they were no longer under wind action at the observation site (low correlation between wind and wave direction). In fact, these energetic easterly or southeasterly waves may not have sufficient time to establish because they propagate rapidly and reach the Roussillon coast early after their formation.

At Sète, two groups of large waves were observed. The first group consisted of an established swell with heights of up to 4 m and less steep than predicted in deep water. At Banyuls, such swells were not observed, suggesting that these came from the south. The smaller steepness value also indicates that these long swells (mean period longer than 10 s) were already modified by the limited water depth (30 m) at the observation site in Sète. The second group contained the highest waves. It was observed in Sète and in Banyuls. Meanwhile, the highest wave tends to be younger in Sète than in Banyuls indicating a smaller travel distance after their generation to reach Sète. Furthermore, the highest wave tends to be smaller in Sète than in Banyuls. This suggests the highest waves in the region more frequently originate from the east than from south-east, which is also consistent with the more frequent return period for extreme events in Banyuls compared to Sète. Indeed, a Gumbel law fit suggests an 8 m height would have a return period of 50 years in Sète and 10 years in Banyuls.

Arena et *al*. (2015) have calculated the wave parameters for two points corresponding to 2 buoys in the outer part of the Gulf of Lions, named P25 and P26.

Table 1: Coordinates of the investigated points, water depth and distance from coast (*Modified from Arena et al., 2015*)

Marker	Latitude [°N]	Longitude [°E]	Depth [m]	Distance [Km]
P1	35,70000	-3,00000	866	29.1
P2	36,95000	2,00000	2680	41.8
P3	36,95000	4,37500	559	6.50
P4	37,20000	8,50000	133	30.0
P5	36,38750	11,56250	224	65.0
P6	34,70000	12,75000	120	160.0
P7	33,26250	13,18750	237	40.0
P8	31,38750	17,18750	139	28.5
P9	32,45000	20,00000	257	27.0
P10	31,95000	20,525,5	806	45.0
P11	31,45000	28,50000	1382	40.0

P12	31,57500	33,18750	244	38.0
P13	33,45000	34,75000	1516	47.0
P14	35,95000	30,75000	2595	44.0
P15	35,13750	23,25000	3557	30.0
P16	36,20000	21,68750	3467	69.0
P17	38,20000	19,56250	3513	70.0
P18	38,45000	17,00000	1424	36.0
P19	42,20000	17,50000	1118	68.0
P20	42,38750	14,75000	98	24.5
P21	38,20000	14,06250	1290	18.4
P22	36,57500	13,68750	609	42.2
P23	40,26250	13,50000	1902	94.0
P24	43,95000	9,00000	880	43.0
P25	42,57500	6,25000	2547	52.0
P26	41,95000	3,50000	339	22.5
P27	40,07500	1,00000	113	61.0
P28	42,20000	8,00000	2795	46.5
P29	42,20000	10,00000	359	36.5
P30	40,45000	7,50000	2624	59.0
P31	39,95000	10,00000	1548	25.5

Table 2: Wave parameters of point of interest at different return periods

Location	H_s [m]	H_{smax} [m]	u	w [m]	k1 [h]	k2 [m^{-1}]	Φ [KW/m]	h (5 yr) [m]	h (10 yr) [m]	h (20 yr) [m]	h (50 yr) [m]	h (100 yr) [m]
P25	1.39	8.69	1.545	2.024	73.02	2.30	11.0	8	8.5	8.9	9.5	9.9
P26	1.23	12.52	1.270	1.320	73.21	2.64	8.7	6.8	7.2	7.7	8.3	8.7
P27	0.86	6.58	1.052	0.782	72.87	1.01	4.1	5.8	6.3	6.8	7.4	7.9
P28	1.25	7.93	1.198	0.736	92.46	0.01	11.4	4.4	4.8	5.1	5.5	5.8
P29	0.65	8.27	0.900	0.503	80.41	0.22	2.2	5.3	5.8	6.4	7.1	7.6
P30	1.40	10.27	1.176	1.499	100.11	0.25	15.1	9.2	9.9	10.6	11.5	12.1
P31	0.68	7.47	0.924	0.580	81.70	0.46	2.8	5.7	6.2	6.8	7.5	8.1

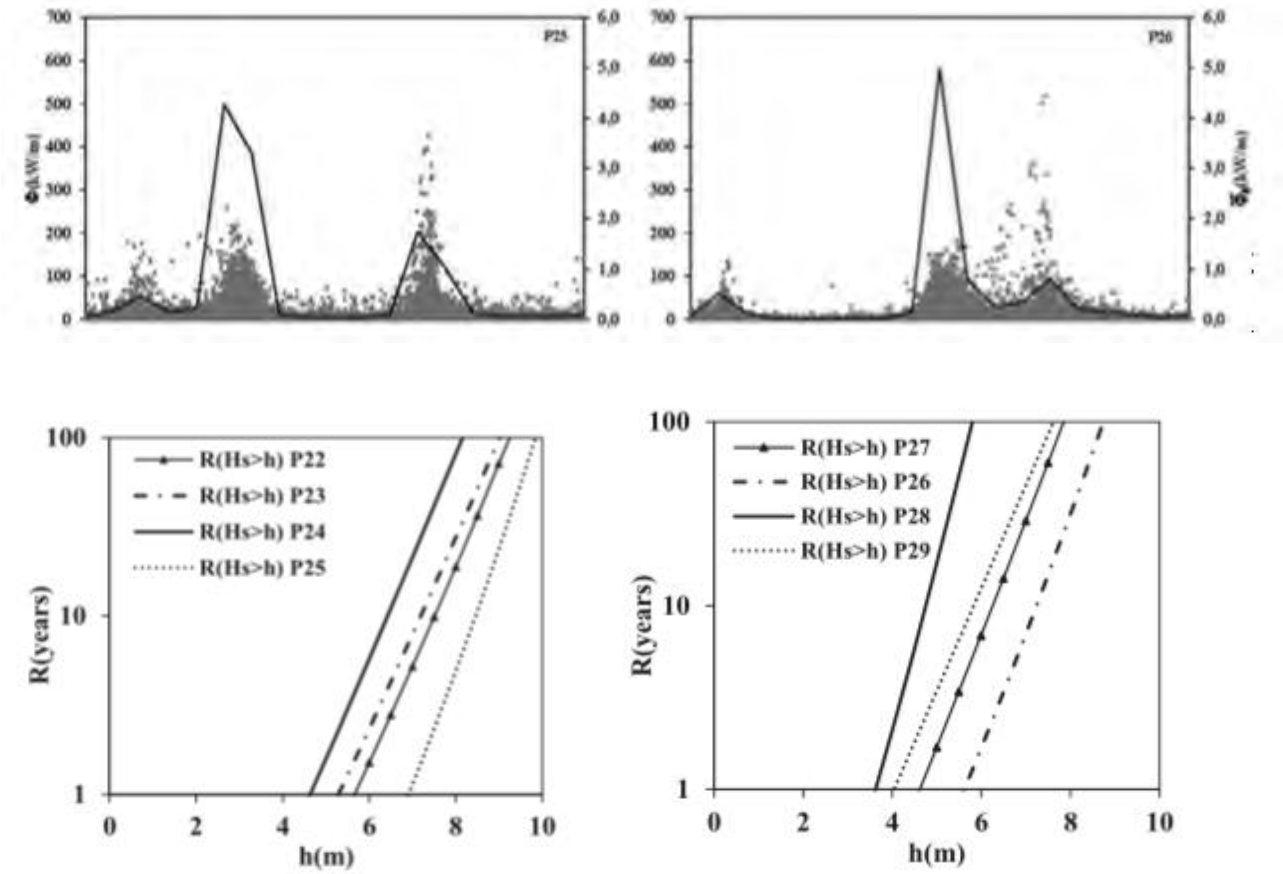


Figure 16: Return periods at investigated points (*Source: Arena et al., 2015*)

Waves are physical drivers able to condition and structure ecosystems functioning. Indeed, the input of wave energy to nearshore ecosystems causes water column mixing and seabed disturbances that affect in many, sometimes antagonistic, ways their functioning and structure (Grémare et *al.,* 2003). Waves may enhance recycled production by releasing nutrients from permeable seabeds through advection (Precht & Huettel 2003) and promoting non-permeable oxygenation by enhanced diffusion. But, sediment disturbance by waves may also enhance the release of toxic gases like sulfur and buried contaminants, making them available for trophic transfers. Finally, waves may also disturb fauna assemblages by redistributing some species (Commito et *al.,* 1995) or potentially killing others. The southern coasts of France are generally quite calm, and waves seasonality can be rather pronounced: in Banyuls, wave heights remained lower than 2 m in summer, while in winter they reached comparable values to the ones observed in Yeu Island. Furthermore, extremely energetic wave events may also be observed in the Mediterranean, with return periods comparable to the Atlantic (10 years in both Biscarrose and Banyuls for a wave with 8 m significant height), although both regions exhibits a significant spatial variability due to the effects of coastline orientation or bathymetry. In summary, waves are certainly driver as important for Mediterranean ecosystems as for more energetic ones, but should be viewed clearly as an extreme perturbation, both spatially and temporally.

3.1.4 Winds

The Gulf of Lions is a wind-dominated area, with frequent episodes of strong winds blowing. The effects of such wind intensity have an effect on ocean circulation and waves, although the general setting of the Gulf of Lions limits the fetch of these winds and thus the height of the waves they produce (significant wave height is generally lower than 2 m). The strongest wind episodes come from the northerly winds Tramontane and Mistral, which blow intensively during the winter months. The Tramontane episodes promote local downwelling along the western coastline of the gulf, while the Mistral wind induces local upwelling along the northern. Both winds induce distinctive and opposite circulation cells on the continental shelf, favouring the intrusion of slope waters in the eastern and central parts, promoting at the same time the export of shelf water towards the south-western end of the Gulf (Millot, 1990).

The cold and dry northern winds that blow intensively during autumn and winter months cause the rupture of the water column summer stratification. The cooled shelf waters eventually lead to the formation of lenses of homogeneous coastal waters, denser than the offshore waters, leading to a process of baroclinic instability (Ulses et *al*., 2008). The density of surface waters can approximate that of the deeper ones, forming a bottom gravity plume that moves across the shelf and cascades down the continental slope until it reaches its equilibrium density (Millot, 1990). The presence of the river inputs along the continental shelf, mainly due to the Rhône River, implies that the density of the newly formed dense water only sinks down to a few hundred metres, flowing mostly along canyon heads. Because of the relatively low speed values induced by cascading, this phenomenon is unable to excavate the canyons and their associated furrows, but it does have an impact on sediment dispersal along the gulf (Millot, 1990).

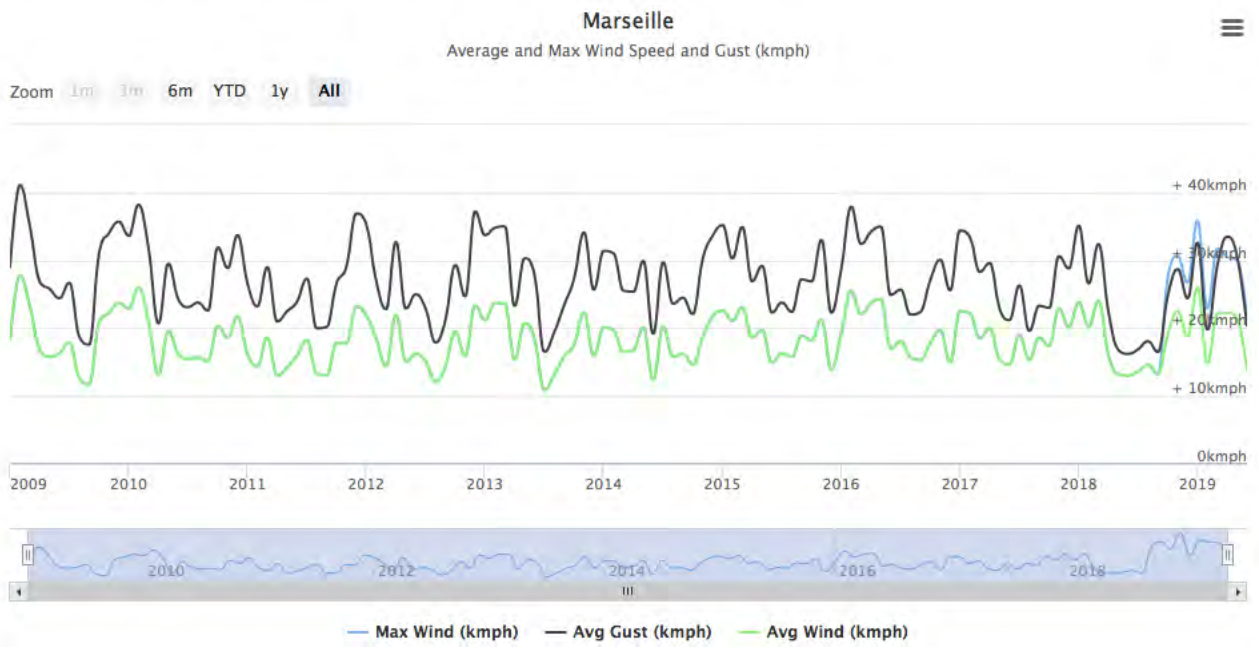


Figure 17: Average and maximum wind speed in Marseille

3.1.5 Sea water temperature

Temperature of superficial waters ranges in the Gulf of Lions from 10 °C in costal areas in winter to 25°C in the central part of the Gulf.

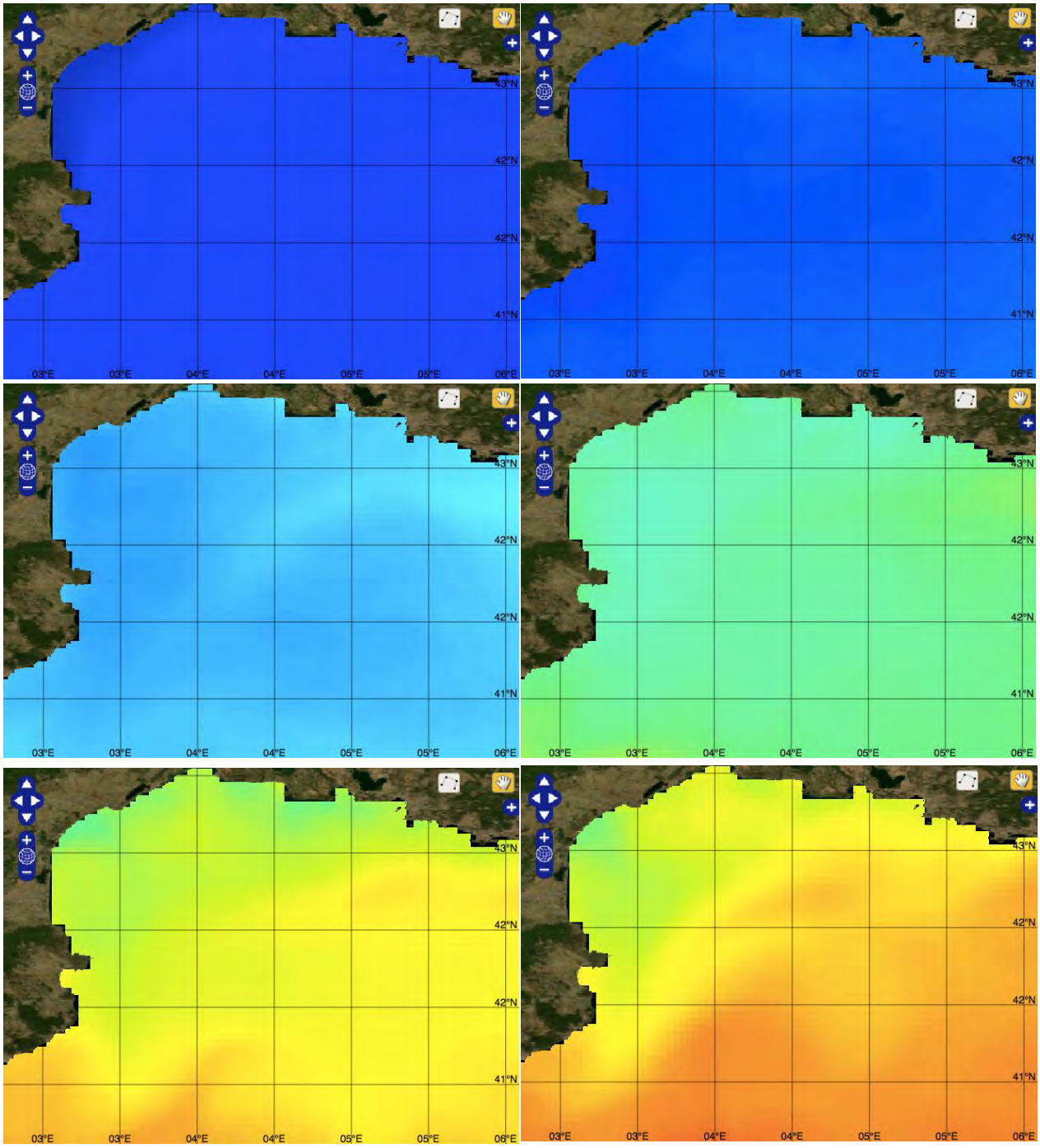


Figure 18: Monthly mean temperature pattern, surface values
(*Source: CMEMS, product IBI ANALYSIS FORECAST PHYS 005 001*)

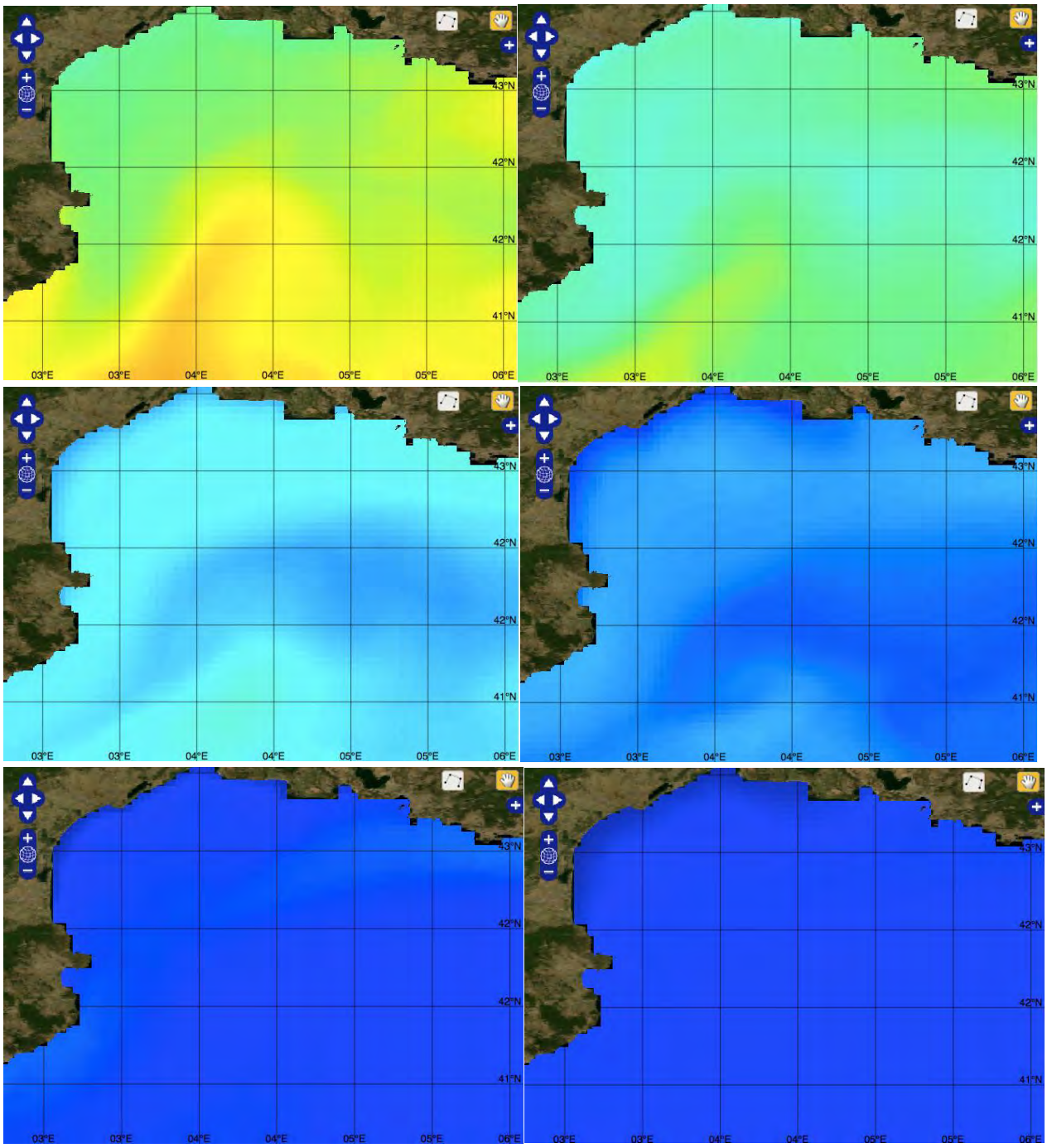


Figure 18, continue.

The vertical stratification that begins to establish in spring, proceed to form a definite thermocline during summers, lasting until fall. The occurrence of intense storms in the late autumn/ beginning of winter disrupts the thermal stratification, to lead to a homogeneous water column, at least in the BGF selected area.

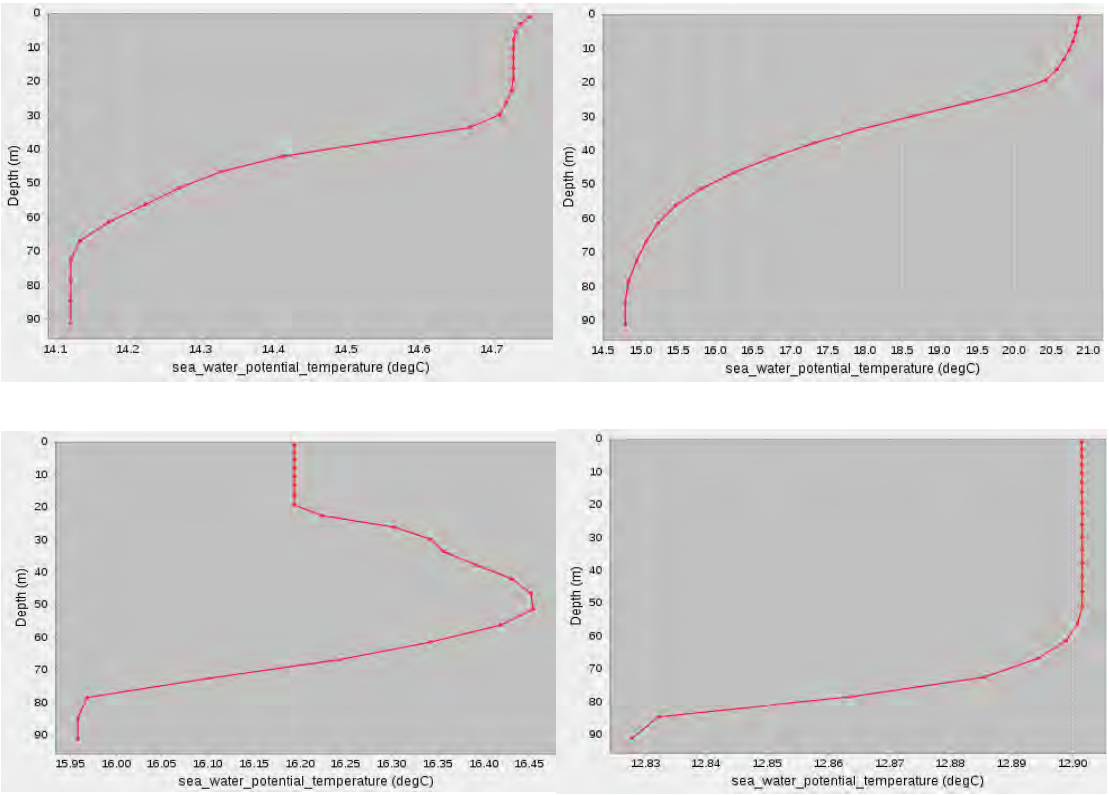


Figure 19: Seasonal thermal stratification
(*Source: CMEMS product IBI ANALYSIS FORECAST PHYS 005 001*)

The seasonal variability that can be found in the stratification of surficial waters has a great influence in the hydrological setting of the Gulf of Lions. From spring to autumn, the thermocline is present at 10-20 m depth on continental shelf waters, separating an upper layer with a mean temperature of about 20°C from a bottom layer with minimum temperature around 13.5°C on the shelf. This thermocline facilitates the movement of surface waters over the bottom layer. When cold temperatures arrive, the stratification disappears and the waters become homogeneous, especially in the offshore region of the gulf (Millot, 1990).

3.1.5 Rain

In autumn, the Mediterranean coasts are often prone to heavy precipitation events (HPEs) (typically more than 100 mm in 24 h) that can lead to flash floods. These situations are generally linked to the presence of cold air in altitude blocked over the Iberic Peninsula that induces a rapid diffluent southerly flow in the upper layer over Western Europe. HPEs frequently occur in southern France when low-level southerly winds advect warm and moist air towards hilly topography such as the Cevennes (the southern part of the Massif Central). The convective available potential energy is then at a maximum. Mountains or wind convergence on the sea allow the triggering and enhancement of convection. When local feedbacks are at play and/or when synoptic conditions evolve slowly, convective systems can become stationary and can lead to severe flash floods (Nuissier et *al*., 2008).

The Cevennes is separated from the Alps to the east by the Rhône valley and from the Pyrenees to the west by the Aude valley. This layout is such that the region is also subject to strong winds when westerly to northerly winds blow across France. In fact, the flow is then channeled by the valleys in southern France and accelerates: the Mistral (Drobinski et *al*., 2005;) and the Tramontane (Drobinski et *al*., 2001) blow respectively from the Rhone and the Aude valleys. These winds are particularly cold and dry, inducing strong evaporation over sea and the whole north-western Mediterranean can cool by a few degrees when they blow for several days in autumn. The Gulf of Lions is located just south of the Cevennes, where strong northerly wind and intense air sea flux enhance the oceanic cyclonic circulation with mixing and entrainment in addition to cooling of the sea surface. The deepening of the oceanic mixed layer in autumn is a pre-conditioning of strong deep convection around 428N 58E that can occur in winter. The sea surface temperature (SST) in the Gulf of Lions can thus change from 20 °C in summer to 10 °C in winter.

If such strong air sea interaction events occur before a precipitation event, the cooling of the sea can be such that it induces changes in the thermodynamic properties of the atmosphere when southerly winds blow over it towards the Cevennes mountains. In fact, the Mediterranean Sea can directly contribute to the heat and moisture feeding of the systems (Duffourg and Ducrocq, 2011) and changes in the SST can change the precipitation amounts of HPE (Berthou et *al*., 2014).

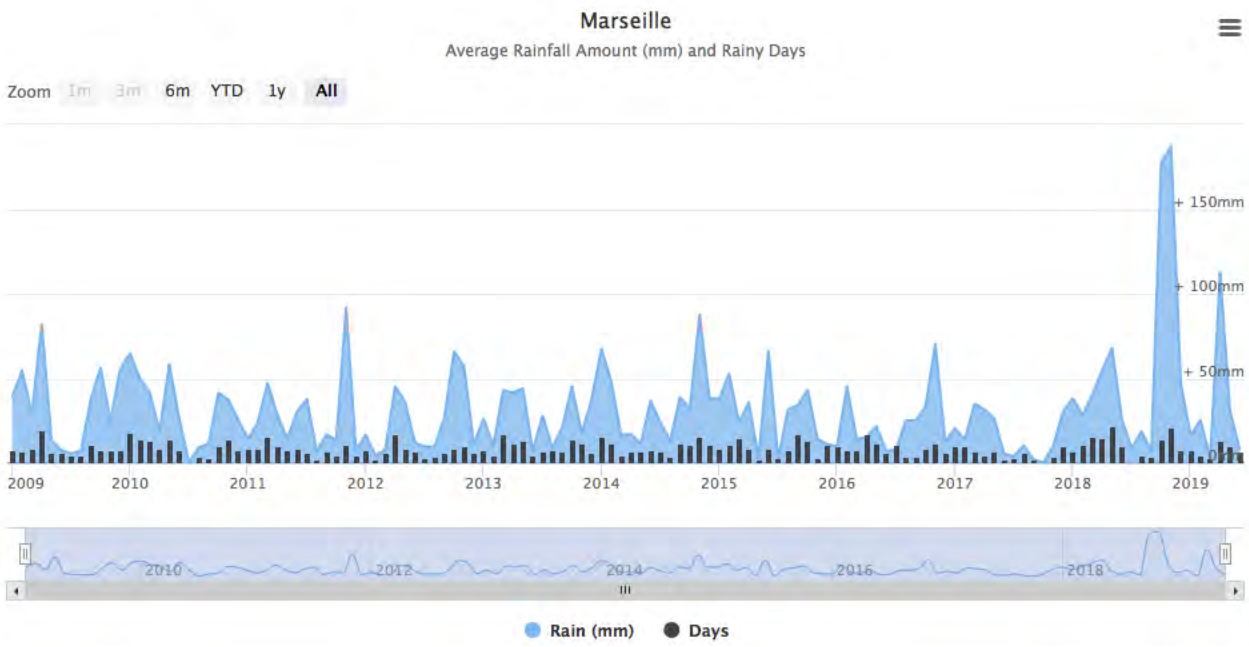


Figure 20: Average rainfalls and rainy days in Marseille

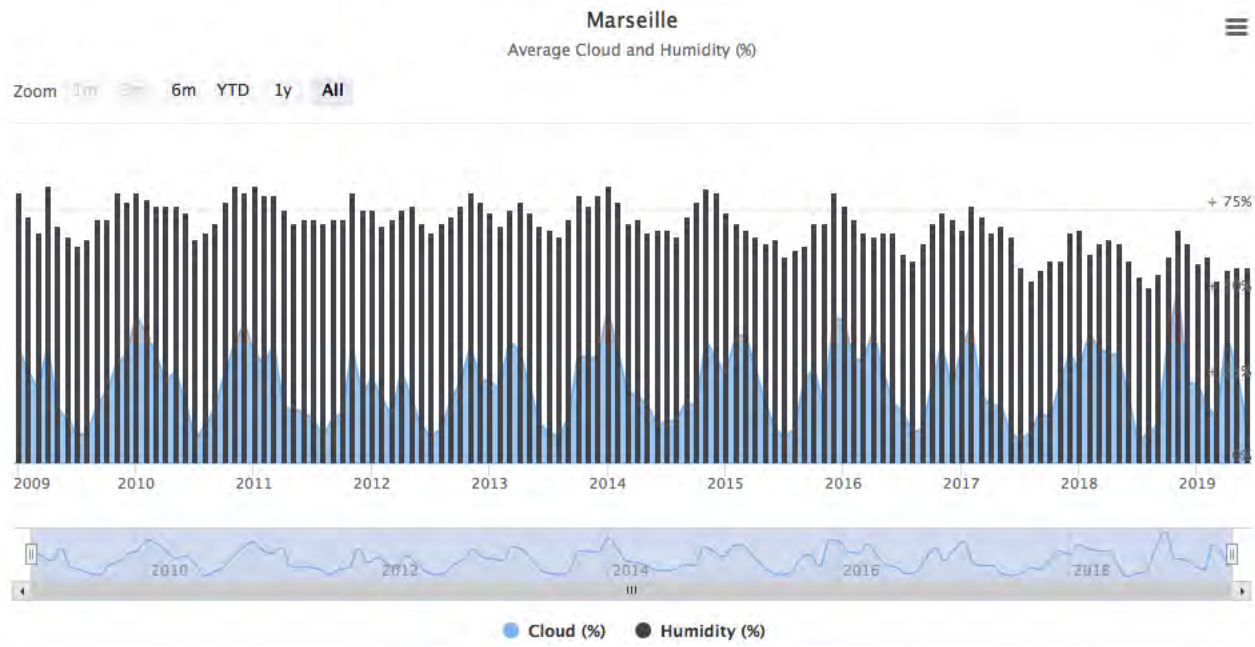


Figure 21: Cloud coverage and humidity in Marseille

River discharge

Topography, sediment supplies and water circulation mainly determine the depositional system of the Gulf of Lions. The sediment inputs irregularly discharged over the years due to the Mediterranean climatic conditions has influenced the geological features of the shelf and slope. Almost 11 million tons of fine-grained sediment are discharged annually by the Rhône and the other north-western Mediterranean rivers that flow into the gulf. The Rhône River alone supplies most of the terrigenous sediment to the Gulf of Lions continental shelf, accounting for almost 80-90% of the new terrigenous inputs (Bourrin and Durrieu de Madron, 2006).

This fluvial system is characterised by a strong inter-annual variability, where the discharge of large amounts of sedimentary material can occur within just a few days (Bourrin and Durrieu de Madron, 2006). The Rhône River largely contributes to the input of freshwater and suspended-sediment discharge to the Gulf of Lions, mainly due to the large catchment area it encompasses, of nearly 100,000 km^2. It represents 80-90% of the Gulf of Lions freshwater input, with mean liquid discharge at the mouth of 1,700 m^{3}s^{-1} and peak discharges of up to 13,000 m^{3}s^{-1} (Data from December 2003, Arnau et *al*., 2004), averaging annual discharges of 55,000 million m3 of water per year (Bourrin and Durrieu de Madron, 2006). As it can be expected, highest river discharge periods are generally found in spring and autumn. The freshwater input of the Rhône can be negligible from a dynamical point of view since its values are 1000 times lower than the flux of the general circulation (Millot, 1990).

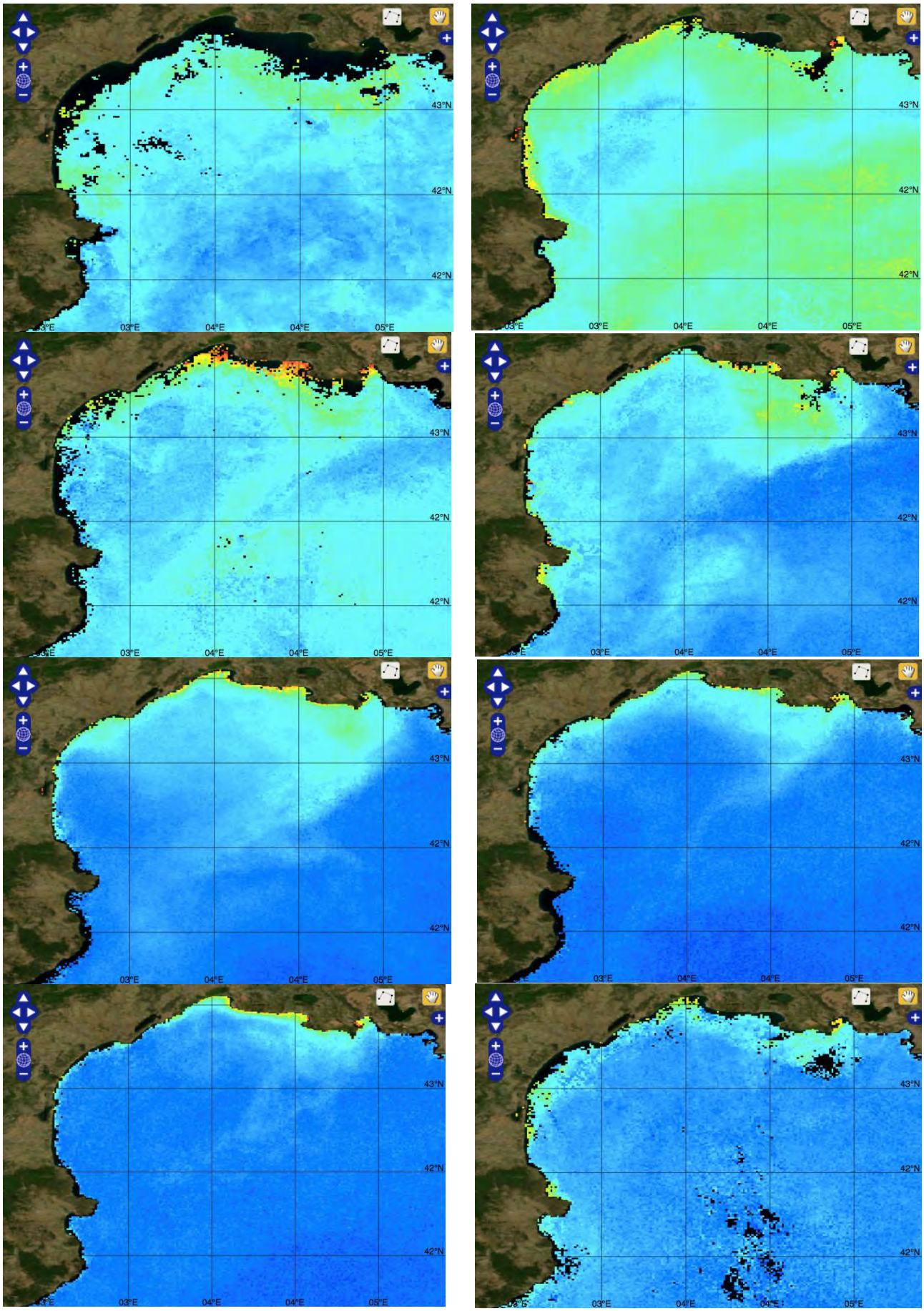
The dominant current system on the Gulf of Lions flows towards the southwest. Hence, the associated freshwater plume produced by the Rhône river sediment discharge tends to get deflected south-westward by the general water-mass movement, moving sediments along the coastline. River

plumes usually expand over the continental shelf at a relatively short distance from the coast. In situations when Mistral and Tramontane winds blow, the brackish waters produced by the Rhône can reach the outer part of the shelf and slope, located a few kilometers away from the coastline. This situation creates a wind- induced coastal upwelling of deeper and denser waters.

3.1.6 Photosynthetic active radiation

Figure 22: PAR reaching bottom (*Source: EMODnet,* www.emodnet.eu)

As visible, the photosynthetic active radiation penetration is restricted to the shallow coastal zones.


43°N
42°N
42°N
03°E
04°E
04°E
05°E

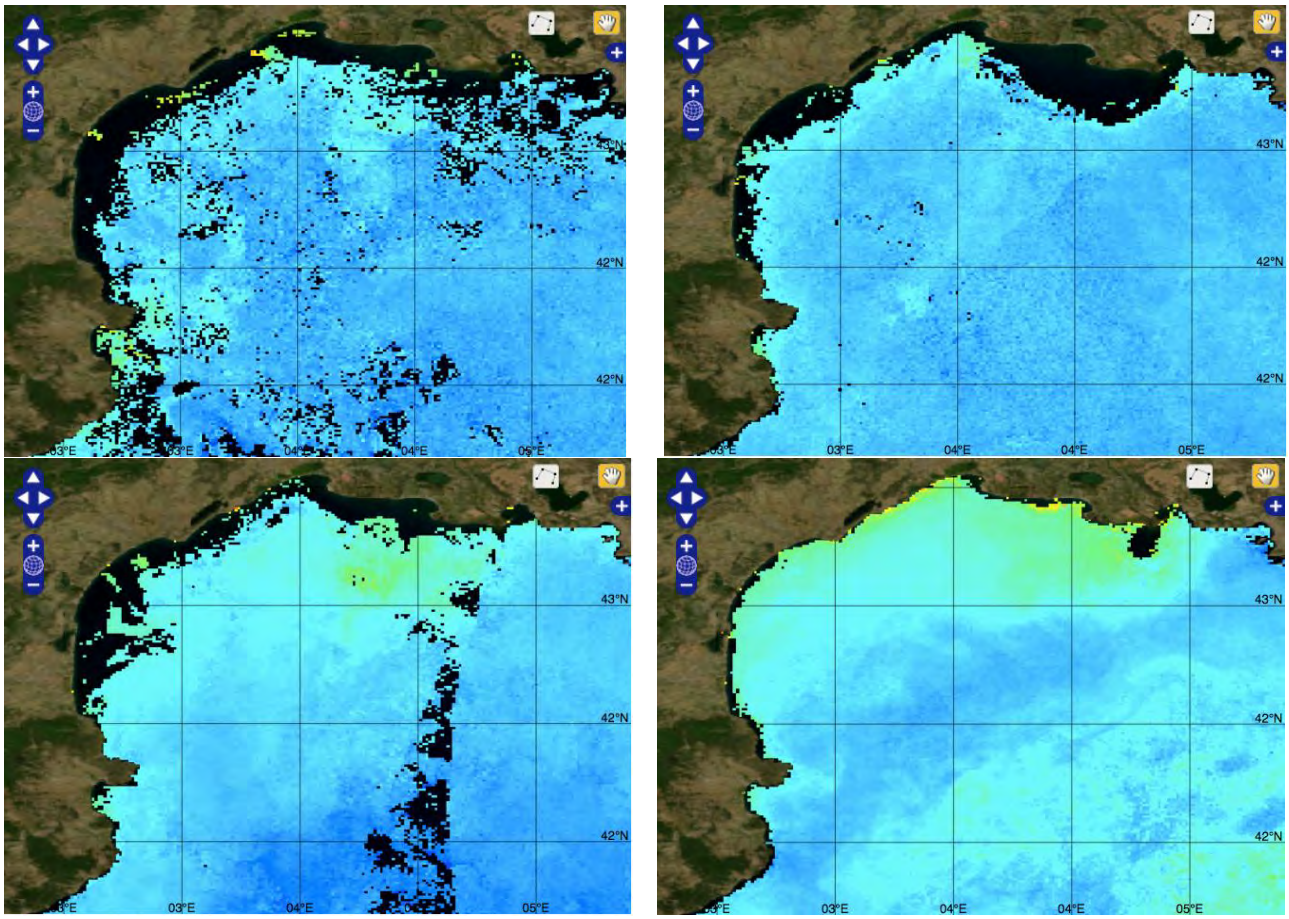


Figure 23: KD absorbance per volume (m^3) of 490 nm wavelength
(*Source: CMEMS, product IBI ANALYSIS FORECAST PHYS 005 001*)

3.2 NATURAL ENVIRONMENT

3.2.1 Protected areas

For further details see Protected Areas in Environment Legal Framework (2.2.8).

3.2.2 Birds

The NW sector of the Mediterranean, and the Gulf of Lions in particular, are among the hotspots of marine productivity as a result of water dynamics, bathymetry and the influence of the river Rhône. High productivity extends over the continental shelf to the shelf slope. Human fishing activities mimic the same distribution since, with the exception of pelagic longlining, they are generally restricted to reachable depths. The presence of fishing vessels acts as a visible mark for seabird distribution, and only one species has a spatial distribution that does not overlap with the main fishing grounds.

Seabirds from colonies situated 150-500 km away fly 4-16 hours to forage in the Gulf waters. The Mediterranean seabird community contains several endemic taxa, including some species that

are threatened globally, and the area is important for their conservation. All four Procellariiforms (petrels and shearwaters) present in the Mediterranean are endemic taxa: two at species level (*Puffinus mauretanicus* and *Puffinus yelkouan*) and two at subspecies level (*Calonectris d. diomedea* and *Hydrobates pelagicus melitensis*). Besides, one endemic cormorant (Shag Phala*crocorax aristotelis desmarestii*), three gulls (Mediterranean *Larus melanocephalus*, Audouin's *Larus audouinii* and Yellow-legged *Larus michahellis michahellis*) and one tern (Lesser-crested *Sterna bengalensis*) also originate from the Mediterranean region.

Yelkouan shearwater *Puffinus yelkouan* has recently been uplisted to IUCN 'VU' status due to ongoing rapid population decline, caused by extremely low breeding success and adult survival owing to fisheries bycatch and predation by introduced mammals (BirdLife International, 2011). Some 10,000 birds feed in central and coastal waters of the Gulf of Lions during the breeding season, although the French breeding population is 'only' 1400- 1700 pairs.

The distribution of the critically-endangered Balearic shearwater *Puffinus mauretanicus* extends to the S coastal waters of the Gulf of Lions, where several 100s-1000s may concentrate for foraging, a large proportion of the global population. The species feeds on small pelagic fish and also on trawler discards, and is at threat from bycatch in longline fisheries.

Cory's shearwater *Calonectris diomedea* is the most pelagic of Mediterranean shearwaters. The endemic Mediterranean population is large, but the species suffers the heaviest bycatch toll of all seabirds in longline fisheries, and is declining in several areas. The Gulf of Lions attracts foraging birds from local as well as distant colonies (Corsica, Sardinia, Balearics), so is important at regional scale.

The Mediterranean Storm-petrel *Hydrobates pelagicus melitensis* has a disperse distribution over the outer half of the continental shelf of the Gulf of Lions, often far from land. This minimises their probability of contact with humans and makes the species less vulnerable to interactions at sea than other Mediterranean seabirds. But as a predator in the ecosystem, the species depends on the general health and productivity of the marine environment. It is extremely long-lived, and so dependent on low adult mortality.

Other species with relevant populations in conservation terms whose distribution extends to the offshore waters of the Gulf of Lions are: the endemic Mediterranean shag *Phalacrocorax aristotelis desmarestii*; a coastal species, the Northern gannet *Morus bassanus* of the Atlantic continental shelf, which penetrates the Mediterranean in winter; Audouin's gull *Larus audouinii*; Mediterranean gull *Larus melanocephalus* and the Sandwich tern *Sterna sandvicensis*.

The conservation of the Gulf of Lions for seabirds has implications over a much wider area. The long-term preservation of its role as a major foraging ground in the north-western Mediterranean Sea is probably a key to the stability of the populations that nest in Spain, France and Italy, and also to those that use it during the winter season and nest elsewhere.

Three areas within the Gulf of Lions shelf and slope area are of special conservation value for

seabirds:

- **W sector: Cap de Creus area**

Particularly important for all 3 shearwater species, Shag, Northern gannet and other migratory seabirds. Intensively fished (trawling, longlining, artisanal, purse-seining), with several episodes of bycatch recorded recently; addressing this issue must be forefront of management policy. Fishing should be regulated to prevent excessive captures and the destruction of fish habitat.

- **Central canyons and continental shelf of the Gulf of Lions**

Based on its conservation value for Mediterranean seabirds, an important area for birds is identified over the external continental shelf and heads of canyon in the central part of the Gulf of Lions. Frequented by large numbers of shearwaters of the 3 species and intensively fished, thus leading to a high probability of interaction. Management measures should seek to minimise the probability of mortality through bycatch and safeguard the long-term maintenance of fish populations, particularly anchovy and sardine. A scientific observer programme, in collaboration with the fishing industry, is especially appropriate in this area.

- **E sector: Marseille – îles d'Hyères**

Similar characteristics to W sector: Cap de Creus area at the opposite end of the Gulf of Lions. Fishing and disturbance are equally the main threats at sea, and management should seek to address risks of interaction and minimise the probability of mortality through bycatch. Fishing regulations should seek long-term sustainability and minimal impact on the ecosystem. Disturbance should also be kept to a minimum near key spots on land (breeding colonies, resting places).

Increased risk of pollution near important harbours like Marseille, as well as high density of plastic debris, close to bird-rich areas are major threats. The distant slope waters are considered to be of undifferentiated value for foraging seabirds.

- **Continental slope area**

This area is comparatively large but is relatively poor as a potential habitat for foraging seabirds. The absence of significant features in the bathymetry or in the water column, and the dispersed fishing activity (mostly consisting of pelagic longlining), give homogeneity to the area and make it rather unattractive for foraging seabirds. Only Storm petrels regularly forage on these waters, and they do so at low densities. Thus, the S portion area made of the external waters beyond the continental shelf is not identified as an important area for birds.

Another characteristic of the Mediterranean marine avifauna is its long-term exposure to human influence. Through history, some aspects of human activity have had positive effects on seabirds (e.g. the provision of food through fishery discards, etc.) but overall and in the long-term the result of the human-seabird interaction has been detrimental for seabirds. Their current population sizes are nowhere near what they were before the 'humanisation' of the Mediterranean.

Today, despite the legal protection and the positive management of seabird colonies, several threats imperil the future of this unique seabird community, namely the interaction of seabirds with fisheries (causing unnecessary mortality and impacting heavily on their populations), overfishing (which decimates fish populations and heavily alters the habitats where marine organisms live) and climate change (causing disruptions in the ecosystem).

The high productivity of the Gulf of Lions offers ideal conditions for foraging seabirds, which concentrate on it over much of the year. Because the area offers few opportunities for rocky island nesters, most of the birds present in the area come from colonies that are situated 150-500 km away (generally, a 4-16 hours' flight, depending on the species and wind conditions). Therefore, the conservation of the Gulf of Lions for seabirds has implications over a much wider area than could be immediately thought. The long-term preservation of its role as a major foraging ground in the north- western Mediterranean Sea is probably key to the stability of the populations that nest in Spain, France and Italy, and also to those that use it during the winter season and nest elsewhere.

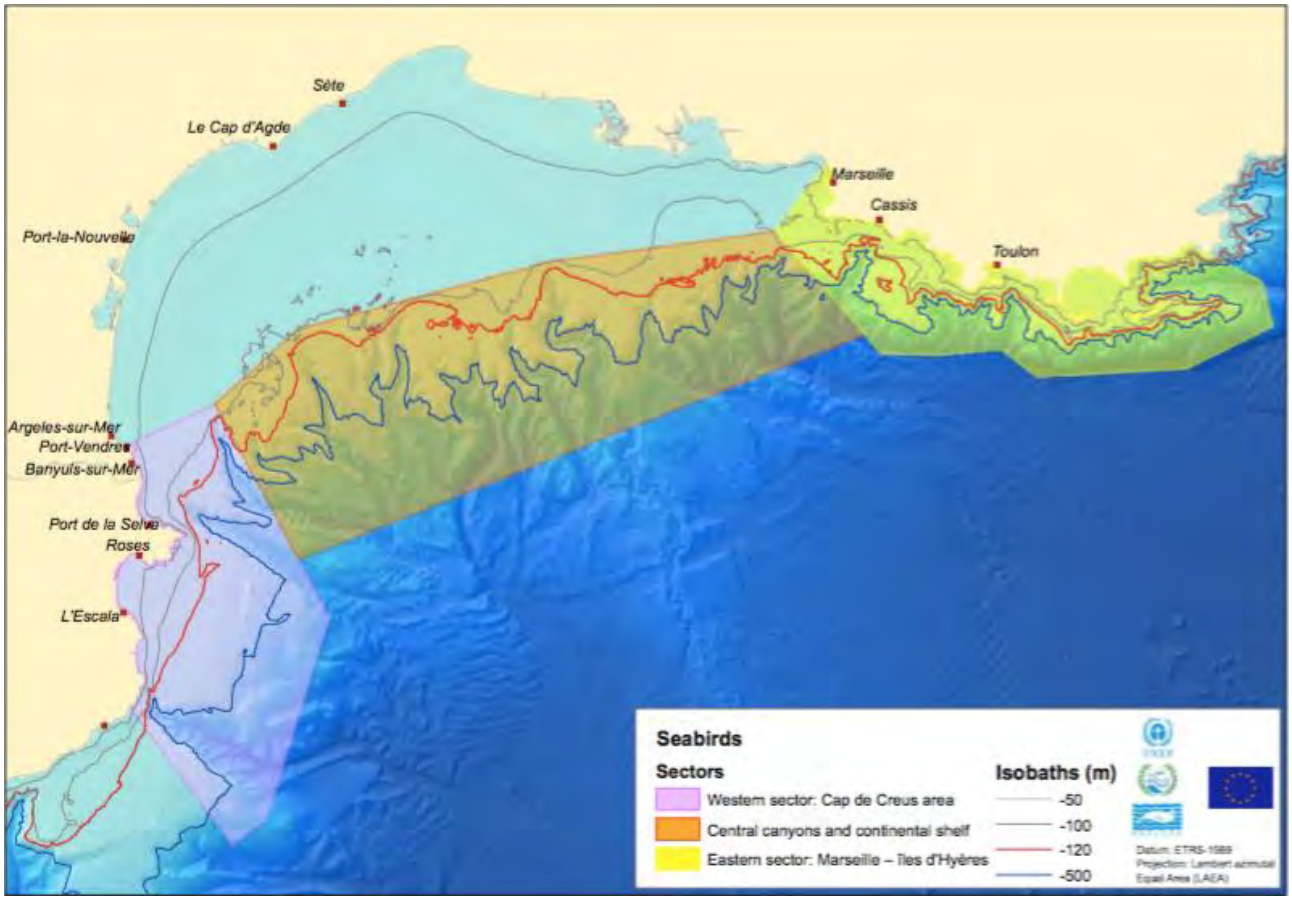


Figure 24: Areas of main interest for pelagic seabirds (*Source:* UNEP-MAP-RAC/SPA, 2013)

<u>Birds species</u>

- ***Puffinus yelkouan* – Yelkouan shearwater**

The Yelkouan shearwater is a medium-sized Procellariiform endemic to the Mediterranean and

the Black sea. It is of similar size and habits to the Balearic shearwater *Puffinus mauretanicus*. Until recently, both were considered to belong to the same species, but they have been separated based on differences in morphology, genetics, behaviour and ecology. The species tends to form large flocks and only nests in a few colonies on offshore islets and rocky outcrops. It is exposed to predation on the breeding islands and to human-induced mortality at sea, mainly as a result of interactions with fisheries.

The Yelkouan shearwater is present in the Gulf of Lions between October and July, with a peak in February-June, when an estimated 10,000 birds use the area for feeding during the breeding season. The French breeding population is relatively small, with an estimated 1350-1650 breeding pairs in 2006 (1100-1500 bp on Ílles d'Hyères, plus 40-50 bp on islands of Marseille) (Issa 2008), so the area presumably serves as foraging ground for birds from more distant colonies.

Ecology: Yelkouan shearwaters feed by surface-seizing and underwater pursuit, mainly on small pelagic fish such as sardines and anchovies. Like for other shearwater species in the Mediterranean, discards from fisheries (mostly trawlers) are probably important, and may represent more than an opportunistic resource. Outside of the breeding season, Yelkouan shearwaters tend to concentrate in areas with large shoals of sardines and other Clupeiforms.

The species occupies the coastal area and feeds mainly in the nearshore (Péron & Grémillet in press) but is also known to forage in frontal areas (Beaubrun et al. 2000), where it can feed naturally or attend trawlers in search of discards. In fact, most birds observed in the open sea are travelling, which might suggest that there is little feeding in offshore waters, but the evidence that individuals of this species get caught in pelagic longlines (Bourgeois & Vidal 2004) indicates that some degree of foraging also takes place away from the coast.

Conservation status (IUCN) and threats: Near Threatened (NT) since 2008. The population is currently estimated at 100,000 individuals but may be larger because of poor knowledge of breeding numbers in Turkey and Greece (BirdLife International 2011). Reports of extremely low breeding success at several key breeding colonies indicate that current declines may accelerate markedly when current breeders approach the end of their life cycle, so it is currently listed as Near Threatened by the IUCN. Declines have probably been ongoing for long, and are projected to continue. Yelkouans face specific threats on land and at sea. Breeding colonies are gravely affected by predation from alien invaders, mostly rats and cats.

Several projects have been directed at addressing this issue and some are still ongoing targeting a reduction or even the eradication of alien predators. Dead shearwaters are regularly found in drift- and gill-nets and, more recently, in longlines. At-sea mortality is a major cause of the dramatic decline of the closely related P. mauretanicus and may be similarly affecting P. yelkouan. Breeding success may be affected by reduced abundance of anchovies and sprats due to competition from fisheries. Oil spills are an increasing risk due to increased maritime traffic in the Mediterranean.

International measures of protection: *Puffinus yelkouan* is listed in Annex I of the European Directive 2009/147/EC on the conservation of wild birds. It has been proposed as a candidate

species for listing in Annex I of the Agreement on the Conservation of Albatrosses and Petrels, ACAP (Cooper & Baker 2008). It is listed in Annex II of the SPA/BD Protocol of the Barcelona Convention and in Annex II of the Berne Convention.

National measures of protection: In France, *Puffinus yelkouan* is legally protected by "Arrêté du 29 octobre 2009 fixant la liste des oiseaux protégés sur l'ensemble du territoire et les modalités de leur protection (art. 3)" and considered a threatened species by "Liste rouge des oiseaux nicheurs de France métropolitaine", where it is listed as Vulnerable (VU) under IUCN criteria. The following Natura 2000 sites in the Gulf of Lions area have been established in France and its territorial waters for the protection of *Puffinus yelkouan*:

- FR9112034 – Cap Béar–Cap Cerbère (very important site)
- FR9112035 – Côte Languedocienne (very important site)
- FR9310019 – Camargue (very important site)
- FR9312007 – Îles Marseillaises–Cassidaigne (breeding; remarkable site)
- FR9310020 – Îles d'Hyères (breeding; remarkable site)

In Spain, the species is legally protected by "Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad (Annex IV) and listed by Real Decreto 139/2011, de 4 de febrero, para el desarrollo del Listado de Especies Silvestres en Régimen de Protección Especial y del Catálogo Español de Especies Amenazadas". The following site has been identified as a marine IBA in Spain and has been proposed as a candidate Natura 2000 marine site in the Gulf of Lions for the conservation of Puffinus yelkouan (Arcos et al. 2009):

- ES411 – Mar del Empordà, for wintering birds (Average = 2100 in 2003-07)

- ***Puffinus mauretanicus* – Balearic Shearwater**

Similar to *P. yelkouan*, the Balearic shearwater is restricted, as a breeding bird, to the Balearic Is., Spain. Until recently, both forms were considered to belong to the same species, but they have been separated on the basis of differences in morphology, genetics, behaviour and ecology. The nesting colonies of *Puffinus mauretanicus* are situated in caves and cliff cavities of the most of the Balearic Islands and surrounding islets. The species is highly gregarious despite the fact that the global population is small (probably less than 10,000 individuals, BirdLife International 2011), so sometimes a significant proportion of the global population is concentrated in a single flock. The species is classed as Critically Endangered by IUCN because it suffers unsustainable levels of mortality at sea which, coupled with predation on land by introduced cats and rats, is causing a steady decline in numbers.

Balearic shearwaters are present in the Mediterranean between September and June; most birds leave the Mediterranean and 'summer' in the Atlantic Ocean (Galicia, Bay of Biscay, Brittany). Breeding birds from the Balearics forage off the continental coast of Spain, regularly reaching the S waters of the Gulf of Lions. Smaller numbers venture further N to forage off the coast of Bouches du Rhône and the PACA region of France.

Ecology: Like Yelkouan, Balearic shearwaters feed by surface-seizing and underwater pursuit, mainly on small pelagic fish such as sardines and anchovies. They regularly attend trawlers and reach sunken discards by diving underwater thus avoiding the competition of more aggressive species, particularly gulls. Studies show that Balearic shearwaters increase their use of discards during the breeding season, when their demand of food is greatest (Navarro et *al*., 2009). Like Cory's shearwaters, they might resort to feeding astern of longline vessels on the days/hours when trawlers are not so easily available (Laneri et *al*., 2010). This would increase their risk of mortality, which is higher in longline fisheries.

Puffinus mauretanicus is also typically found on the nearshore, where it forages, migrates or gathers for roosting. However, in areas where the continental shelf extends further offshore, as in the Ebro delta or in the Gulf of Lions, they also frequent shallow waters away from the coast. The species frequently associates with areas of high productivity and cold waters, as are typically found around river mouths. *Puffinus mauretanicus* is highly gregarious, and may concentrate by the hundreds or thousands in favourable areas. Such ephemeral concentrations, which are of conservation importance, may move move back and forth considerably along the coast for several days before disaggregating.

Conservation status (IUCN) and threats: IUCN has classed this species as Critically Endangered (CR) since 2004 because it has a tiny breeding range and a small population which is undergoing an extremely rapid population decline owing to a number of threats, in particular predation at breeding colonies by introduced mammals and at-sea mortality as a result of interactions with commercial fisheries. However, recent records at sea indicate that this species may not have suffered declines as drastic as previously thought (BirdLife International 2011).

The main conservation concern for Balearic Shearwaters is adult survival, which is unusually low for a Procellariiform. Mortality at sea has long been suspected to take a heavy toll in this species; evidence points at longlines, particularly demersal, killing most birds, although this is a difficult event to watch (BirdLife International 2009). Mortality episodes with >50 birds dead have been reported and, although they are necessarily rare, they may take in a single occasion the equivalent of half the breeding birds in a medium-sized breeding colony (Oro et *al*., 2009). Other important threats at sea include overfishing (which reduces the availability of natural prey and forces birds to feed on discards and interact with fisheries), pollution (from oil and heavy metals) and climate change. On land, alien predators break eggs and kill adults and young at the breeding colonies. Human harvesting of eggs and young has been greatly reduced, but disturbance (by lights and noise) still continues at some places, and available habitat for breeding is decreasing through encroachment by mammalian predators and urbanisation of the coastal zone (Oro et *al*., 2009, BirdLife International 2011).

International measures of protection: *Puffinus mauretanicus* is listed in Annex I of the European Directive 2009/147/EC on the conservation of wild birds and is the subject of an International Species Action Plan. It is listed in Annex I of the Convention on Migratory Species, whose Resolution 8.29 designated it for concerted action. The 6th Meeting of the Advisory Committee of the Agreement on the Conservation of Albatrosses and Petrels, ACAP, agreed to propose listing of

Puffinus mauretanicus in the Agreement, following the recommendations of Cooper & Baker (2008). The species is listed in Annex II of the SPA/BD Protocol of the Barcelona Convention and in Annex II of the Berne Convention.

National measures of protection: In France, *Puffinus mauretanicus* is legally protected by "Arrêté du 29 octobre 2009 fixant la liste des oiseaux protégés sur l'ensemble du territoire et les modalités de leur protection (art. 3)" and considered a threatened species by "Liste rouge des oiseaux non nicheurs de France métropolitaine" where it is listed as Vulnerable (VU) under IUCN criteria. The following Natura 2000 sites in the Gulf of Lions area have been established in France and its territorial waters for the protection of *Puffinus mauretanicus*:

- FR9112034 – Cap Béar – Cap Cerbère (important site) FR9112013 – Petite Camargue Laguno-Marine (presence) FR9310019 – Camargue (presence)
- FR9312007 – Îles Marseillaises – Cassidaigne (breeding; remarkable site) – It corresponds to IBA PA07 – Îles Marseillaises: Maire, Jarron, Jarre, Riou, Calseraigne, Congloue et Pomegues
- FR9310020 – Îles d'Hyères (breeding; remarkable site) – It corresponds to IBA PA11 – Îles d'Hyères

The Spanish Red Data Book, "Libro Rojo de las Aves de España", lists *Puffinus mauretanicus* as Critically Endangered (CR) under IUCN criteria. The species is legally protected by "Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad (Annex IV)" and listed as In Danger of Extinction by the Spanish Catalogue of Threatened Species (Real Decreto 139/2011, de 4 de febrero, para el desarrollo del Listado de Especies Silvestres en Régimen de Protección Especial y del Catálogo Español de Especies Amenazadas). Such classification requires that a National Conservation Strategy is implemented in Spain; the current version was adopted in 2005. The following site has been identified as a marine IBA in Spain and has been proposed as a candidate Natura 2000 marine site in the Gulf of Lions for the conservation of *Puffinus mauretanicus* (Arcos et *al*., 2009):

- ES411 – Mar del Empordà (Average breeding season = 1850 birds in 1999- 2007; Average winter = 235 birds)

- ***Calonectris diomedea* – Cory's shearwater**

Cory's is the largest Procellariiform species in the Mediterranean Sea, where it is still quite numerous (recent estimate for total breeding population: ~150,000-200,000 breeding pairs). The Mediterranean race *C. d. diomedea* is endemic and is currently declining over the whole range; possibly, at a faster pace than the Atlantic subspecies *C. d. borealis*. Cory's shearwaters make the longest foraging trips of all Mediterranean seabirds, and birds from distant breeding colonies often converge spatially. It regularly attends trawlers and longlining vessels, and is the species suffering the heaviest mortality toll. Globally, it is considered of Least Concern (LC) under IUCN criteria because the world population is very large (possibly > 1,000,000 individuals, BirdLife International 2011) and recorded declines in the Atlantic still situate the species below the thresholds for

threatened status.

The Cory's shearwater is a long-distance migrant that leaves the Mediterranean to spend the non-breeding season in Atlantic waters off Africa and S America. It is present in the Mediterranean between March and October. There, it favours areas of wide continental shelf and the areas of influence of large rivers, where productivity is highest. Thus, the wider Gulf of Lions offers excellent foraging conditions and attracts birds from breeding colonies in the Balearics, the PACA region of SW France, Corsica, and Sardinia and possibly even beyond.

Ecology: In the Mediterranean, Cory's shearwater feeds on medium-sized to small fish (regularly, sardine and anchovy), alone or in association with tuna and cetaceans. Squid is also an important component of its diet. It regularly attends trawlers when these are available, shifting to longline vessels when they are not, particularly during the pre-breeding and chick- rearing periods (Laneri et *al*., 2010). Fishing discards, a predictable source of food, have become a growing foraging option for Cory's shearwaters in the Mediterranean after the population decline of tuna and cetaceans, and the reduced availability of natural prey caused by overfishing. This increases the dependence of shearwaters on human activities, as the birds become attracted to fishing vessels, and modifies their foraging behaviour (Bartumeus et *al*., 2010).

When not in the vicinity of the breeding colony, Cory's shearwater is a true pelagic bird with a preference for offshore waters over the continental shelf and around the shelf break. Foraging birds tend to aggregate in areas of high trawler densities along frontal systems (Louzao et *al*., 2009). Cory's shearwater makes extensive use of the offshore waters in the central part of the Gulf of Lions area, both for foraging and for travelling, and is the dominant species in this sector of the Mediterranean (Zotier et *al*., 1999). The areas where most of birds concentrate are: (a) in the SW, around Cap de Creus and its associated frontal zone; (b) along the shelf break and its associated canyons; and (c) in the NE, in the waters around Îles d'Hyères and offshore area.

Conservation status (IUCN) and threats: Considering the species globally, Cory's shearwater does not approach the thresholds for IUCN threatened status (BirdLife International 2011), even though there is evidence of ongoing declines in several of its populations. The Atlantic population (mostly in Azores, Madeira and Canary Is.) is still very large; however, evidence amounts that the endemic Mediterranean subspecies is declining, probably through its entire range, and so is given threatened status in Spain (EN) and France (VU). The bulk of that population is in its southern half, particularly around the centre of the Mediterranean (Tunisia, Sicily and Malta make up >80% of all breeding pairs); towards the N, the size of the populations is (or has become) much smaller, with 1000-1300 bp in France (Issa 2008) and probably less than 4000 bp in Spain, as the population in Minorca (Balearic Is.) is much smaller than previously thought (Carboneras et al. 2010).

Present population size around the Gulf of Lions area must represent a significant reduction compared to former times due to continuing threats on land (alien predation) and at sea (mortality through bycatch). The quality of the area as a foraging ground for the species has probably not degraded at the same speed, and there is currently more breeding habitat available than is being occupied. At the same time, a number of former colonies or colony sectors that had been occupied

in the past and were later abandoned have not been recolonised.

As with other Procellariiforms, the threats for Cory's shearwaters in the NW Mediterranean come both from land and sea. At the breeding colonies, introduced cats and rats prey on eggs and small chicks, reducing breeding success significantly where they are present. At sea, this is the species suffering the heaviest mortality from bycatch in longline fisheries, both demersal and pelagic. The current levels of adult mortality are unsustainable in the long term, and annual declines of 4-6 % have been recorded putting some Mediterranean populations in serious danger of extinction (Carboneras 2004).

International measures of protection: Annex I of the European Directive 2009/147/EC on the conservation of wild birds lists *Calonectris diomedea* (all subspecies). The species has been recommended for listing under the Agreement on the Conservation of Albatrosses and Petrels ACAP, together with the other Mediterranean shearwaters (Cooper & Baker 2008). Cory's is also listed in Annex II of the SPA/BD Protocol of the Barcelona Convention and in Annex II of the Berne Convention.

National measures of protection: In France, *Calonectris diomedea* is legally protected by "Arrêté du 29 octobre 2009 fixant la liste des oiseaux protégés sur l'ensemble du territoire et les modalités de leur protection (art. 3)" and considered a threatened species by "Liste rouge des oiseaux de France métropolitaine (2008)", where it is listed as Vulnerable (VU) under IUCN criteria. The following Natura 2000 sites in the Gulf of Lions area have been established in France and its territorial waters for the protection of *Calonectris diomedea*:

- FR9112034 – Cap Béar – Cap Cerbère (important site)
- FR9112013 – Petite Camargue Laguno-Marine (presence)
- FR9310019 – Camargue (presence)
- FR9312007 – Îles Marseillaises – Cassidaigne (breeding; remarkable site) – corresponds to IBA PA07 – Îles Marseillaises: Maire, Jarron, Jarre, Riou, Calseraigne, Congloue et Pomegues
- FR9310020 – Îles d'Hyères (breeding; remarkable site) – corresponds to IBA PA11 –Îles d'Hyères

In Spain, the Mediterranean race *Calonectris d. diomedea* is listed as Endangered (EN) in the Red Data Book, "Libro Rojo de las Aves de España" under IUCN criteria. The species is legally protected by "Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad (Annex IV)" and listed as Vulnerable by the Spanish Catalogue of Threatened Species (Real "Decreto 139/2011, de 4 de febrero, para el desarrollo del Listado de Especies Silvestres en Régimen de Protección Especial y del Catálogo Español de Especies Amenazadas)".

- ***Hydrobates pelagicus melitensis* – Mediterranean Storm petrel**

The European Storm petrel is only above the size of a swallow (16 cm, 27 g) and is therefore the smallest of all seabirds in the Mediterranean region. Despite this, the species is extremely long-

lived (reaches breeding age at ~4 years, then has an average lifespan of ~11 years) for an animal of its size. These data predict that the population ecology of the species will be based on high adult survival (0.87, Robinson 2005) and a comparatively low reproductive rate. In the Mediterranean, the endemic subspecies *melitensis* has a small population (<16,000 bp) that is in slight decline in most breeding colonies.

Storm petrels are present in the Mediterranean in all months, although in the N Mediterranean and in the Gulf of Lions in particular, observations concentrate in spring and summer (Issa, 2008). Birds are present near the breeding colonies from February onwards; the breeding season is extended, with the late birds not fledging until October. It suffers heavy predation from terrestrial (introduced rats, cats) and aerial (gulls) predators, so selects rocky islands and islets for breeding. Nests are in natural crevices, fissures in rocks and cliff faces, amongst and under stones and boulders, in burrows, and in caves.

Ecology: This is a marine species feeding mainly on small fish, squid and crustaceans, but it will also feed on medusa and offal. It feeds mainly on the wing by pattering and fishing, and will occasionally follow ships and attend trawlers. The Storm petrel is found over the external half of the continental shelf and in the high seas, often very far from land. The selection of this type of habitat, which is typical among the storm petrel family, minimises their probability of contact with humans and makes the species less vulnerable to interactions at sea than other Mediterranean seabirds. However, as a predator in the ecosystem, the species depends on the general health (e.g., from pollution) and productivity of the marine environment.

Conservation status (IUCN) and threats: Although little known due to its behaviour and habitat choice, it is generally believed that the Storm petrel population is still very large (over 1 million individuals) but has been undergoing a sustained decline over its entire European range (BirdLife International 2011). Even so, it does not approach the thresholds for threatened status under IUCN criteria. The endemic Mediterranean population is much smaller (<16,000 bp, or less than 50,000 individuals) and has probably been subject to the introduction of mammalian predators on its breeding islands and to habitat destruction for several centuries.

The main threats for the species on land are related to its small size and nocturnal habits: predation by introduced mammals, habitat occupation and degradation, luring of fledglings to built-up areas by artificial lights and the increase in generalist predators such as gulls favoured by poor management of rubbish dumps. At sea, storm petrels are threatened by pollution (although there is evidence that they are less affected by oil spills due to their aerial habits) and overfishing, particularly as they affect the food chain and reduce the availability of plankton and other small prey on which the species feeds.

International measures of protection: *Hydrobates pelagicus* is listed in Annex I of the European Directive 2009/147/EC on the conservation of wild birds, in Annex II of the SPA/BD Protocol of the Barcelona Convention and in Annex II of the Berne Convention.

National measures of protection: In Spain, *Hydrobates pelagicus* (all races) is listed as Vulnerable

(VU) in the Red Data Book, "Libro Rojo de las Aves de España" under IUCN criteria. The species is legally protected by "Ley 42/2007, de 13 de diciembre, del Patrimonio Natural y de la Biodiversidad (Annex IV)".

In France, *Hydrobates pelagicus* (all races) is legally protected by "Arrêté du 29 octobre 2009 fixant la liste des oiseaux protégés sur l'ensemble du territoire et les modalités de leur protection (art. 3)". The Mediterranean subspecies *melitensis* is considered threatened by "Liste rouge des oiseaux de France métropolitaine", where it is listed as Endangered (EN) under IUCN criteria. The following Natura 2000 sites in the Gulf of Lions area have been established in France and its territorial waters for the protection of *Hydrobates pelagicus*:

- FR9310019 – Camargue (presence)
- FR9312007 – Îles Marseillaises – Cassidaigne (breeding; remarkable site) – corresponds to IBA PA07 – Îles Marseillaises: Maire, Jarron, Jarre, Riou, Calseraigne, Congloue et Pomegues
- FR9310020 – Îles d'Hyères (important site) – corresponds to IBA PA11 – Îles d'Hyères

<u>Additional species</u>

- **Mediterranean shag *Phalacrocorax aristotelis desmarestii***

The Mediterranean shag forms an endemic subspecies and is a flagship species for Mediterranean seabird conservation. It is listed in Annex II of the SPA/BD and is legally protected in France and Spain. The Red Data Books of both countries list the Mediterranean shag as Vulnerable (VU) under IUCN criteria, and the Spanish Catalogue of Threatened Species also list the species as Vulnerable (making a National Conservation Plan compulsory).

Ecology: The Shag feeds by diving underwater for fish (mostly, non-commercial species); it selects shallow waters (generally <80 m deep) and shows a preference for foraging over Posidonia seabeds. The species therefore remains mostly in coastal waters and does not venture far offshore. In the Gulf of Lions area, small populations (<10 bp) of Shag persist around the SW (Cap de Creus) and NE (île de Riou, îles d'Hyères) ends. In both cases, the local populations are reinforced after the breeding season with disperses from the much larger Balearic and Corsican strongholds. The Shag occurs only very occasionally outside of these areas or in the high seas.

- **Northern gannet *Morus bassanus***

This strictly marine species wanders mostly over the continental shelf, where it feeds on shoaling pelagic fish which it catches by plunge-diving from large heights. It also attends trawlers and will form large congregations where food is plentiful. Both young birds and adults winter regularly in the Mediterranean, and there are a few records of successful nesting inside harbours in the Bouches du Rhône area (Issa, 2008).

The gannet has a large population of probably over 1 million individuals (BirdLife International 2011) that is continuing to increase, as it did over much of the 20th century when it started to

recover from previous exploitation by humans. Its success is mostly attributed to the availability of fish discards and the legal protection afforded to its nesting colonies in the Atlantic Ocean. The species is not listed in the SPA/BD Protocol or in the Red Data Books of Spain or France, although it is legally protected in both countries.

- **Audouin's gull *Larus audouinii***

Audouin's gull is another flagship species for the conservation of Mediterranean seabirds. It is endemic and considered Near Threatened (NT) globally because its population size has increased substantially since the 1970s but still remains localised and is dependent on current fishing practices that make large quantities of discards available but are unsustainable (BirdLife International 2011). It is anticipated that a collapse in the fisheries would induce a population decline of *Larus audouinii*. For these reasons, it is legally protected in France, where it nests exclusively in Corsica; the French Red Data Book lists it as Endangered (EN). In Spain, the species is legally protected and listed in the Catalogue of Threatened Species as Vulnerable (and therefore requiring a Conservation Plan); the Spanish Red Data Book lists Audouin's gull as Vulnerable (VU). Internationally, it is listed in Annex I of the European Directive 2009/147/EC on the conservation of wild birds, in Annex II of the SPA/BD Protocol of the Barcelona Convention, in Annex I of the UNEP-Bonn Convention on Migratory Species, in the African-Eurasian Waterbird Agreement (AEWA) and in Annex II of the Berne Convention.

The world population of Audouin's gull is estimated at <60,000 individuals; 90% of the breeding population is found in only 4 sites, and 70% concentrate in a single site (Ebro delta). The species scavenges around fishing vessels, and uses discards extensively and very efficiently. The species' association with fisheries is more pronounced in the western than in the central and eastern Mediterranean. However, it occurs only in small numbers N of Barcelona. It is regular but scarce along the coast in the Languedoc-Roussillon and PACA regions of France, particularly favouring Aude and Camargue, Issa 2008). Most birds are probably dispersers from the Spanish and Corsican colonies. Their numbers are small and irrelevant at population level.

- **Mediterranean gull *Larus melanocephalus***

The Mediterranean gull is a common but localised species that is present in the NW Mediterranean throughout the year. It nests in wetlands and lagoons, with a significant population (around 3,000 bp; Issa, 2008) in the Camargue area. Outside of the breeding season the species becomes entirely coastal, favouring estuaries, harbours, saline lagoons and other sheltered waters. It may venture offshore (up to 25 nautical miles; Cama et *al*., 2011) following trawlers, from which it forages on discards. Regionally, in winter it is virtually absent from the western Gulf of Lions (Cap de Creus, Languedoc-Roussillon) but common in the central and eastern parts, between Hérault and Var with a few thousand birds present (Issa, 2008).

The Mediterranean gull is legally protected in France and Spain and is listed in Annex I of the European Directive 2009/147/EC on the conservation of wild birds, in Annex II of the SPA/BD Protocol and in the African-Eurasian Waterbird Agreement (AEWA). However, it is not listed in

the Red Data Books of any of those countries. Globally, it is considered of Least Concern (LC) following IUCN criteria because of its extensive range and stable population size (BirdLife International 2011).

- **Sandwich tern *Sterna sandvicensis***

The Sandwich tern is present in four continents and has a large population with a fluctuating trend, so it is globally considered of Least Concern (LC) (BirdLife International 2011). However, because it is extremely localised as a breeding bird, it is legally protected in France and Spain and is listed in their Red Data Books as Vulnerable (VU) and Near Threatened (NT), respectively. The species is listed in Annex I of the European Directive 2009/147/EC on the conservation of wild birds, in Annex II of the SPA/BD Protocol of the Barcelona Convention, in the African-Eurasian Waterbird Agreement (AEWA) and in Annex II of the Berne Convention.

The Sandwich tern behaves as a coastal species throughout the year. It nests on wetlands but forages mostly at sea; outside of the breeding season it frequents sandy beaches, estuaries, harbours and bays. Its diet consists predominantly of surface-dwelling marine fish 9-15 cm long as well as small shrimps, marine worms and shorebird nestlings. Its presence in the Gulf of Lions area is restricted to the coastal waters, predominantly along low-lying coasts. It is rare in the open sea, far from land.

3.2.3 Fish

In the Gulf of Lions live several commercially important populations of demersal species of fishes, crustaceans and molluscs. A number of these species are mainly coastal, i.e. grey mullets (*Mugilidae*), sea breams (*Sparus aurata*), sea bass (*Dicentrarchus labrax*), some shrimps and many molluscs. The upper zones of the continental shelf are inhabited by species like red mullets (*Mullus barbatus, Mullus surmuletus*), sole (*Solea solea*), gurnards (*Trigla sp.),* poor cod (*Trisopterus minutus capelanus*), Black Sea whiting (*Merlangius merlangus*), and some shrimps. On the continental slope there are many fish species of great economic interest. Thus in the upper part of the slope (200 and 400m) there are hake (*Merluccius merluccius*), Norway lobsters (*Nephrops norvegicus)* and various shrimps (e.g. *Peneus longirostris*). In deeper waters, from 400 to 600m, the dominant species are the greater forkbread (*Phycis blennoides*), the blue whiting (*Micromesistius poutassou)* and the red shrimps (*Aristeus antennatus, Aristaemorpha foliacea*).

The bottom trawl surveys carried out by the Fishery Laboratory of IFREMER on the continental shelf and the upper part of the slope of the Gulf of Lions between 1983 and 2009 have provided quantitative biological data, geographic distribution and abundance indices of the main demersal resources. These works give information on more than 40 species. Altogether, their results show that the distribution of most of these species is mainly linked to the bathymetry and to the types of substratum.

Table 3: Species recorded during IFREMER trawl surveys 1983-2009

Species	Common name	Average abundance (Kg/Km^2)		
		Total	Shelf	Slope
Trisopterus minutus	Poor cod	88	108	1
Trachurus trachurus	Horse mackerel	61	72	15
Micromesistius poutassou	Blue whiting	58	20	225
Merluccius merluccius	Hake	47	52	22
Lopius budegassa	Monkfish	34	39	15
Galeus melastomus	Black mouth dogfish	34	0	179
Eutrigla gumardus	Grey gurnard	31	38	3
Eledone cirrhosa	White octopus	26	29	13
Scyliorhinus canicula	Dogfish	22	22	19
Lophius piscatorius	Monkfish	20	9	66
Pagellus acarne	Axillary seabream	16	17	11
Octopus vulgaris	Octopus	13	16	1
Helicolenus dactylopterus	Rosefish	13	0	66
Nephrops norvegicus	Norway lobster	12	1	59
Trachurus mediterraneus	Horse mackerel	9	11	2
Mullus barbatus	Striped mullet	9	11	0
Boops boops	Bogue	9	11	0
Eledone moschata	White octopus	6	8	0
Lepidorhombus boscii	Four spot megrim	6	5	10
Phycis blennoides	Greater forkbead	6	1	27
Raja clavata	Thornback ray	6	4	15
Aspitrigla cuculus	Red gurnard	6	6	3
Pagellus bogaraveo	Red sea bream	5	1	22
Citharus linguatula	Spotted flounder	5	6	0
Zeus faber	John dory	4	4	1
Illes coindetii	Shortfin squid	4	4	1
Pagellus erythrinus	Common pandora	3	3	0
Solea vulgaris	Common sole	2	2	0
Aristeus antennatus	Red shrimp	2	0	9
Mullus surmuletus	Red mullet	2	2	1
Spicara flexuosa	Picarel	1	1	0
Spicara smaris	Picarel	1	1	0
Loligo vulgaris	Common squid	0	0	0
Trigla leucerna	Tub guarnard	0	0	0
Trigloporus lastoviza	Streaked gumard	0	0	0
Parapenaeus longirostris	deep Rose shrimp	0	0	0
Sepia officinalis	Cuttlefish	0	0	0
Aristeomorpha foliacea	Aristeid shrimp	0	0	0

The distribution of the species according to an east-west gradient has also been repeatedly confirmed, as well as the big spatio-temporal stability of the specific structures characteristic of the coastal zone, the continental shelf and the continental slope of the Gulf of Lions.

The distribution and the seasonal abundance of the most commercially important species have remained particularly stable in time from many years. This situation is due to the presence of the canyons of the continental slope, situated outside the traditional fishing sectors, which are "reservoirs" sheltering fishes having escaped the fishery of juveniles on the continental shelf and being able to reach the adulthood, reproduce and insure the perpetuity of the resources.

3.2.4. Mammals

3.2.4.1 Bats

General description

Bats have exceptional adaptations that differentiate them from all other mammals (Dietz et *al*., 2009):

- an active flight allowed by their wings, where the fingers are connected by a wing membrane;
- a great longevity in relation to their size, that is given by the conquest of an ecological niche where the risk of predation is weak because of their nocturnal activity and their capacity of flight which allow them to escape most of predators. If they have a long-life span, females only give birth to one young each year (two for some species) in Europe;
- a long sperm viability that allows fertilization of the egg in the spring while copulation usually occurs in the fall (some European species can however mate in winter). This adaptation allows rapid embryonic development, without loss of time related to finding a partner in the spring;
- an echolocation apparatus, a unique feature in terrestrial mammals, which allows to move and to hunt at night;
- the occupation of a multiplicity of ecological niches which explains that there are insectivorous, carnivorous, frugivorous, piscivorous, nectarivorous species in the world, etc. However, in Europe, the 37 species of bats present feed mainly on invertebrates (insects, spiders, etc.) that they catch in the sky or on surfaces (water, soil, foliage, etc.).

The annual life cycle of bats is punctuated by the seasons (Figure 25). In autumn, males and females often meet at the entrance of caves for mating. The caves frequented on this occasion are called swarming sites. After several months of hibernation to spend the bad season, the females gather in the gestation beds. These colonies gather about ten to several thousand individuals who can group different species.

Each female of reproductive age (from 2 to 3 years of age) gives birth to one young per year, exceptionally two. The juvenile mortality rate is very high. For the majority of French species, movements between summer and winter lodgings are transits from a few tens of meters to a few

tens of kilometers. However, some species make real migrations. The Nathusius Pipistrelle commonly travels more than 1000 km between its breeding and hibernation sites (recorded record: 1,905 km).

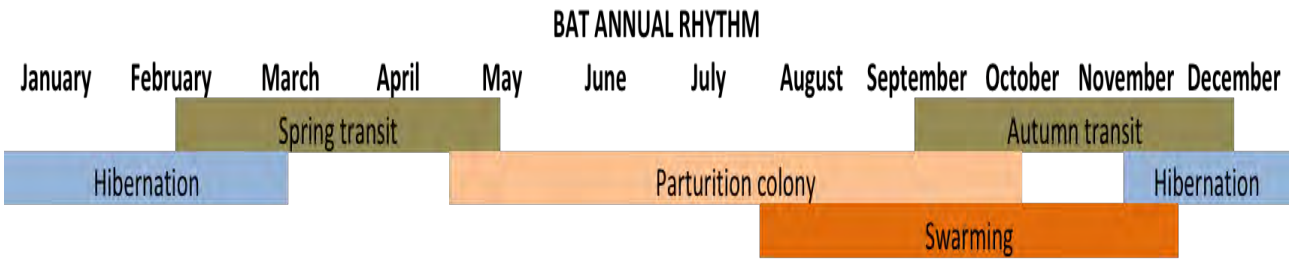


Figure 25: Circannual rhytm of bats

Bats use a wide range of habitats. Three types of habitats that can be closely related are generally considered:

- habitats for bat roosting to breed or rest;
- hunting habitats, i.e. the feeding areas of bats,
- the areas of movement which are the spaces above which bats fly between the different previous habitats.

The feeding areas of bats vary according to species and during the season. They can be at small distances from the resting area (a few hundred meters for example for the Murin of Bechstein) until several tens of kilometers (about twenty kilometers for example for the Great Murin).

Every night, during activity, bats move to one or more feeding areas that they can exploit for a significant part of the night.

Feeding areas are exploited in different ways depending on the species. Some capture their prey in the open, such as Pipistrelles or Noctules, others can hunt on the wing, suspended, like the Rhinolophes while others glean their prey in the foliage (like small species of the genus Myotis).

Bats move in flight to reach their lodgings or their hunting grounds. Flight behavior is very different between species and depending on the type of movement, which induces a significant variability of the circulation spaces of bats. Some movements may be important, especially for migratory species (Table 4).

The chiroptera exploit nocturnal environment thanks to an echolocation system. They emit, by the mouth or the nostrils, series of sounds very acute, inaudible (ultrasound) or almost inaudible by the man. They then analyze the perceived echo to locate themselves or their prey.

The ultrasounds used are characterized by different parameters: frequency ranges used, variation of frequencies, rhythm (Tupinier, 1996). These characteristics are specific to each species or group of species, making it possible to acoustically identify chiroptera by means of an ultrasonic detector. Identification, however, has limitations, small species of murine being for example difficult to differentiate. Moreover, such an analysis must take into account the type of environment (distance to obstacles) and the behavior of the individual, which are appreciable through the rhythm of the signals. Indeed, bats structure their ultrasound according to the habitat they frequent (open environments, closed environments) (Barataud, 1999, Barataud, 2002).

The migration of bats has mainly been studied thanks to the ringing of bats. Hutterer et al. (2005) published the Europe-wide result of ringed bat movements. They distinguish three categories of bats with regard to banding results:

- Sedentary species with a reduced dispersal radius, from a few kilometers to a hundred kilometers;
- Regional migratory species that make seasonal migrations of a few hundred kilometers or that experience significant dispersal;
- Long-distance (or long-haul) migratory species that fly between wintering and summering sites over more than 3,000 to 4,000 kilometers (return distance).

Table 4: Migratory character of bats (*Source: Hutterer et al., 2005*)

Sedentary	Regional migratory	Long distance migratory
Rhinolophus euryale	*Barbastella barbastellus*	*Nyctalus leisleri*
Rhinolophus ferrumequinum	*Eptesicus serotinus*	*Nyctalus noctula*
Rhinolophus hipposideros	*Myotis myotis*	*Pipistrellus nathusii*
Myotis bechsteinii	*Pipistrellus pipistrellus*	
Myotis emarginatus	*Miniopterus schreibersii*	
Myotis nattereri		
Myotis daubentonii		
Myotis mystacinus		
Pipistrellus kuhlii		
Plecotus auritus		
Plecotus austriacus		

Pygmy pipistrelle, Alcathoe murine, and Grande noctule are not classified by Hutterer et *al*. (2005) due to the lack of ring recovery. The Pygmy Pipistrelle would however migrate significantly (Ahlén et *al*., 2007). The Great Noctule would probably also be a long-distance migrant (Dietz et *al*., 2009)

For long-distance migratory species, the preferred direction in Europe between summer and winter lodgings is southwesterly. However, migrations to the south or the south-east exists, as for example of the Pipistrelles of Nathusius of Great Britain which could migrate towards France and Benelux.

Rodrigues et *al*. (2008) suggest that migratory species follow the large linear elements of the landscape (river valleys, ridges, coastline) in their movements. Migratory species are species suitable for long-distance flight, capturing prey during fly. They usually hibernate in trees or in rocky cracks. Gender segregation exists for migration. Some of the males do not return to the farrowing areas but stay in the more southern regions. Beginning in the fall, males form harems to mate on female migration routes or on wintering sites.

Attendance of the marine environment by bats

Several publications and testimonies report the presence of bats on the coastal fringe, or even offshore, at sea. Although the number of studies devoted to this subject remains limited, and mainly by works in North Europe (North Sea and Baltic Sea) or in North America, it remains nonetheless that these information's provide a first glimpse of the use of the sea by chiroptera and its causes.

In fact, the number of record of bats at sea is increasing, as observers are interested in their presence offshore. They tend to suggest that maritime space is frequented in unsuspected proportions until then. The literature shows that long-distance migrations and, to a lesser extent, more regional seasonal movements, or even foraging, can lead bats to move along the coast or across vast extensions of the sea.

To reach the wintering grounds at the end of summer, or conversely to reach the calving grounds in the spring, some migratory populations have to cross marine areas, of greater or lesser extent, given the geographical configurations.

These crossings have been proven by ringing for several species (Hutterer et *al*., 2005), for example:

- for the *Nathusius Pipistrelle* between Great Britain and Holland, between Holland and the Channel Islands (Jersey),
- for the common Noctule, between Sweden and Germany, etc.

Numerous direct observations of individuals at sea corroborate these observations, for example:

- Hill & Hüppop (2007) contacted Nathusius pipistrelles using sound level meters between 2004 and 2007 on a gas platform 45 kilometers offshore in the south-east of the North Sea;
- Of the 34 bat observations made by Boshamer & Bekker (2008) on platforms in the North Sea between 1988 and 2007, 26 are Nathusius pipistrelles. Among the other migratory species, the Common Noctula and the two-colored Sérotine were observed. The latter is not known in Brittany and Pays de la Loire;
- Ahlén et *al*. (2007 and 2009) contacted off Sweden, more than 10 kilometers offshore, Nathusius Pipistrelles, Pygmy Pipistrelles, Leisler's Noctules and Common Noctules.

Other observations of movements of migrating bats at sea come from acoustic studies carried out on islands, for example:

- a Leisler noctule in Jersey (25 kilometers from the coast) (Magris, 2003);
- Leisler's Noctule, Common Noctule, and Nathusius's Pipistrelle in Helgoland, Germany (40 km from the coast) (Skiba, 2007); etc.

Studies have also been conducted in North America. They have shown that bats can migrate offshore to more than 30 kilometers off the coast (Cryan & Brown, 2007, Smith, 2013).

Although not commensurate with bird migrations, bats make seasonal movements between their winter and summer roosts. Some species travel distances of up to 1000 or even 2000 km (Leisler's Noctule, Common Noctule, Nathusius Pipistrelle, for example) (Hutterer et *al*., 2006). Others, on the other hand, are known for their sedentary character, with movements generally less than 10 km (the Little Horseshoe Bat, for example).

Some species of mammals take a risk of energetically expensive and risky long-distance 2-way migration, mainly to avoid undesirable conditions at a particular time of year. Compared to birds,

far fewer mammals are migratory. Long-distance migrants are known in cetaceans, pinnipeds, ungulates, and bats (Vaughan et *al*., 2000). In the latter group, migration plays an important role mainly for temperate zone species. To avoid low temperatures and lack of food in winter, and to find suitable roosts in a milder climate, several species migrate long distances (2,000 km) including the European species *Nyctalus noctula* (noctule), *N. leisleri* (Leisler's bat), *Pipistrellus nathusii* (Nathusius's bat), *P. pipistrellus* (common pipistrelle), and *Vespertilio murinus* (particolored bat), and American species *Lasiurus cinereus* (hoary bat), *Lasiurus borealis* (red bat), *Lasionycteris noctivagans* (silver-haired bat), *Leptonycteris curasoae* (southern long-nosed bat), *Leptonycteris nivalis* (Mexican long-nosed bat), *Choeronycteris mexicana* (Mexican long-tongued bat), and *Tadarida brasiliensis* (Brazilian freetailed bat). Other bat species are regional migrants, traveling 100–500 km. These include *Barbastella barbastellus* (barbastelle), *Myotis myotis* (greater mouse-eared bat), *Myotis daubentonii* (Daubenton's bat), and *Myotis dasycneme* (pond bat Cryan et *al*., 2004; Fleming and Eby 2003; Hutterer et *al*., 2005; Steffens et *al*., 2004; Strelkov 1969).

Extensive tagging programs in some countries (see summary in Steffens et al. 2004; Hutterer et al. 2005) revealed that bat migration routes within Europe are directed north–south, northeast-southwest, or northwest–southeast. In general, bats from high-latitude summer breeding sites move to milder climatic zones in the southern part of the continent, where winter conditions are more moderate and where bats can hibernate aboveground in trees and buildings (Fleming and Eby 2003; Strelkov 1969, 2000).

Research on the migratory movements of Schreibers's bat (*Miniopterus schreibersii*) in northeastern Spain showed that migratory paths mainly follow valleys and coasts, sometimes running through mountain passes (Serra-Cobo et *al*., 1998). Serra-Cobo et al. (2000) suggested as well that rivers are landmarks for orientation and paths for migration. Several studies provided evidence for migration of *P. nathusii* along seacoasts (Jarzembowski 2003; Petersons 1990, 2004; Strelkov 1969). Other investigations and sporadic observations also indicated that bats can cross open water such as the North Sea, Baltic Sea, and Black Sea (Ahlén 1997; Ahlén et *al*., 2007; Strelkov 1969; Walter et *al*., 2005). However, specific information about offshore migration is still not available.

A clearly marked pattern of directional flights has been found in long-distance (*N. noctula* and *P. nathusii*) and regional (*M. daubentonii*) migrants. Nathusius's bat travels 2,000 km, the noctule bat about 1,500 km, and Daubenton's bat about 300 km (Hutterer et *al*., 2005; Steffens et *al*. 2004; Strelkov 1969). There was a less obvious pattern in *P. pipistrellus* and *P. pygmaeus*, which may be due to their being less prone to long-distance movement (Hutterer et *al*., 2005; Steffens et *al*., 2004). Most populations of *P. pipistrellus* in central Europe are thought to be sedentary, although some individuals may occasionally migrate over large distances (Hutterer et *al*., 2005; Steffens et *al*., 2004).

The studies mentioned have highlighted the presence of species considered as partial or sedentary migrants, whether at sea (either from platforms or from boats) or on islands (they are then no resident). However, these observations appear to be more anecdotal than for migratory species. They are mainly Pipistrelles communes and Kuhl, Serotine commune, Murin de Daubenton, Oreillards red and gray, etc.

In rare cases and under certain geographical conditions, bats can cross arms of a few kilometers between the roosts and terrestrial feeding areas. This is the case, for example, of a Murine colony

on the island of Porquerolles, whose individuals hunt on the peninsula of Giens (3 km away) (Quekenborn, 2005). Ahlén et al. (2007) also mention round trips of bats on seabeds (about ten kilometers) to terrestrial hunting grounds, for the Daubenton Murin, the Pipistrelle, the Pygmy Pipistrelle, the Nilsson's Sérotine (not present in Brittany and Pays de la Loire), the common Sérotine and the red-eared bat.

Bats can also cross important inlets between summer and winter homes. This is the case, for example, of the Schreibers Miniopter (a very rare species in Brittany and the Pays de la Loire) and of the Capaccini Murine (a species not present in Brittany and the Pays de la Loire) that cross 40 to 50 kilometers of sea between the islands of Menorca and Mallorca, in the Balearic Islands in Spain (Amengual-Pieras et al., 2007). Finally, a genetic study (Castella et al., 2000) showed that populations of Greater Murin on both sides of the Strait of Gibraltar were in contact, thus testifying to regular passages on this 14-kilometer stretch of sea.

Ahlén et *al*. (2007 and 2009) have shown that bats are hunting at sea. Migratory species or seasonal transits feed on these areas during their movements. It also appeared that sedentary species went to the open sea in summer to feed there before returning to the mainland at the end of the night.

They thus observed feeding at sea, the following species:

- the Swamp Murine,
- the Daubenton Murine,
- the pipistrelle of Nathusius,
- the common Pipistrelle,
- the Pygmy Pipistrelle,
- the Leisler's Noctule,
- the common Noctule,
- the Sérotine of Nilsson,
- the common serotin,
- the two-colored serotin.

They show that bats hunt invertebrates offshore in the Baltic Sea and have inventoried the present species, which are mainly Diptera (Chironomidae, Cecidomyiidae, Tipulidae), Trichoptera (Leptoceridae), Hymenoptera (Ichneumonidae), Lepidoptera (Noctuidae). Some of these invertebrates come from the land and are found at sea after "drifting" in the air masses. They also mention the possibility for the Daubenton murine to be able to hunt marine crustaceans on the surface of the sea.

In contrast to Boshamer & Bekker (2008) who believed that offshore insects couldn't represent an exploitable food resource because of its unpredictability, Ahlén et al. (2007 and 2009) were able to demonstrate through scientific studies that the resource was at least partly localized and therefore exploited by chiroptera.

The feeding habitus of chiroptera at sea is so far insufficiently characterized (only one study, in the particular context of the Baltic) to be able to draw forecasts of frequentation in other marine environments. Nevertheless, a food resource seems to exist for bats.

From a bibliographical analysis, Le Campion, (2010) proposed a work of analysis of the species according to their affinity with the marine environment.

Based on studies carried out in northern Europe or the Mediterranean, this work does not logically take into account the local biogeographical characteristics of bat species.

Table 5: Overall index of potential maritime affinity degree of 23 species bats (*Source: Le Campion, 2010*)

Species	Migratory character	Coastal displacement or "Offshore"	Presence on the open sea	Hunting activity in littoral or marine area	Global index
Rhinolophus euryale	•				1 x •
Rhinolophus ferrumequinum	•			•	2 x •
Rhinolophus hipposideros	•			•	2 x •
Myotis myotis	••	•			3 x •
Myotis daubentonii	•	•	•	••	5 x •
Myotis brandti	••			•	3 x •
Myotis mystacinus	•			•	2 x •
Myotis alcathoe					
Myotis emarginatus	•	•			2 x •
Myotis nattereri	•			•	2 x •
Myotis bechsteinii	•			•	2 x •
Nyctalus noctula	•••	•••	••	••	10 x •
Nyctalus leisleri	•••	•••	••	••	10 x •
Nyctalus lasiopterus	••		•		3 x •
Eptesicus serotinus	••	••	••	••	8 x •
Pipistrellus pipistrellus	•		•	••	4 x •
Pipistrellus pygmaeus	••	•	•	••	6 x •
Pipistrellus kuhlii	•			•	2 x •
Pipistrellus nathusii	•••	•••	•••	••	11 x •
Barbastella barbastellus	••			•	3 x •
Plecotus auritus	•	•	••	•	5 x •
Plecotus austriacus	•	•	•		3 x •
Miniopterus schreibersii	••	••	•		5 x •

The following indices are given for each category:

<u>Migratory nature of the species</u>

- • Sedentary species
- •• Regional migratory
- ••• Migratory species

Costal displacement or ‘’offshore’’
- Offshore or coastal displacement poorly documented, just occasional, or over short distances only
- ●● Offshore or coastal displacement regular over average distances (a few tens of kilometers)
- ●●● Offshore or coastal displacement considered regular over long distances (> 100 km)

Presence on the open sea
- Presence on open sea rarely mentioned, or close to the coast (less than 20 km)
- ●● Presence on open sea regularly mentioned, at least a few kilometers from the coast (more than 20 km)
- ●●● Presence on open sea often mentioned, sometimes at very large distances (more than 100 km)

Hunting activity in littoral or marine area
- Mentioned-hunting activity on the coastal fringe (dunes, cliffs, etc.)
- ●● Mentioned open sea hunting activity

Bat presence offshore

In Europe, where existing offshore wind farms have encouraged the study of bat use of marine areas and behavior, researchers have documented bats presence in offshore waters. In Scandinavia, Ahlén et *al*. (2009) documented bats migrating and foraging in the offshore environment between Sweden and Denmark. They detected individual and small flocks of bats flying at low altitudes (less than 30 feet) over the surface of the water. Ahlén et *al*. (2007) detailed bat activity around offshore wind turbines in the Baltic Sea near Kalmarsund, Sweden, approximately 10 miles offshore. They observed bats migrating through the area and foraging around the turbines and blades.

Ahlén et *al*. (2007) also observed bats foraging on the abundant invertebrate prey located near or at the water’s surface and using offshore wind turbines as roosts. Boshamer and Bekker (2008) documented bats roosting on offshore oil platforms in the North Sea. Between 1988 and 2007, 34 bats were reported on offshore oil platforms during both the spring and fall migratory seasons. The average distance of bats at offshore oil platforms was 41 miles from shore, with the maximum distance over 100 miles.

Bat research in offshore environments is relatively limited, in contrast, bats at onshore wind energy facilities have been well studied. Bat collisions with offshore wind facilities would likely be much lower than at onshore facilities, because bat activity is relatively low in offshore environments, based on existing evidences.

Based on the data available (Stantec 2016), bat occurrences in offshore waters appear to be concentrated during migratory periods. Potential impacts on bats may include turbine collisions and possibly displacement from potential offshore migration areas (Pelletier et *al*. 2013). The northern long-eared bat, which is listed as threatened in U.S., could be particularly sensitive to these impacts if the species occurs in offshore waters, because its population is already vulnerable.

Also important for predicting presence offshore are the weather factors associated with offshore activity. Cryan and Brown, (2007) found that hoary bat presence on Southeast Farallon Island was associated with dark phases of the moon, low wind speeds, low barometric pressure, and cloudy skies. Sjollema, (2011) found that wind speed was the only factor that was associated with bat acoustic activity recorded up to 22 km offshore, with activity decreasing as wind speed increased. Bats flew over the Baltic Sea in winds up to 10 meters per second (m/s), although most activity took

place at wind speeds less than 5 m/s, and all observations of foraging were made during "suitable weather" (calm weather or a light breeze; Ahlén et *al*., 2007).

Presence of prey items likely plays a large role in presence of bats offshore. Bats roosted and foraged on and near existing turbines in European studies, and insects were found to accumulate around turbines (Ahlén et *al*., 2007, 2009). Insect surveys collected primarily chironomids (nonbiting midges), but other flying species were also captured (including terrestrial species that were drifting into the offshore environment) and evidence was found of bats feeding on crustaceans (Ahlén et al., 2007, 2009).

Attractiveness of offshore wind turbines

European studies have confirmed that bats forage and migrate offshore, exposing them to risk of collision mortality. Bats have been shown to be attracted to offshore wind turbines (Ahlén et *al*., 2007). A number of hypotheses for attraction of bats to onshore wind turbines have been identified, including roost attraction, landscape attraction, heat attraction, and visual attraction (Kunz et *al*. 2007). Each of these hypotheses would likely apply to offshore wind facilities, where turbines present a dramatic visual and structural contrast to the surrounding water. Rydell et *al*. (2010) suggest that prey concentration at turbines may be a primary cause of bat attraction based on analysis of bat mortality patterns documented at European wind facilities. This is consistent with observations of bats at offshore wind facilities mentioned above, where insects were observed to be concentrated around turbines (Ahlén et *al*., 2007).

Ahlén et *al*. (2007) have shown that bats can hunt more than 10 kilometers off the coast, whereas they are species with known action radius of a few kilometers around their roost.

They show that bats hunt invertebrates offshore and have inventoried the present species which are mainly Diptera (Chironomidae, Cecidomyiidae, Tipulidae), Trichoptera (Leptoceridae), Hymenoptera (Ichneumonidae), Lepidoptera (Noctuidae). Some of these invertebrates come from the land and are found at sea after "drifting" in the air masses. They also mention the possibility for the Daubenton murine to be able to hunt marine crustaceans on the surface of the sea.

The effect of the loss of hunting territory could be considered. However, Ahlén et *al*. (2007) do not indicate the possibility of disturbance of species by the construction of wind turbines on hunting habitats. On the contrary, it seems that offshore wind farms attract some drifting invertebrates, creating pabulum for bats while increasing their risk of collision mortality.

Bat flight behavior

Bat flight behavior was documented using radar and visual surveys, and acoustic surveys documented activity patterns on shore as well as at the base of turbines (Ahlén et *al*., 2007). Bats typically flew at heights of less than 40 m above the surface, although bats were observed foraging up to the top of wind turbines, with flight height presumably dependent on insect distribution (Ahlén et *al*., 2007). Bats were also observed to increase flight height around other structures such as ships and bridges in addition to wind turbines (Ahlén et *al*., 2009). Bats appeared most active when wind speeds were low, and bats often appeared to forage in close proximity to turbines and

were also observed resting on turbine structures (Ahlén et *al*., 2007). However, collision mortality rates could not be determined using these methods.

Meteorological constrains to activity at sea

Smith, (2013) has shown that it is possible to model the migration of North American bats on the coast from meteorological data (temperature and wind in particular).
Ahlén et *al*. (2007) showed that pipistrelles could fly up to winds of 9 $m.s^{-1}$ but that the majority of species were flying at sea below 5 $m.s^{-1}$ winds (about 10 knots). Jonge Poerink et *al*. (2013) also showed that activity only existed when the wind was weakest.

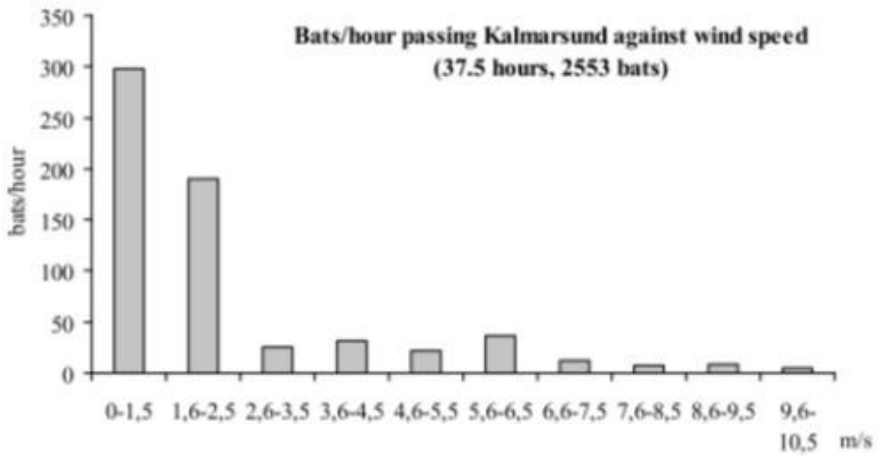


Figure 26: The relationship between the number of bats' contact and the wind speed

(Source: Ahlén et al., 2007)

Flight height and rigging in the wind farm

In Scandinavian marine waters, Ahlén et *al*. (2007) studied flight altitude of bats at sea. For migratory species, it is reported that individuals fly mostly at a height of 0-10 m above sea level. for example, a migratory flight altitude for Pipistrelle Nathusius or Pygmy Pipistrelle 1 to 3 m. For larger species, the flight altitude is higher but in the case, for example, of the Noctule commune, the majority of the altitudes noted are less than 40 m. They indicate, however, that there is a probability that bats flying high may not have been counted.

In another publication (Ahlén et *al*., 2009), they conclude that migrating bats fly low over the sea surface, while stating that they may change flight altitude during the phases of hunting.

They also indicate that moving species can quickly change their height to hunt near the rotors. The search for rest homes at the turbine is not impossible either.

For this last reason, it has been chosen to ignore the flight height of bat species at sea, as they cannot at present estimate their behavior.

Threat

Many factors threaten their populations:

- the disappearance or modification of resting areas: renovation of buildings or bridges, closing of the entrance to underground houses, felling of trees with cavities, lighting monuments not taking into account these mammals habitats;
- the transformation of their home range (flight routes and hunting grounds): densification of the road network, abandonment of extensive grazing, destruction of hedgerows, disappearance of wetlands, homogenization of forestation, artificialisation of rivers;
- disturbances during hibernation or reproduction;
- the use of chemicals: treatment by pesticides, or pest control;
- direct mortality: predation by the domestic cat, wind farm development.

Wind farm impacts

In terrestrial environments, the effects of wind farms are generally of three types:
- Direct loss of habitat (by destroying the landscape elements necessary for their food or shelter);
- Indirect loss of hunting habitat and barrier effect (disturbance, modification of hunting grounds and movement routes);
- Mortality (by direct collision or barotrauma).

For offshore wind projects, the potential mortality effect is the only one documented and is therefore the only one taken into account.

Bats can collide with moving blades of wind turbines. Mortality occurs either by direct collision with the blades or by internal injury following rapid changes in air pressure near the blades, a phenomenon known as barotrauma (Horn et *al*., 2008, Baerwald et *al*., 2008). It seems that the bats echolocation system does not detect the moving blade early enough (Long et *al*., 2009).
Almost all publications indicate that bat mortality by wind turbines is particularly high at the time of dispersal and postnuptial migration (Rydell et *al*., 2010a, Camina 2012, Cornut & Vincent, 2010).
An isotope analysis study in Europe has shown that impacted individuals can either be from local populations or migrating populations (Voigt et *al*., 2012).
Several hypotheses have been put forward to explain why bats entered the blades' rotation area and therefore why they can collide with wind turbines:

- In migration, they could use little or no echolocation and thus collide with the blades, not detecting them. However, some studies are inconclusive on this behavior (Kunz et *al*., 2007), while others show that bats, on the other hand, use migration echolocation (Ahlén et *al*., 2007);
- One could inspect wind turbines to look for roosts or breeding lodges (Cryan 2008, Cryan & Barclay 2009);
- they could be attracted by aerial flashing lights of wind turbines (Horn et *al*., 2008);
- insects, and therefore bats, are attracted by light (Beucher et *al*., 2013), noise, heat or magnetic fields generated by nacelles (Kunz et *al*., 2007).

- However, for this latter hypothesis, Rydell et *al*. (2010b) provide another reason why bats feed mostly close to wind turbines, as demostrated also in several studies (Ahlén, 2002, Ahlén et *al*., 2007 and 2009, Brinkmann et *al*., 2006, Horn et *al*., 2008, etc.): Wind turbines could interfere with active or passive migrations of insects. Clouds of insects could then be formed at the level of wind turbines, by "top" effect. The authors do not develop the hypothesis, certainly for lack of scientific resources on the movements of aerial plankton.

Baerwald and colleagues (2008) revealed that bats may die BY barotrauma at wind turbines, i.e., killed bats may show no external signs of injuries such as bone fractures. Instead, bats killed by barotrauma exhibit extensive hemorrhages in the thoracic and abdominal cavities (Baerwald et *al*., 2008) and/or hemorrhages in the middle or inner ears (in more than 50 % of all bats studied by Grodsky et *al*., 2011).

Barotrauma is most likely caused when bats are subject to sudden air pressure reductions near moving turbine blades. Recent studies highlight that both blunt-force trauma caused by direct collision and barotrauma caused without physical contact may be responsible for the deaths of bats at wind turbines (Grodsky et *al*., 2011). Possibly, large wind turbines with longer blades inflict stronger physical forces on bats, i.e., a stronger reduction in air pressure in the tailwind vortices, and these may result in a higher percentage of bats killed by barotrauma in relation to those killed by blunt-force trauma. Such considerations are important because bats killed by bone fractures via blunt force trauma may fall to the ground close to the wind turbines and are likely to be found by researchers. In contrast, bats suffering from barotrauma may experience mild symptoms that may allow them to survive for minutes, hours, or even days before they eventually die. Such bats are almost impossible to find because they do not drop dead in close proximity to the turbines. If mild but nonetheless lethal barotrauma is a significant cause of death for bats at wind turbines, the total number of bat fatalities may be largely underestimated. And if taller wind turbines cause a larger pro- portion of bats to die of barotrauma, the recent and future installation of larger turbines may result in an increasing number of unrecorded bat deaths.

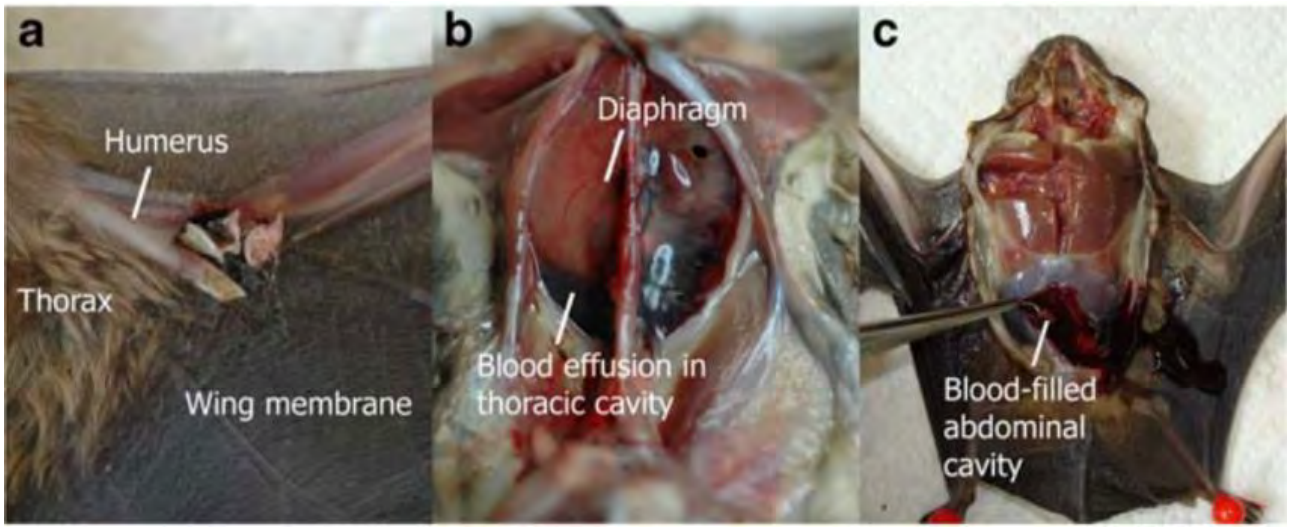


Figure 27: Blunt-force trauma (a) and barotraumata (b, c) in three noctule bats (Nyctalus noctula) killed at wind turbines. A) Ventral view of an open fracture of the left humerus at the height of the elbow joint. B) Ventral view of the opened abdominal cavity with blood effusion in the thoracic cavity visible behind the diaphragm (hemothorax). C) Ventral view of opened carcass without bone fractures, but severe bleeding in the abdominal cavity (hemoabdomen) ***(Source: Gudrun Wibbelt, IZW)***

Effect of artificial light at night

Little is known about the wavelength-specific response of light receptors in European bats and less so about the light spectra that affect their behaviour most severely. However, different light spectra can have different effects on the emergence behaviour of bats (Downs et *al*., 2003). Compared to absence of artificial illumination, red light had the least effect on number of emerging *Pipistrellus pygmaeus* from two roosts while the number dropped significantly when the roost exits were illuminated with blue and white light (Downs et *al*., 2003). Red light was proposed for being used in bat roost checks, supposedly having least effect on bats (Downs et *al*., 2003).

A recent study (Spoelstra et *al*., 2017) showed that reducing the blue and increasing the red part of the spectrum of a light source significantly mitigates its impact on slow-flying Myotis and Plecotus species in their foraging habitat. Conversely, the absence of blue light reduced the attraction of insects and thereby the attraction of agile, opportunistic species such as Pipistrellus spp.

Voigt et *al*. (2018) observed an increase in flight activity for migrating *P. pygmaeus* and a trend for a higher activity for *Pipistrellus nathusii* around red LED lights, which is unrelated to foraging and could be explained by phototaxis. A recent study highlights that migratory P. nathusii might as well get disoriented, when exposed to artificial green or red light (Voigt et *al*., 2017, 2018), yet the underlying causes and any potential interference of artificial light with the navigational system of bats are still under debate and require further research. Therefore, response of bats to light spectra modifications may differ during migration season and seems site and species specific.

Mitigation measure

The most widespread mitigation measure for wind turbine- related bat fatalities is to define a threshold wind speed, a so- called cut-in speed, at which the rotors start to operate. This can be an efficient mitigation measure because bats are only active at rotor height at relatively low wind speeds. Thus, if wind turbines are switched off or feathered at low wind speeds - when net energy production is low any-ways - bat fatalities may be drastically reduced (Baerwald et *al*., 2009; Arnett et *al*., 2013). In addition, bat activities vary seasonally, e.g., bats are inactive in winter and most active during migration. These factors can also be incorporated into the operation schedules of turbines (Rodrigues et *al*., 2008). Indeed, the enforcement of cut-in speeds for the operation of wind turbines may reduce bat fatalities by as much as 60-80 % (Baerwald et *al*., 2009; Arnett et *al*., 2013). Most commissioned operation protocols employ cut-in speeds of 6-7 m s^{-1}at ambient temperatures higher than 13–15 °C (measured at nacelle height) and limited to the season of highest bat activity in autumn. Notably, some bats, particularly the migratory species *N. nyctalus* and *P. nathusii*, may still be active at wind speeds higher than 7 m s^{-1}. Therefore, the current practice of cut-in speeds may selectively affect those species that can forage or migrate in stronger winds.

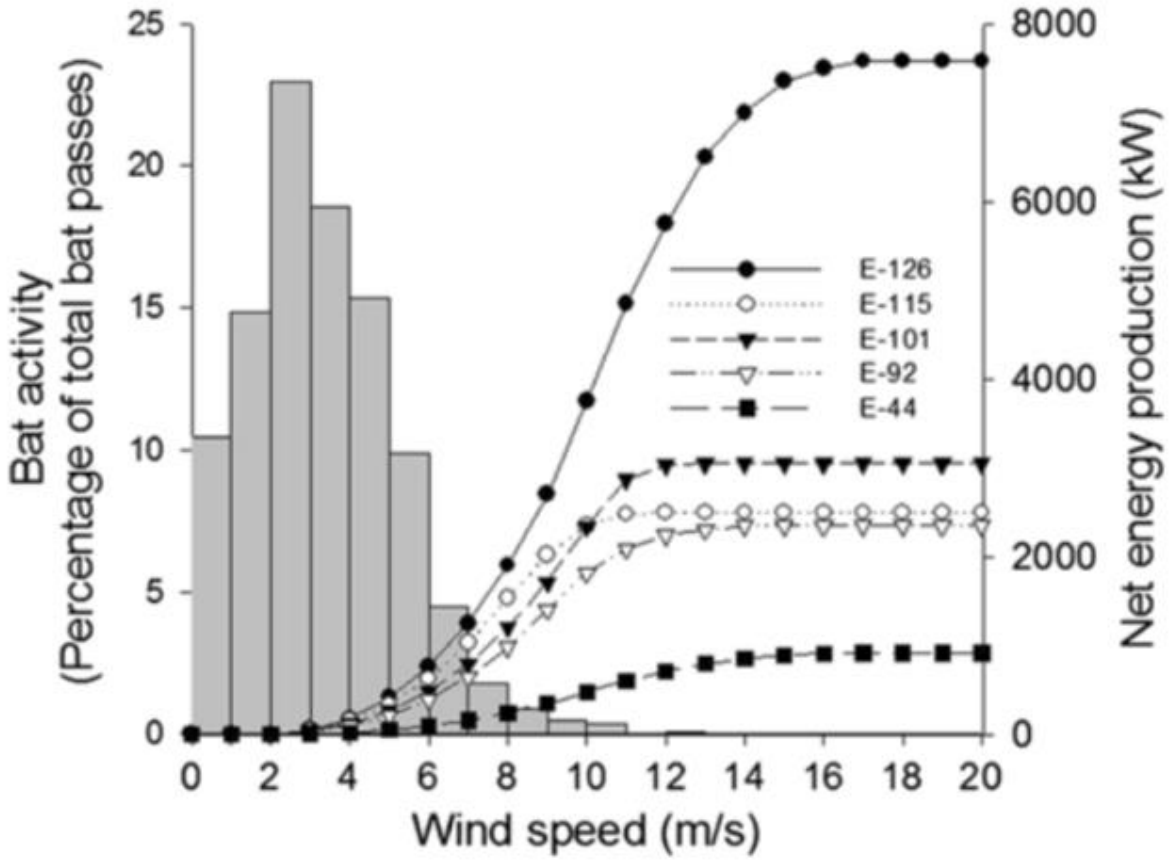


Figure 28: Overlap between bat activity and wind turbine energy production in relation to wind speed. Numbers represent the swept area by different WT. Novel larger WT produce at a lower wind speed, thus overlapping with bat activity. ***(Source: Ahlén et al., 2007)***

Bat species in France

Of the 34 species of bats identified in France to date, 30 are currently present in the PACA region, making it one of the richest regions in terms of species. They are divided into 4 families: Rhinolophids, Vespertilionidae, Miniopteridae and Molossids.

- ***Rhinolophids***

They owe this curious name - literally "leaf-shaped nose" - to the peculiar appearance of their nose, shaped like a horseshoe surmounted by a slender appendage called a lancet. They use it to emit ultrasound with extraordinary precision. The ears, vast and punctual, have no tragus. Another characteristic feature: at rest, the rhinolophes grow in their wings. Provence has sheltered 4 species but one has disappeared during the 20th century: Mehalely's Rhinolophe.

- ***Vespertilionidae***

It is by far the largest family in Provence. There are 25 species, of very varied morphologies. Their main common point is to have a tragus in the hollow of the ear. The large noctule (46 cm wingspan for 60 g) and the pygmy pipistrelle (19cm wingspan for 4 g), both members of this family, are respectively the largest and the smallest bats in the world. Europe.

- ***Miniopteridae***

Previously attached to the Vespertilionidae, this family has recently been designated. The chiroptera are characterized by long, thin wings, a rounded head with a convex forehead and short ears. The Schreibers Miniopter - named after an Austrian naturalist of the late 18th century - is the only representative of this family in Europe. It is also one of the rare bats whose deposits are exclusively composed of underground cavities (caves, caves, chasms, etc.) throughout the annual cycle.

- ***Molossids***

They have a long tail clearly protruding from the uropatagium and large ears pointing forward. Only one species of this family lives in Europe, the Molossus of Cestoni, whose wingspan can reach 45cm. It is also the only bat that does not hibernate but remains active all winter.

Within the PACA region, all species are protected by the law (Article L.411-1 of the Code of Environment and ministerial order of April 23, 2007). This fixes the modalities of respect for their physical integrity, but also the integrity of their living environment, namely lodgings, hunting grounds and movement corridors. Other European arrangements (Habitats Directive, Berne Convention, Eurobats Agreement) and international (Bonn Convention, CITES) complement the regulatory protections that bats enjoy.

The PACA chiropterological fauna currently has 31 species (including one missing), out of 34 French and around 38 European. Of these 31 species, 11 are listed in Annex 2 of the Habitats Directive.

Table 6: Rarity of Chiroptera in PACA region departments

Common name	Scientific name	Alpes Hte Prov. (04)	Htes Alpes (05)	Alpes mar. (06)	B. du Rh. (13)	Var (83)	Vaucl. (84)
Mehely's horseshoe bat	*R. mehelyi*	0	0	0		0	0
Mediterranean horseshoe bat	*R. euryale*		0				0
Lesser horseshoe bat	*R. hipposideros*						
Greater horseshoe bat	*R. ferrumequinum*						
Schreibers's long-fingered bat	*M. schreibersii*						
Long-fingered bat	*M. capaccinii*						
Bechstein's bat	*M. bechsteinii*						
Western Barbastelle	*B. barbastellus*						
Lesser Mouse-eared bat	*M. blythii*						
Greater mouse-eared bat	*M. myotis*						
Geoffroy's bat	*M. emarginatus*						
Alcathoe bat	*M. alcathoe*				0	?	0
Brandt's bat	*M. brandtii*				0	?	0
Common noctule	*N. noctula*						0
Leisler's Noctule	*N. leisleri*						
Greater Noctule Bat	*N. lasiopterus*	0	0				0
Northern bat	*E. nilssonii*				0	0	0
Particoloured bat	*V. murinus*				0	0	0
Nathusius' pipistrelle	*P. nathusii*						
Soprano Pipistrelle	*P. pygmaeus*						
Alpine long-eared bat	*P. macrobullaris*						0
Whiskered Bat	*M. mystacinus*				0	0	
Natterer's bat	*M. nattereri*						
Common serotine	*E. serotinus*						
Brown long-eared bat	*P. auritus*						
Grey long-eared bat	*P. austriacus*						
European free-tailed bat	*T. teniotis*						
Daubenton's Myotis	*M. daubentonii*						
Common Pipistrelle	*P. pipistrellus*						
Kuhl's Pipistrelle	*P. kuhlii*						
Savi's pipistrelle	*H. savii*						

Very rare, exceptional	Rare	Fairly uncommon	Common	Disappeared	Present but unknown	Unknown status	Absent

Table 7: biological risk of in PACA region for Chiroptera species

Species	RI	Species	RI	Species	RI	Species	RI	Species	RI
R. mehelyi	Disp	*R. hipposideros*	H	*N. leisleri*	M	*M. mystacinus*	L	*M. daubentonii*	VL
R. euryale	VH	*R. ferrumequinum*	H	*N. noctula*	M	*M. nattereri*	L	*P. pipistrellus*	VL
M. schreibersii	VH	*M. myotis*	H	*M. brandtii*	M	*E. serotinus*	L	*P. kuhlii*	VL
B. barbastellus	VH	*M. emarginatus*	H	*V. murinus*	M	*P. auritus*	L	*H. savii*	VL
M. capaccinii	VH	*M. alcathoe*	H	*P. nathusii*	M	*P. austriacus*	L		
M. bechsteinii	VH	*N. lasiopterus*	H	*P. pygmaeus*	M	*T. teniotis*	L		
M. blythii	VH	*E. nilssonii*	H	*P. macrobullaris*	M				

VH = Very high	H = High	M = Moderate	L = Low	VL = Very low	Disp = Disppear

The urgency of conservation is not the same depending on the species. Reading the distribution maps and associated comments, taking into account the different red list categories, the table of biological issues and the protection status of the PACA chiroptera made it possible to select 10 species for which the conservation issues are the same. These prioritary species are:

- **Murine Capaccini**: France has the largest population of this species from Morocco to Italy, which gives it an international responsibility vis-à-vis this murine. With 3000 individuals, the breeding population of PACA represents 75% of the national population. In addition, Provence has the largest known hibernation colony, with 300 individuals in the Verdon Gorge.
- **Miniopter of Schreiber**: the Provençal population, although still relatively important (12 000 ind.), is extremely fragile. Like the European population, it experienced a sharp and brutal fall in its workforce in 2002-2003 following an epidemic of unknown origin. On the other hand, because this population is present in a small number of sites, some of them concentrating a very important population (a single lodging in PACA hosts 10 to 15% of the national wintering population, which makes it a site of international importance).
- **Euryal horseshoe bat**: this species, common at the beginning of the last century in most cavities, is represented today by about a hundred individuals only in reproduction. This precarious situation is widespread throughout the country, Midi-Pyrenees forming the bastion of this Rhinolophe.
- **Greater Horseshoe Bat**: a common species 50 years ago in PACA, in decline in a number of areas (Alpilles, Hautes-Alpes). The Camarguais Bastion represents a large population in the Mediterranean area, which can serve as a recolonization area towards deserted territories.
- **Small Horseshoe Bat**: the regional population, with the strongholds that are the plateau of Valensole, Vachère, Entraunes and Roya, represent an important part of the French continental population. The conservation of this population is important, given the regressions observed in the Bouches du Rhône for example, where this Rhinolophe has almost disappeared.

- **Murine Bechstein**: in France, this forest species is described as disseminated, uncommon and dependent on a habitat quality. This situation is found in PACA, region which host one of the most important breeding colonies known in France (in Gémenos) with up to 72 individuals.
- **European Barbastelle**: As for the Bechstein Murine, the Barbastelle is a rare forest species in general, and very rare in the Mediterranean biogeographical zone.
- **Short-eared Murine**: a Habitat Directive Appendix II species often linked to pastoral areas. Colonies often mixed with those of the Greater Horseshoe Bat, which represents an advantage in terms of efficiency of the conservation measures applied on the roostings.
- **Small Murine**: PACA has the largest hibernation colony known in France. Regional numbers are relatively large, giving the territory a national responsibility for this species. Finally, some colonies lie in natural subterranean cavities, which is infrequent.
- **Great Murine**: Habitat Directive Appendix II species forming important mixed - and often indistinguishable - colonies with Little Murine. The conservation measures applied to the deposits will therefore often be common to these two species.

Regulatory and legal protection of Chiropteres

International protection status

At the international level, two conventions concern bats: the Bonn Convention (JORF of 30/10/1990) which relates to the conservation of migratory species belonging to wildlife and the Bern Convention (JORF of 28/08 / 1990 and 20/08/1996) which relates to the conservation of Europe's wildlife and natural environment.

The Agreement on the Conservation of Bat Populations in Europe (EUROBATS, JORF of 16/03/96) is a variation of the Bonn Convention and commits the signatory parties to take into account fundamental obligations, including take appropriate measures to encourage the conservation of bats.

The European Habitats Directive (92/43 / EEC) calls for the strict protection of species in Annex IV of the Directive, as well as the protection of breeding and resting areas. The designation of Special Areas of Conservation is provided for Appendix II species. Twelve species of Appendix II are present on French territory. A total of 625 sites of Community importance being mentioned as hosting Chiroptera have been proposed to the European Commission to join the Natura 2000 network.

National protection status

The species of bats living in metropolitan France are protected in France under Article L.411-1 of the Environment Code and by the ministerial decree of 23 April 2007 (JORF of 10/05/2007), which fixes the list of terrestrial mammals protected throughout the territory and the modalities of their protection. The protection of breeding sites and resting areas for species is provided for in the same law. This new legislation now protects the 33 species of bats currently described on the metropolitan territory by name.

Red Lists and Conservation Status

The red lists are available on several scales. At the global level, the International Union for the Conservation of Nature (IUCN) Red List draws attention to the state of conservation of the different species of the world, by classifying species according to a precise methodology (IUCN, 2002). Similarly, the French Red List divides endangered species into several categories: extinct, endangered, vulnerable or rare species (Maurin & Keith, 1994). Some regions have also done this at the lower level.

Table 8: Bat species in France and in PACA region

Common Name	Scientific Name	PACA	RLF	RLE	RLG	Protection status
Mediterranean horseshoe bat	*Rhinolophus euryale*	x	NT	VU	NT	Vp
Greater horseshoe bat	*Rhinolophus ferrumequinum*	x	NT	NT	LC	Vp
Lesser horseshoe bat	*Rhinolophus hipposideros*	x	LC	NT	LC	Vp
Mehely's horseshoe bat	*Rhinolophus mehelyi*		CR	VU	VU	Vp
Western Barbastelle	*Barbastella barbastellus*	x	LC	VU	NT	Vp
Northern bat	*Eptesicus nilssoni*	x	LC	LC	LC	Vp
Common serotine	*Eptesicus serotinus*	x	LC	LC	LC	Vp
Savi's pipistrelle	*Hypsugo savii*	x	LC	LC	LC	Vp
Alcathoe bat	*Myotis alcathoe*	x	LC	DD	DD	Vp
Bechstein's bat	*Myotis bechsteini*	x	NT	VU	NT	Vp
Lesser mouse-eared bat	*Myotis blythi*	x	NT	NT	LC	Vp
Brandt's bat	*Myotis brandti*	x	LC	LC	LC	Vp
Long-fingered bat	*Myotis capaccinii*	x	VU	VU	VU	Vp
Pond bat	*Myotis dasycneme*		NA		NT	Vp
Daubenton's Myotis	*Myotis daubentoni*	x	LC	LC	LC	Vp
Geoffroy's bat	*Myotis emarginatus*	x	LC	LC	LC	Vp
Greater mouse-eared bat	*Myotis myotis*	x	LC	LC	LC	Vp
Whiskered Bat	*Myotis mystacinus*	x	LC	LC	LC	Vp
Natterer's bat	*Myotis nattereri*	x	LC	LC	LC	Vp
Maghreb Mouse-eared Bat	*Myotis punicus*		VU	NT	DD	Vp
Escalera's bat	*Myotis escalerai*		DD		LC	Vp
Greater Noctule Bat	*Nyctalus lasiopterus*	x	DD	DD	VU	Vp
Leisler's Noctule	*Nyctalus leisleri*	x	NT	LC	LC	Vp
Common noctule	*Nyctalus noctula*	x	NT	LC	LC	Vp
Kuhl's Pipistrelle	*Pipistrellus kuhli*	x	LC	LC	LC	Vp
Nathusius' pipistrelle	*Pipistrellus nathusii*	x	NT	LC	LC	Vp
Common Pipistrelle	*Pipistrellus pipistrellus*	x	LC	LC	LC	Vp
Soprano Pipistrelle	*Pipistrellus pygmaeus*	x	LC	LC	LC	Vp
Grey long-eared bat	*Plecotus austriacus*	x	LC	LC	LC	Vp
Brown long-eared bat	*Plecotus auritus*	x	LC	LC	LC	Vp
Alpine long-eared bat	*Plecotus macrobullaris*	x	DD	NT	LC	Vp
Particoloured bat	*Vespertilio murinus*	x	DD	LC	LC	Vp
Schreibers's long-fingered	*Miniopterus schreibersi*	x	VU		NT	Vp

bat						
European free-tailed bat	*Tadarida teniotis*	x	LC	LC	LC	Vp

Vp: Very protected

3.2.4.2 CETACEANS

The northern part of the western Mediterranean Sea is a highly important area for all kind of cetaceans: planctophageous (Fin whale *Balaenotera physalus*), teutophageous (Pilot whale *Globicephala melas*, Cuvier's beaked whale *Ziphius cavirostris*, Risso's dolphin *Grampus griseus* and sperm whale *Physeter macrocephalus*), ichtyophageous (bottlenose dolphin *Tursiops truncatus*) and mixed (striped dolphin *Stenella coeruleoalba*). Among these common and regular species, one species is classified, within the IUCN status of conservation, as Endangered (sperm whale), three as "Vulnerable" (fin whale, striped dolphin and bottlenose dolphin) and three as Data Deficient (Risso's dolphin, pilot whale and Cuvier's beaked whale).

The Mediterranean Sea is a militarily strategic area, and is also of increasing interest for hydrocarbon exploration and exploitation. All military or geological or oceanographic activities involving high-intensity noise carried out in the proximity of some species, like sperm whale and Cuvier's beaked whales are of great concern. This kind of high sound exposition can also be an aggravating factor for collision in masking a vessel approach sound or in diminishing the auditory capacities of animals.

Considering species, no management or conservation measures have been taken as yet specifically for the conservation of several species: sperm whale, pilot whales, striped dolphin or Risso's dolphin, although generic protection laws for cetaceans exist.

Table 9: Conservation status and tools concerning cetaceans' species

Common name	Scientific name	Conservation statuts	International and national conservation instruments
Fin Whale	*Balaenotera physalus*	Vulnerable	Bern Convention, App. II; Bonn Convention, App. I, App.II; CITES, App.I; SPA/BD Protocol, Barcelona Convention, Annexe II; French law: Arrêté du 1er juillet 2011; Spanish law: Decree 1727/2007 of 21 December 2007; Decree of 12 January 2008
Striped dolphin	*Stenella coeruleoalba*	Vulnerable	Bern Convention, App. I; Bonn Convention, App.II (East tropical Pacific, Mediterranean); CITES, App.II; SPA/BD Protocol, Barcelona Convention, Annexe II, (Western Mediterranean); French law: Arrêté du 1er juillet 2011

Common bottlenose dolphin	*Tursiops truncatus*	Vulnerable	Bern Convention, App. I; Bonn Convention, App.II (North and Baltic sea) CITES, App.II EU Habitats Directive, Ann. II SPA/BD Protocol, Barcelona Convention, Annexe II, Western Mediterranean) French law: Arrêté du 1er juillet 2011 Spanish law: Decree 1727/2007 of 21 december 2007; Decree of 12 January 2008
Long-finned Pilot whale	*Globicephala melas*	Data deficience	Bern Convention, App. I; Bonn Convention, App.II (North and Baltic sea); CITES, App.II; SPA/BD Protocol, Barcelona Convention, Annexe II; French law: Arrêté du 1er juillet 2011;Spanish law : Decree 1727/2007 of 21 December 2007; Decree of 12 January 2008
Risso's dolphin	*Grampus griseus*	Data deficience	Bern Convention, App. I; Bonn Convention, App.II (North and Baltic sea); CITES, App.II; SPA/BD Protocol, Barcelona Convention, Annexe II; French law : Arrêté du 1er juillet 2011; Spanish law : Decree 1727/2007 of 21 December 2007; Decree of 12 January 2008
Sperm whale	*Physeter macrocephalus*	Endangered	Bern Convention, App. II (Mediterranean); Bonn Convention, App. I, App.II; CITES, App.I; SPA/BD Protocol, Barcelona Convention, Annexe II; French law : Arrêté du 1er juillet 2011; Spanish law : Decree 1727/2007 of 21 December 2007; Decree of 12 January 2008
Cuvier's beaked whale	*Ziphius cavirostris*	Data deficience	Bern Convention, App. I; CITES, App.II; SPA/BD Protocol, Barcelona Convention, Annexe II; French law : Arrêté du 1er juillet 2011; Spanish law : Decree 1727/2007 of 21 December 2007; Decree of 12 January 2008

Various kinds of marine protected areas exist or have been proposed throughout the Mediterranean. Although not always specifically intended for one species or another, several measures once implemented, could contribute to their conservation: the PELAGOS Sanctuary, a 90,000 km^2 cetacean sanctuary in the Corsican-Ligurian Basin, created in 1999 by Italy, France and the Monaco Principality.

Cetaceans, are protected at different levels, by the following legal instruments:

1) ACCOBAMS;
2) The Protocol of the Barcelona Convention concerning Specially Protected Areas and Biological Diversity in the Mediterranean;
3) the Bern Convention;
4) the CITES;

5) the EC regulation lists the species in its Appendix A, (which prohibits trade for primarily commercial purposes);
6) the FAO Code of Conduct for Responsible Fisheries;
7) the "United Nations Straddling Stocks Agreement";
8) the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas;
9) the Agreement for the Establishment of the General Fisheries Commission for the Mediterranean (GFCM);
10) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, or "Habitats Directive" whose annex IV protects all cetacean species.

Considering ship strikes, the national French law (Arrêté du 1er juillet 2011) and the Spanish laws (Decree 1727/2007 of 21 December 2007; Decree of 12 January 2008) could largely limit these impacts.

Cetacean presence in the area of the Gulf of Lions

The Gulf of Lions represents the natural continuation westward of the contiguous PELAGOS Sanctuary recognised for its cetacean richness. It shares important cetacean habitats and is likely inhabited by the same cetacean populations that occur in the Sanctuary (Di-Méglio and David, 2010). The continental shelf is the habitat of the bottlenose dolphin (*Tursiops truncatus*), from the coast through the shelf edge and canyon's head. The slope appears more frequented by four teutophageous species: Risso's dolphins (*Grampus griseus*) are encountered all along the slope, merely its upper part. Concerning sperm whales (*Physeter macrocephalus*), Pilot whales (*Globicephala melas*) and Cuvier's beaked whales (*Ziphius cavirostris*), they seem to exploit more the lower part of the slope and preferentially some peculiar canyon's systemes: Creus and Lacaze-Duthier for the three species and Sète and Marti for the sperm whale and pilot whale. Concerning more pelagic waters, they are frequented by fin whales (*Balaenoptera physalus*), pilot whales and the striped dolphin (*Stenella coeruleoalba*).

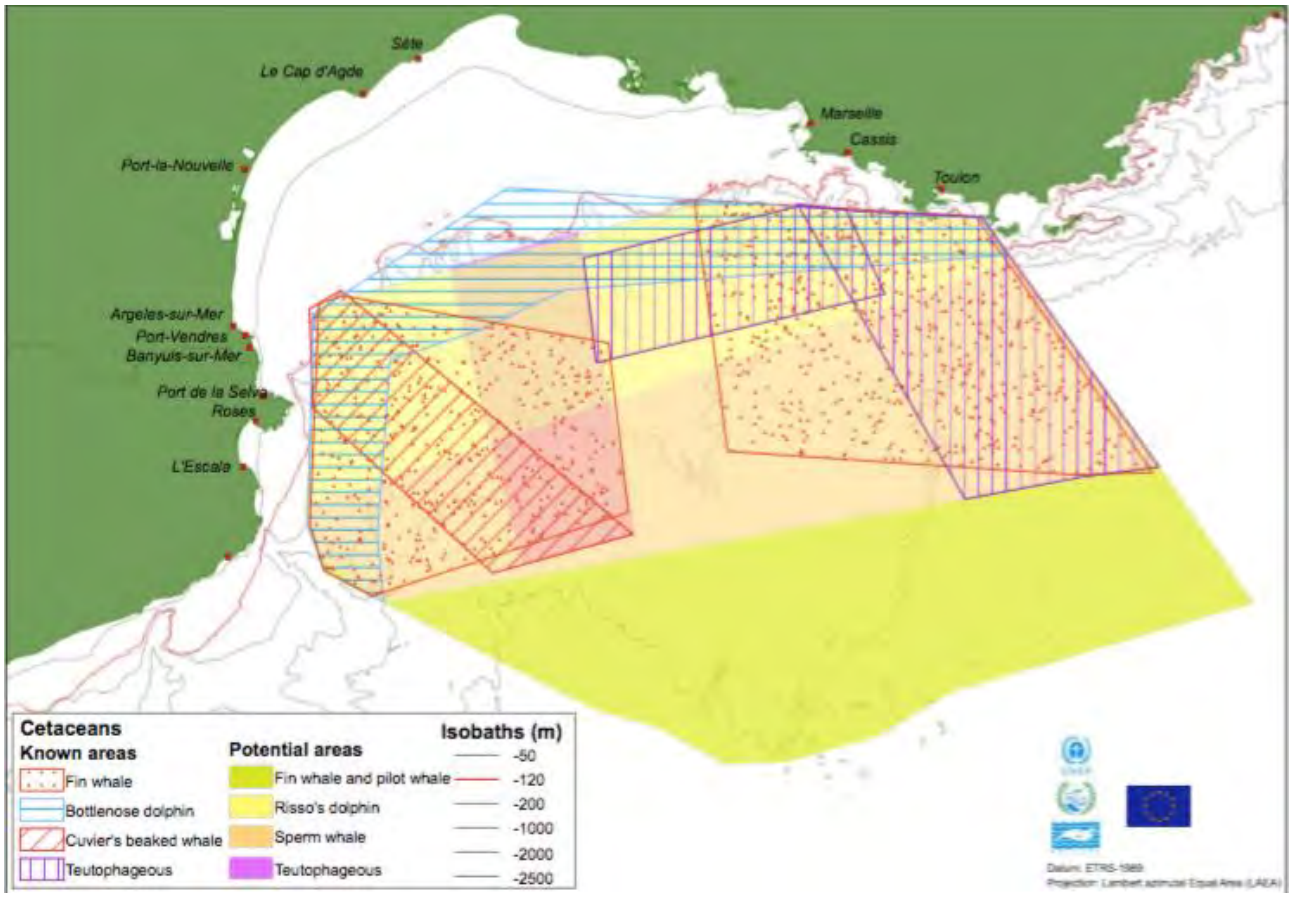


Figure 29: Cetacean species and their distribution in the gulf of Lion, from UNEP-MAP-RAC/SPA, 2013

A very large portions of the high seas remain unknown even nowadays, because data on cetaceans presence are lacking for some period of the year, merely seasons outside summer, it is difficult to dress an exhaustive and representative portrait of what occurs in the "Gulf of Lions" area.

- **Fin whale - *Balaenoptera physalus***

Fin whales (*Balaenoptera physalus*) in the Mediterranean are known to be preferentially pelagic: their preferential habitat begin after the 2000 m isobaths, but it they can occur in slope and shelf waters as well, depending on the distribution of their prey. They favour upwelling and frontal zones with high zooplankton concentrations (Cotté et *al*., 2009).

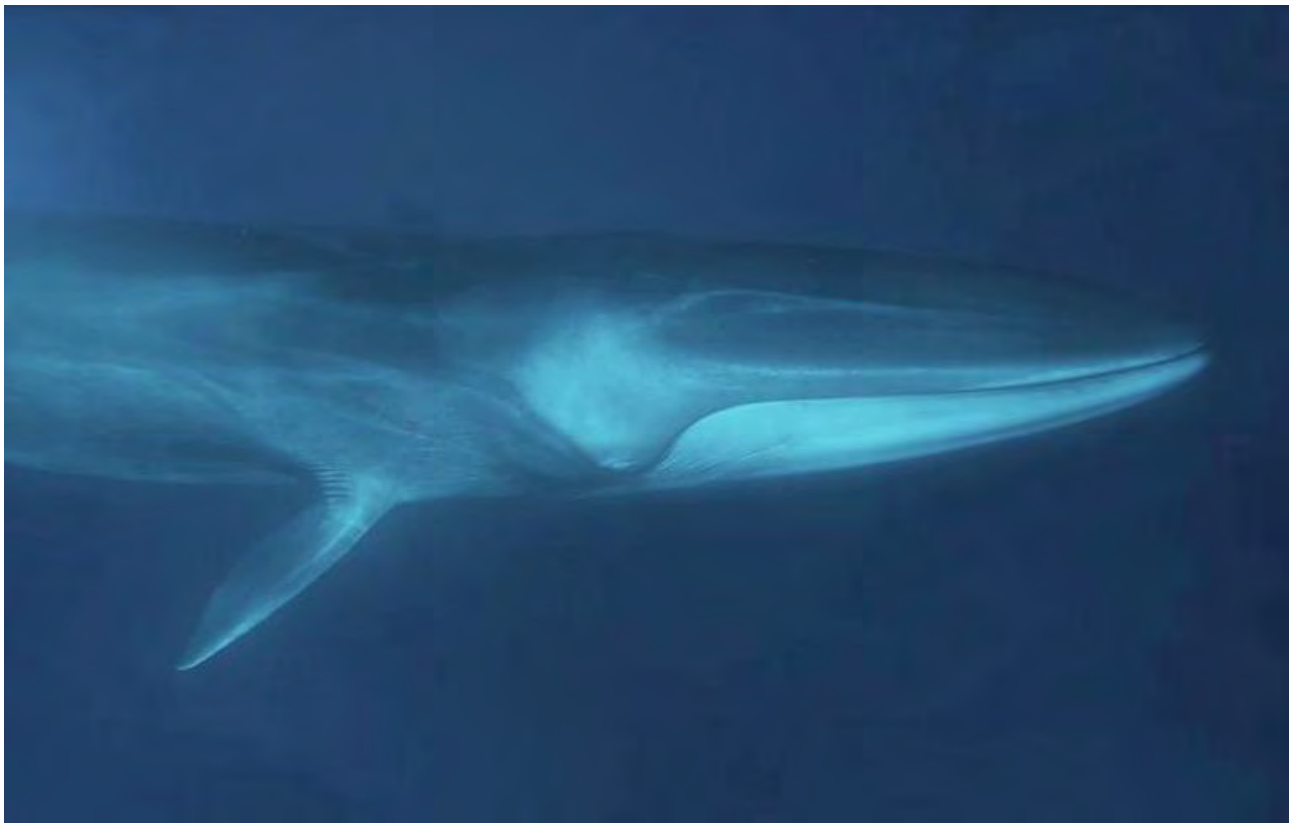


Figure 30: Fin whales (*Balaenoptera physalus*)

The main direct threats for this species are ship strikes (David and Di-Méglio, 2011).

Fin whales are regularly encountered all year round throughout the north-western basin where abundance is far higher than elsewhere in the Mediterraean sea (Notarbartolo et *al*., 2003; Cotté et *al*., 2009). The concentration is the highest in summer in highly productive portions of the Corsican, Ligurian, Tyrrhenian Sea and offshore the Gulf of Lions (Delacourtie et *al*., 2009; Monestiez et *al*., 2006) and less in winter (Gannier 2005; Di-Méglio et *al*., 2010). Thus, this species could frequent the offshore Gulf of Lions from spring until autumn at least, several individuals staying even in winter (Bentaleb et *al*., 2011).

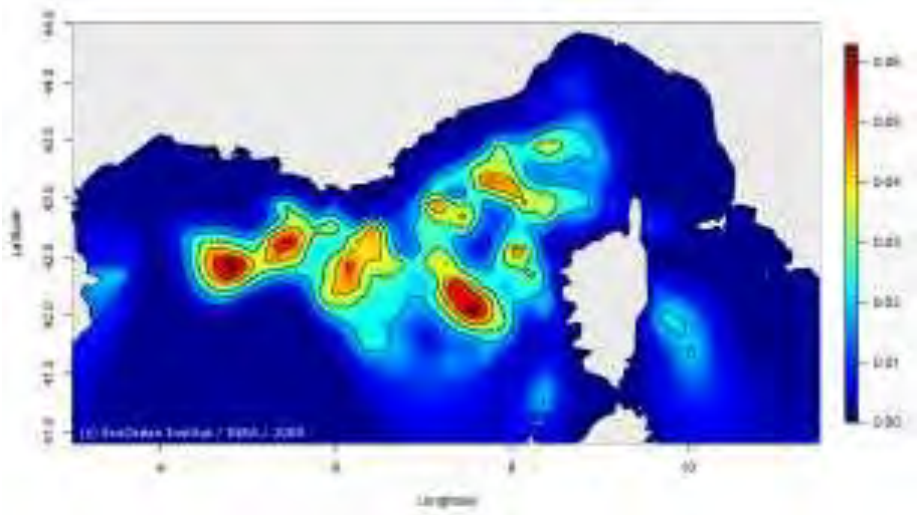


Figure 31: Kriging values of the sighting rate of fin whale expressed in terms of nb of sightings per km for the period 1994-2008 (Delacourtie et *al*., 2009)

Considering population estimates, studies yielded estimates of 3,583 fin whales over a large portion of the western Mediterranean in 1991 (Forcada et al., 1996). In summer in the area offshore the Gulf of Lions, the relative abundances of fin whales are between 0,013 et 0,043 individuals per km (Gannier & Bourreau, 1999).

- **The sperm whale - *Physeter macrocephalus***

This species prefers the continental slope, including canyons and also highly productive open waters with thermo-saline fronts, like those associated with the ligurian current and eddies (Gannier and Praca 2007). These places consist certainly mostly of sectors of high abundance of mesopelagic cephalopods, the species' preferred prey.

Figure 32: The sperm whale - *Physeter macrocephalus*

The most likely cause of recent decline of sperm whales in the Mediterranean is entanglement in driftnets, even in recent years offshore Toulon (David 2005). The second most threat is the disturbance from intense marine traffic and collisions with vessels (David et Di-Méglio, 2011). Underwater noises from seismic airguns prospections and military operations are other sources of concern as well as pollution by contaminants (Laran et *al*., 2010).

In the Gulf of Lions mainly isolated male mature were encountered, but occasionally social units with females and young, even neonates are sighted in the north-western Mediterranean Sea (Di-Méglio and David 2008) confirming that calving takes place there. In the occidental basin, sperm whales are particularly abundant in the Gulf of Lions (2.2 $x10^{-2}$ $ind.km^{-1}$), (Gannier et *al*., 2002).

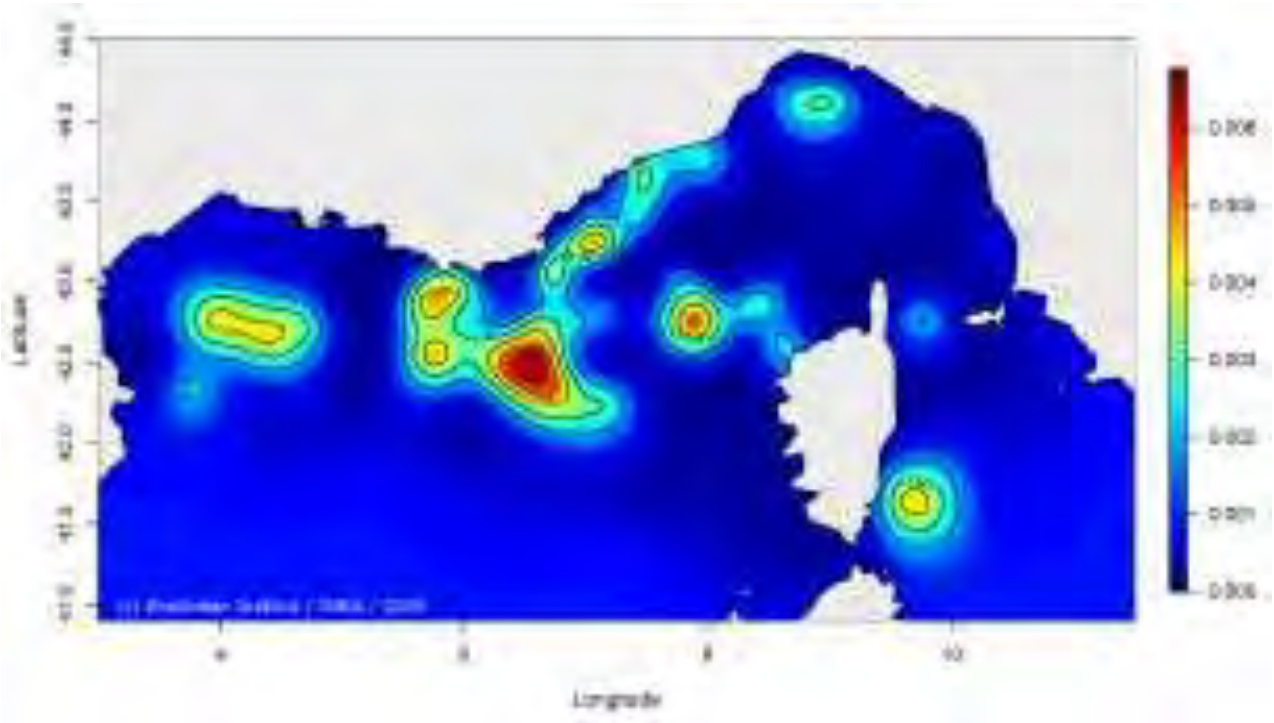


Figure 33: Kriging values of the sighting rate of sperm whale expressed in terms of nb of sightings per km for the period 1994-2008 (Delacourtie et *al*., 2009)

- **The pilot whale - *Globicephala melas***

Pilot whale (*Globicephala melas*) is known as a pelagic species, preferring open and deep waters but can go near the coast in other seasons (Di-Meglio et David 2011). The species is regarded as predominantly a squid-eater, but can also feed at least occasionally on pelagic fish (Olson and Reilly 2002). In summer the groups of pilot whales seen in the north-western Mediterranean Sea contain all calves, supporting the idea that reproduction occurs in this region.

Figure 34: Pilot whale (*Globicephala melas*)

No serious threats have been identified in the Mediterranean Sea yet. Because they are scarce, mainly in offshore waters, feeding on preys not targeting by fisheries, they are therefore less expose to anthropogenic activities than other cetacean species. However, in summer when they are near the provençal coasts they are exposed to disturbance and harassment from high traffic of leisure vessels and whale-watching activities. Estimates of abundance in the North-western Mediterranean Sea are not known, but this species is relatively scarce. It seems more frequent off the provençal coasts and also in the western portion of the Mediterranean Sea (Alboran and Balearic Seas).

- **The Risso's dolphin**

Risso's dolphins (*Grampus griseus*) prefer deep offshore waters and continental slope areas, in particular over steep shelf slopes and submarine canyons (Bearzi et *al*., 2010). They occur all year round in the north-western Mediterranean Sea. Risso's dolphin feed mainly on oceanic cephalopods found in the middle slope. Risso's dolphins are victim of by-catch by longlines and gillnets. They can suffer from harassment and disturbance generated by high traffic of leisure vessels and whale-watching (Miragliuolo et *al*., 2001), merely where continental slope is near the coast (Provence, Corsica islands). Being a deep-diving species, Risso's dolphins are potentially threatened by anthropogenic noise (commercial shipping, seismic prospection, military exercises, etc). Being a squid eater, Risso's dolphins suffer from plastic debris ingestion (Bearzi et *al*., 2010).

Figure 35: Risso's dolphins (*Grampus griseus*)

High abundance of Risso's dolphins occurs in the Ligurian-Corso-Provençal basin, and also in the Gulf of Lions (Delacourtie et *al*., 2009). The "Gulf of Lions" area would include an interesting portion of the favourable habitat of this species. Line-transect abundance estimates exist only for the western central Mediterranean, where aerial surveys from 2001-03 resulted in an estimate of 493 Risso's dolphins in an area of 32,270 km2 (Gómez de Segura et *al*., 2006).

- **The Bottlenose dolphin**

Bottlenose dolphins (*Tursiops truncatus*) in the north-western Mediterranean Sea are mostly sighted over the shelf, in coastal/inshore waters (Gnone et *al*., 2011). However, they are also regularly found near deep canyons on the continental shelf border and even offshore in pelagic waters. Mediterranean bottlenose dolphins are opportunistic feeders with a preference for demersal preys, fish or cephalopods, and also epipelagic fishes.

Figure 36: Bottlenose dolphins (*Tursiops truncatus*)

In the Gulf of Lions continental shelf where trawlers occur, bottlenose dolphins are in some way linked to this activity as in other Mediterranean sectors (Bearzi et *al*., 1999).

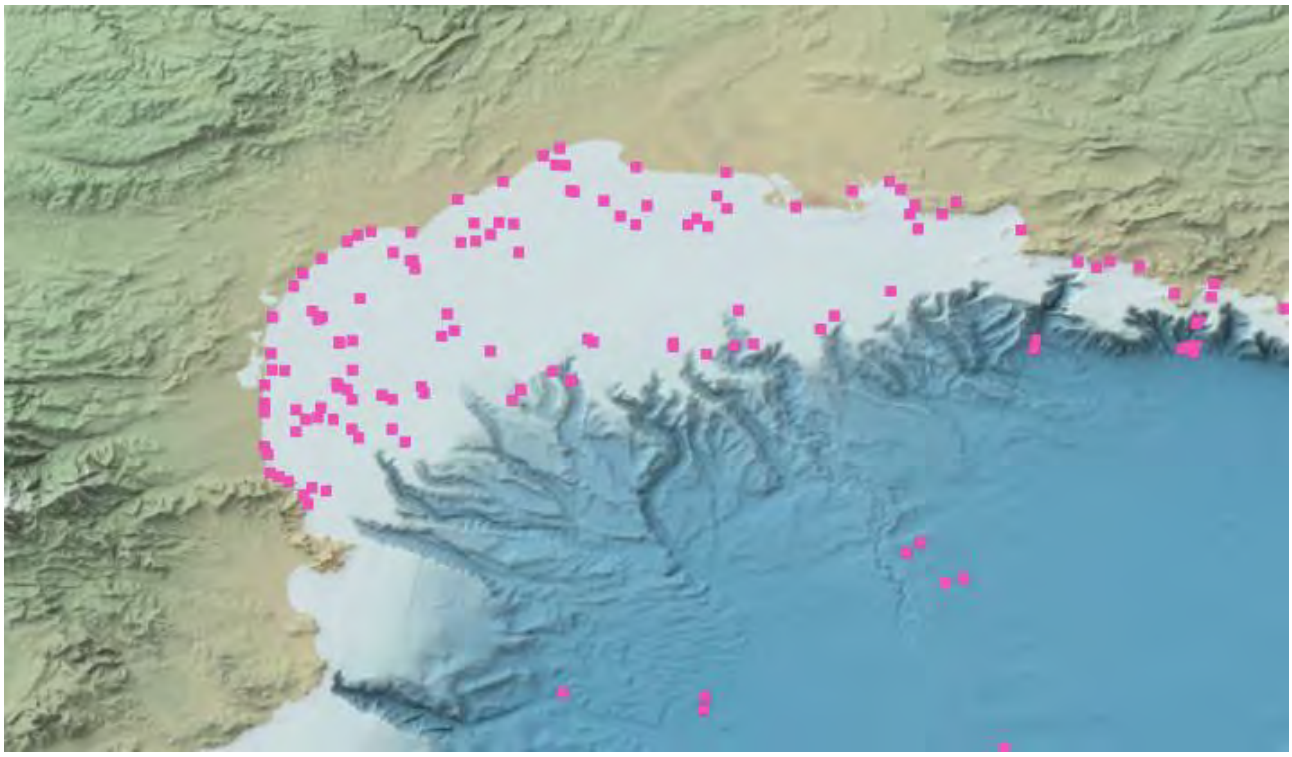


Figure 37: Tursiops sightings in the Gulf of Lions (*Source:* UNEP-MAP-RAC/SPA, 2013)

Biogeographic and hydrographic features influence the distribution of bottlenose dolphins, the favourable habitat being also fragmented by anthropogenic degradation. The last survey in the Gulf of Lions gives an estimation of 200-209 individuals (Ripoll et *al*., 2001) and several dozens in the Provence area (Labach et *al*., 2009).

- **The striped dolphin**

The striped dophin (*Stenella coeruleoalba*) is one of the most abundant cetacean species, and can be encountered from the coast to pelagic waters. It typically shows a preference for highly productive, open waters beyond the continental shelf (Cotté et *al*., 2010). Outside summer striped dolphin exploits also preys over the continental shelf.

Some dolphins realise a nycthemeral movement from the offshore areas to the coastal ones and reverse, some dolphins spending the night feeding over the upper slope and shallow waters. This species feed on mesopelagic fishes, cephalopods and planktonic crustaceans.

Incidental captures in fishing gears is a major threat for this species. In the past, pelagic drift nets have been a major source of mortality all over the western Mediterranean Sea. Reports of mortality induces by other fishing activities are sparse and collected non-systematically, but they indicate that at least pelagic purseseines, longlines, trawls and gillnets bycaught a significant number of dolphins (Ridoux and Van Canneyt, 2011).

The high maritime traffic of leisure boats, whale-watching or nautical activities (jet-ski, kayak)

may disturb dolphins when they are near the coasts.

Figure 38: The striped dophin (*Stenella coeruleoalba*)

The striped dolphin is particularly abundant in the Ligurian Sea, offshore the Gulf of Lions, and in the area between the Balearic Islands and Spain mainland. Reliable abundance estimates are available:

- Gulf of Lions (1991): 30,774 (Forcada and Hammond, 1998);
- Offshore the Gulf of Lions (2010): 38,600 (95% CI: 25,900 to 53,900) (Cotté et *al*., 2010);

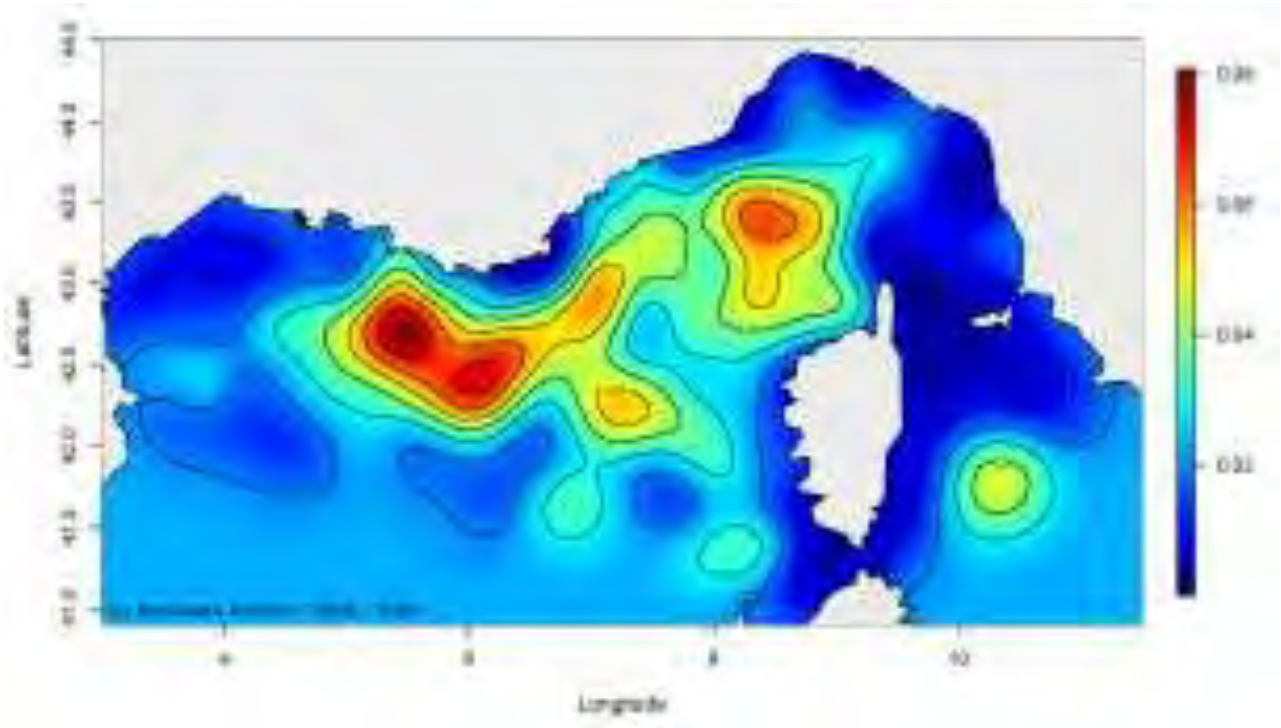


Figure 39: Kriging values of the sighting rate of striped dolphin expressed in terms of nb of sightings per km for the period 1994-2008 (Delacourtie et *al*., 2009)

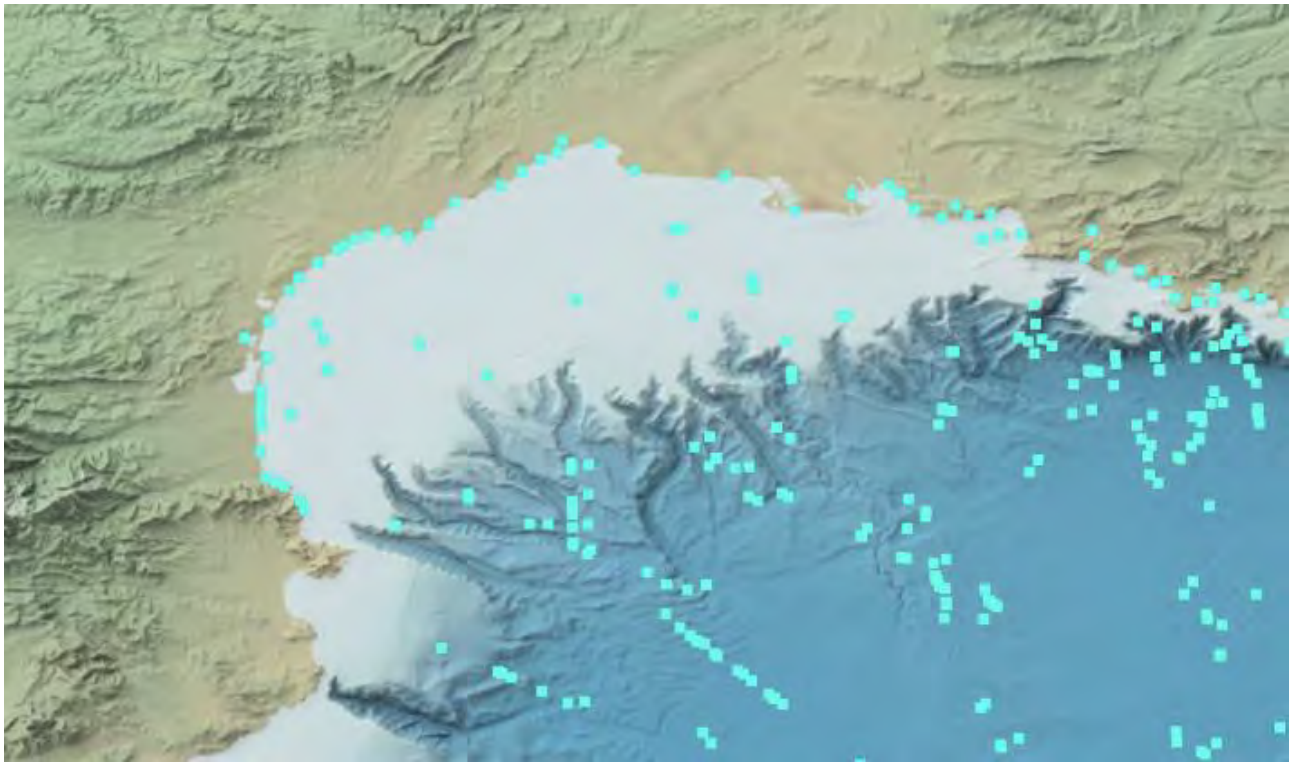


Figure 40: Stenella sightings in the Gulf of Lions (Source: from UNEP-MAP-RAC/SPA, 2013)

- **The Cuvier's beaked whale**

Cuvier's beaked whale (*Ziphius cavirostris*) is a predominantly oceanic species often associated with deep slope habitat and a marked preference for submarine canyons, escarpments or submarine mounts (Podestá et *al*., 2006).

Figure 41: Cuvier's beaked whale (*Ziphius cavirostris*)

Cuvier's beaked whale is mainly teuthophagic. The most common prey species in the Mediterranean are from the family Histioteuthidae, which are oceanic and meso- or bathypelagic, inhabiting depths of around 1000 m, with a preference for escarpments. Fish may also be an important component of their diet (MacLeod, 2005).

One major threat for this species is probably manmade underwater noise: military sonars and possibly high-energy sounds from other anthropogenic sources. Recent atypical mass strandings of beaked whales have been linked to high-powered navy sonar and seismic exploration (Fernández et *al*., 2005).

They appear not to be very abundant in the north-western Mediterranean Sea apart in the northern Ligurian Sea (D'Amico et *al*., 2003). There are no data on abundance or trend for this species in the Mediterranean apart in the Gulf of Genoa (Rosso et *al*., 2009) were 96-100 individuals are estimated through photo- identification analysis.

The Mediterranean Sea is a militarily strategic area, and is also of increasing interest for hydrocarbon exploration and exploitation. All military or geological or oceanographic activities involving high-intensity noise carried out in the proximity of some species, like sperm whale and Cuvier's beaked whales are of great concern. This kind of high sound exposition can also be an aggravating factor for collision in masking a vessel approach sound or in diminishing the auditory capacities of animals.

Threats associated with maritime traffic of large commercial vessels

Di-Méglio et *al*. (2010), have reviewed all threats generated by maritime traffic of large commercial vessels. The main direct threats are collision and noise disturbance.

The Mediterranean Sea is one of the highest places of maritime traffic of large commercial vessels. The northern part bears the traffic between the main European harbours of Barcelona, Marseille and Genoa all year round. High numbers of all type of vessel (merchant and passenger) going from the south of European countries to the north of Africa cross also the area of the "Gulf of Lions". The traffic of ferries is higher in summer season. There is barely area of the sea left of traffic, and this increasing and continued traffic generate potentially disturbance and ships strike for large cetacean species like fin whale and sperm whale. The slope of the "Gulf of Lions" area seems the area the most at risk for ship strike for both species. In the whole north-western Sea, Panigada et al. (2006) evaluate between 27 to 40 number of fin whales struke each year, whereas Di-Méglio et al. (2010) estimates that nearly 5,8 fin whales and 1,2 sperm whale could be on the pathway of a large vessel each day in summer in the PELAGOS Sanctuary. It could be less in the "Gulf of Lions" area, because of less maritime traffic. Fin whales represent 95% of collision cases but sperm whale is also severely threatened by this impact, perhaps even more due to its low density.

Table 10: Potential cetaceans collision against vessels

Species	Nb of animals per day potentially on the pathway of a vessel in summer	Number of ship strikes known
Sperm whale	1,2	5
Fin whale	5,8	60

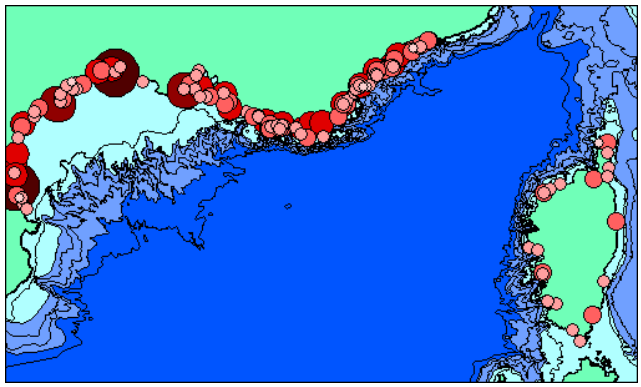


Figure 42: Carrying capacity of harbours, expressed in number of boats (Planchot, 2008)

Fisheries and negative impacts on cetaceans

The Gulf of Lions is one of the highly exploited areas by fisheries. All types of gear are employed, from trawl to longline and net. Most of the fisherboats work over the shelf and shelf edge.

Stranded animals represent an indicator of interaction between cetaceans and fisheries. On all species stranded were discovered traces of interaction with fisheries in 2,7 to 38,9% of the individuals, depending on the species. Mainly nets were responsible of entanglements, but also trawl and purse seine (Sacchi, 2008).

Table 11: Number of cetaceans stranded from 1968 to 2008, and among them number presenting traces of fishery interaction or cause of death (Sacchi and David, 2008)

Species	Total of stranded animals	Total of animals with traces of fishery gear	% Stranded with trace of fishery gear
Fin whale	75	2	2,7
Pilot whale	52	9	17,3
Risso's dolphin	63	14	22,2
Sperm whale	23	4	17,4
Stripped dolphin	1127	164	14,6
Bottlenose dolphin	162	40	24,7
Cuvier's beaked whale	18	7	38,9
Non identified cetacean	26	5	19,2
Non identified dolphin	242	25	10,3
TOTAL	1828	279	15,3

Important areas for cetacean conservation

The northern part of the western Mediterranean Sea appears really as a highly important area for cetaceans globally and for all kind of diet. The continental shelf is the habitat of the bottlenose

dolphin, from the coast through the shelf edge and canyon's head. The slope appears more frequented by teutophageous species. Risso's dolphins are encountered all along the slope.

Concerning sperm whales, Piot whales and Cuvier's beaked whales, they seem to exploit preferentially some peculiar canyon's systemes: Creus and Lacaze-Duthier for the three species and Sète and Marti for the sperm whale and pilot whale. Concerning more pelagic waters it appears that the entire area is important for species inhabiting this habitat, like fin whales and pilot whales and even sperm whales, whereas for the coastal bottlenose dolphin the shelf edge and canyon's head are important.

Table 12: Synthesis of impacts generated by maritime activities on cetaceans (Di-Méglio et *al.*, 2010)

	Type of effect	Impact at the individual scale		Impact at the population level	
		Short term	Long term	Short term	Long term
Disturbance	Behavioral	Horizontal leak Vertical leak More erratic behaviors Group instability Decreased time spent on vital occupations Temporary avoidance of an area	Increase in energy expenditure Risk of decompression sickness Increased risk of predation Reduction of energy acquisition Decline in the general state of health Permanent avoidance of an area Chronic stress	Decreased resistance to diseases and pests Decreased lactation Diminutuin of youth survival Shift in growth and sexual maturity	Increase in mortality rate Decrease in the reproduction rate
Noise pollution	Masking Physical Physiological On the pries	Reduction of communication / echolocation fields Compensation TTS Stress Reduction of food resources	Increase in energy costs and reduction of acquisitions (reduced physical condition) PTS Chronic stress Famine	Risk of missing coupling Increased risk of predation/collision Fertility decline Transfer of stress hormones to the newborn Any aggravated risk	Decrease in the reproduction rate
Collisions	Physical Physiological	Light injury Serious injury Death Stress	Decreased resistance to diseases and parasites Chronic stress	Mortality in general Mortality of breeding females and newborns	Reproduction of the size of the population Decrease in the reproduction rate Extinction (weakened/isolated populations)

Others-Habitats	Physical Chemical Biological GHG emissions	Movement Anchorage Abrasion hull/propeller Macrowaste Petroleum SNPD/biodes/trace metals Introduction of invasive species	Sediment uplift Damage to shallow benthic habitats Entanglement/ingestion-> death/decline in fitness Deat /coporel coating Bioaccumulation-reduced fitness/organ/bone damage Loss of biodiversity Contribution to global warming	Reduction of food resources Decreased resistance to diseases and parasites Feeding becomes difficult Transfer to the offspring Reduction of food resources Loss of physical and sound habitat	Increase in mortality rate Decrease in reproduction rate Extinction (weakened/isolated populations)

3.2.5 Reptiles (Seaturtles)

Three species of sea turtles are commonly found in the Mediterranean waters: the leatherback turtle (*Dermochelys coriacea*), the green turtle (*Chelonia mydas*), and the loggerhead turtle (*Caretta caretta*). Only the last two breed in the basin and their Mediterranean populations have only a limited gene flow with those of the Atlantic (Laurent et al., 1998). However, even a large numbers of Atlantic loggerhead turtles enter the Mediterranean to forage.

In the Mediterranean, severe exploitation of sea turtles has been occurred in the past, especially on the levantine coasts. Currently, commercial exploitation is not a conservation threat for marine turtles in the Mediterranean. Specific national and international legislations aimed at protecting turtles in the Mediterranean has resulted in relatively little take of eggs and/or adult females at nesting beaches, and reduced intentional harvest of turtles at sea, although these threats are still relevant in some cases.

- ***Caretta caretta***

Caretta caretta is found in nearly all the world's temperate and tropical oceans: in the Atlantic Ocean from Newfoundland to Argentina, the Indian Ocean from southern Africa to the Arabian Gulf to western Australia, the Mediterranean Sea, and the Pacific Ocean from Alaska to Chile and Australia to Japan. During winter months loggerhead sea turtles migrate to tropical and subtropical waters. Preferred habitat of *Caretta caretta* individuals changes throughout the life cycle. Adult females go ashore to lay eggs and seem to prefer steeply sloped, high energy beaches. When hatchlings emerge from the nest, they head for the ocean. Young juveniles are typically found among drifting Sargassum mats in warm ocean currents. Older juveniles and adults are most often found in coastal waters and tend to prefer a rocky or muddy substrate over a sandy one. They may also be found near coral reefs and venturing into salt marshes, brackish lagoons, and the mouths of

rivers.

Figure 43: *Caretta caretta* turtle

Like most of turtles, *Caretta caretta* has temperature-dependent sex determination (TSD). The sex of hatchlings is determined by egg temperature during the middle third of incubation. The pivotal temperature - the temperature at which a 50:50 ratio of males: females is produced - varies from location to location around the world. Generally, the pivotal temperature is between 28 and 30 ºC. Temperatures of 24 to 26 ºC tend to produce all males and temperatures of 32 to 34 ºC tend to produce all females. Eggs are not viable outside the extremes of these ranges.

The speed of embryonic development within the egg depends on the temperature within the nest. This temperature can be affected by sun, shade, rain, heat generated within the nest, and an egg's position in the nest. At cool temperatures, around 25 ºC, development to hatching can take 65 to 70 days, but at warmer temperatures, around 35 ºC, development usually takes around 45 days.

Named for their huge heads and powerful jaws, *Caretta* has a heart-shaped carapace, which is often covered with commensal organisms such as barnacles and algae. Generally, the carapace is a reddish-brown hue with olive tones; there are five pairs of pleural scutes, the first pair touching the cervical (neck) scute. The plastron is cream to yellow, and has two longitudinal ridges that disappear with age. The skin is dull to reddish brown dorsally and medium to pale yellow around the edges and ventrally. The skin may have some orange coloration as well. The skin of males is more brown and the head more yellow than those of females. Males also have wider carapaces and

a long curved claw on each forelimb. Loggerhead sea turtle hatchlings tend to be dark brown to reddish brown on the carapace and cream to reddish brown or dark brown on the plastron. The average adult *Caretta caretta* in the Mediterranean Sea is smaller than the average adult in the Atlantic Ocean.

Peak mating season for *Caretta caretta* occurs in the early summer months. During this time, males remain in the waters offshore of the nesting beach, while females alternate between mating in the water, nesting on land, and feeding in estuaries and reefs. A female will nest every 12 to 17 days, or 2 to 5 times, during the breeding season. For each nest she must drag herself onto land, where she is in much greater danger of predation, and excavate a nest. Into this nest she lays 110 to 130 round eggs. The eggs incubate for 45 to 80 days, depending on temperature. Loggerhead sea turtles are migratory and do homing abilities. As juveniles, the home range is their feeding grounds. There is some evidence that feeding grounds are chosen near the natal nest site, known as natal homing. Adults tend to return to the same nesting grounds year after year and many specimens return to the very beach where they themselves hatched.

Communication in *Caretta caretta* has not been well studied. Courtship behavior seems to largely depend on visual and tactile cues, but it has been suggested that glandular may help bring the sexes together.

Perception, however, is highly developed. As soon as hatchlings emerge from their nests (usually at night), they begin analyzing their environment to determine which direction they should go towards the ocean. It is believed that a major clue is the light on the horizon. Hatchlings orient towards the brightest light, which, historically, is the moon or starlight over the ocean. They may also perceive the incline of the beach and orient towards a lower elevation. Once in the water, hatchlings use chemical and magnetic cues to orient themselves and navigate their way to the currents in which they will spend the next 10 or so years of their lives.

Caretta caretta has been called a "keystone species" because of its ecological impact. It feeds on large numbers of invertebrates, affecting their populations. Also, a substantial portion of the eggs laid becomes food for predators. Finally, over 100 species from 13 phyla may live on the carapace of loggerheads, making it somewhat of a mobile reef. Loggerhead sea turtles are primarily carnivorous, but will also eat algae - *Ascophyllum, Ulothrix, Urospora, Sargassum* - and vascular plants - *Cymodocea, Thalassia, Zostera* - making them omnivorous. Their huge heads and massive, powerful jaws make them well adapted to eating hard-shelled prey, such as horseshoe crabs (*Limulus polyphemus*), bivalves, barnacles, whelks, and conchs. However, Caretta caretta is a dietary generalist and also eats many other invertebrates, such as sponges, jellyfish, cephalopods, shrimp, insects, sea urchins, and fish and fish eggs. There are slight variations in the diet of each life stage, but loggerhead sea turtles are generalists throughout life.

When loggerheads are juveniles the differences between the sexes begin to emerge. Age at maturity is variable. Mature size is attained between age 10 and 30; captives are predicted to mature in 16 to 17 years. Reproductve life span (after maturity) is estimated at about 32 years. Loggerhead sea turtles reach sexual maturity at carapace lengths longer than 90 cm, which can occur between 10 and 30 years of age.). Not much is known about the lifespan of Caretta caretta. Is is estimated that they live 30 to 62 years in the wild, but data is insufficient for lifespan in captivity as well as longest known lifespans in the wild and in captivity. In Australia is has been predicted that the annual survival rate is 92% for immature individuals and 88% for adults.

Just before the nesting season, male loggerhead sea turtles migrate to mating grounds, which are usually located offshore from nesting beaches. They wait for females to begin courtship and mating. Parental energy investment in loggerhead sea turtles is largely pre-ovipositional, there is no parental care of young. Females provide nutrition in the form of yolk which is used by embryos for growth and development; residual yolk can probably support a hatchling for several days or weeks. Females also expend considerable energy when migrating to nesting beaches and in the ovipositional (nesting/ egg laying) process. Male investment is largely during courtship and mating, and in sperm production.

As a marine species, loggerhead sea turtles have some special adaptations. They have salt glands near their eyes, which allow them to drink seawater and excrete salt in high concentrations. Loggerhead sea turtles are able to hold their breath for long periods of time. Though a typical dive lasts only 4 to 5 minutes, loggerheads are capable of diving for up to 20 minutes and can rest for hours without breathing. As a general rule, males are more active swimmers than females.

Loggerhead sea turtles are known for their migratory behavior. Some individuals have been recorded migrating up to 4,828 km. Adults and juveniles in temperate waters migrate towards the equator for winter to avoid cold stunning in waters under 10 ºC. Cold stunning occurs in sea turtles that find themselves in waters under 10 ºC, they become lethargic and float on the surface. If the water temperature drops below 5 ºC, the turtles could die.

During the juvenile and adult life it is likely that loggerheads use chemical and magnetic cues to orient themselves during their migrations. It has been demonstrated that C. caretta uses on-site cues, not memory of past movement, in orientation and is therefore capable of map-based navigation.

Sea turtle are not able to withdraw into their shell as a means of escaping a predator. Loggerhead sea turtles have their hard shell, their size, and their rough, scaly skin on the head and neck to protect them from predation. These defenses are usually sufficient for adults and larger juveniles, but these turtles are sometimes preyed on by sharks and killed by humans. Hatchlings and eggs have many predators and few defenses. Females try to disguise newly laid nests as much as possible, but they still suffer high predation rates. Hatchlings generally emerge from the nest at night to lessen chances of predation, but many are then taken by crabs, birds (gulls, frigate birds, vultures, crows, etc.), raccoons, canids (foxes, dogs, etc.), and carnivorous fish.

Nesting sites: There has been no recorded nesting in the Eastern Adriatic (Albania, Bosnia and Herzegovina, Croatia, Montenegro, Slovenia), Algeria and Morocco (although occasional nesting cannot be ruled out, especially in the past), and nesting has not been recorded recently in Malta. In several countries, nesting is considered rare, scattered or sporadic, at least at the present time. Today, most clutches are laid in Greece, Turkey, Cyprus, and Libya. In the entire Mediterranean, the average number of documented nests, as provided by the individual chapters of this report, is over 7200/yr.

In mid-July 2006, a loggerhead-nesting event was reported in Saint-Tropez on Var coast. It is an exceptional event, recorded for the first time on the French Mediterranean coast and representing the northernmost nesting event in the Mediterranean (Oliver, 2006; Sénégas et al., 2008). This nest was laid a few meters from the water line on a very gently sloping beach. Due to inundation by rain

and high sea levels, by mid-September the eggs were removed and put under artificial incubation. Ultimately none of them hatched, although some embryos had reached a developmental stage near hatching.

Marine areas: Loggerhead turtles practically occur in all marine areas of the Mediterranean With the exception of aerial surveys off the coasts of Spain data on relative abundance of turtles in different areas come from fishery bycatch data. The highest density of loggerhead turtles appears to occur in the westernmost part of the Mediterranean (from the Alboran Sea to the Balearic Islands), the Sicily Strait, the Ionian Sea, and the wide continental shelves in the north Adriatic, off Tunisia-Libya, Egypt, and off southeast coast of Turkey.

The loggerhead sea turtle (Caretta caretta) has been observed all along the French Mediterranean coastline and is encountered all year round. However, its presence follows a seasonal cycle during which numbers are more abundant from May to September (77% of annual captures) and particularly from June to August (58% of annual captures). The marine environment along the French Mediterranean coast seems to be used as a feeding area and probably a movement zone during their migration.

Threats: Languedoc-Roussillon coasts extend to 218 km. Following I.G.N. maps (I.G.N., 1990a-c), 92 km, that is 42% of the coast, is urbanized. Provence and Riviera coasts extend 757 km. Today, 198 inventoried development sites (harbours, airport, artificial beaches, dams, etc.) occupy 123 km or 16,2% of this coastline; this percentage rises to 25,2% in the Alpes-Maritimes department and up to 21,8% in the Bouches-du-Rhône department (Meinez et al., 1990).

Resort developments reach down to the edge of the beach and seafronts are generally highly illuminated. Coastal development and non-human predation appear to be the main threats, occurring in most countries with nesting sites, followed by beach restructuring and human exploitation (direct take of eggs or nesting females). Among other threats, erosion and debris are common.

Incidental catch occurs practically everywhere. A recent review of sea turtle bycatch in the Mediterranean (Casale, 2008) estimated over 150,000 captures per year (all species, sizes, and origin combined) within the basin (over 50,000 by pelagic longlines, 40,000 by trawls, 35,000 by demersal longlines, and 30,000 by set nets), and in excess of 50,000 deaths per year. Incidental captures represent 38% of whole recorded specimens: bottom trawl (26%), meshing nets (34%), drifting longline (20%), abandoned fishing gears (20%). Alive specimens found in fishing gears represent 78% of incidental captures in these traps.

Intentional killing, especially after capture at sea, is still relatively widespread in the Mediterranean. It is particularly significant in Egypt and Greece, whereas in some countries it is considered to be low and in other countries it occurs at undetermined levels.

Sandy coasts, particularly those of the Camargue and Languedoc-Roussillon are actively eroding. Some beaches are, more or less regularly, repaired with loads of sand, which is often carried away again by storms, and it is necessary to repeat the same operation again in following

years. The majority of coastal cities clean their beaches with heavy machinery which plough sand to a depth of about 30 cm. Many beaches are subject to erosion and have cliffs that present an obstacle for females. In Camargue, urbanization and lighting are limited on the seafront.

- ***Chelonia mydas***

Green sea turtles (*Chelonia mydas*) are a cosmopolitan species found in tropical and subtropical waters. During the months that this species breeds (June through August), green sea turtles are most frequently found nesting on the coastlines of Cyprus and Turkey. They are also observed nesting on the beaches of Israel, Syria, Egypt and Libya. Overall, green turtles are known to settle on the beaches of over 140 countries. Radio tagging nesting females shows that green turtles are migratory, and their non-breeding range includes locations from as far north as 40 degrees north to as far south as 40 degrees south. These areas include parts of the Pacific Ocean, Atlantic Ocean, Mediterranean Sea, and northern Indian Ocean.

Green sea turtles are common in shallow tropical and subtropical waters as well as coastline beaches. They forage in coastal areas with plentiful of algae and sea grass. Male and female green turtles use major current systems when migrating to nesting beaches. Once females find a suitable beach with accessible sloping platforms, the green turtles will lay their eggs in the sand and then return to the ocean. After the eggs hatch, juvenile green sea turtles will then return to the ocean. Juveniles are known to spend several years drifting in the open ocean as they grow and mature. Once the juveniles have matured, they will return to their natal beach for mating.

Green sea turtles are so named because of the greenish color of their subdermal fat. They have only one pair of prefrontal scales, although other species of sea turtles that have multiple pairs. Their skull shape is described as round and smooth. Green turtles have short snouts and strong beaks that cover the bones of the jaw. Their jaws are short and serrated to properly rip and tear plants apart. The carapace is round and consists of four lateral overlapping scutes. The plastron also consists of four scutes.

Sexual dimorphism isn't completely recognized in green sea turtles until early adulthood. Males and females differ morphologically by the length of their tail and cloacal openings. Female green turtles have smaller tails and a cloacal opening between the anus and tip of the tail.

Green turtles are the second largest overall species of sea turtles. As hatchlings, green turtles have an average weight of 25g and are 5 cm long. Juveniles measure to about 40 cm in carapace length and subadults will measure between 70 to 100 cm. Adult green turtles, male or female, tend to be about 100 to 120 cm long in carapace length and weigh around 150 to 200 kg when reaching adulthood.

Female green sea turtles lay eggs 35-58 mm in diameter. Like many turtles, green sea turtles' development is affected by temperature. Eggs that are laid in cooler environments less than 28.5°C tend to produce more males than females, and warm nests greater than 30.3°C are known to hatch

more females than males. Both sexes incubate in white, soft shells for 30-90 days depending whether or not it is the wet or dry season. Incubation typically takes longer in the wet season. Hatchlings average a weight of 25 g. As the hatchlings grow into juveniles, it takes 27-50 years before green turtles reach full maturity.

Green turtles are polygynandrous, meaning that females and males will have multiple mates. Copulation occurs in the shallow waters off the shore of nesting beaches. When females accept a mate, the male will mount her and grab onto her "mating notches" around her shoulders to assist in copulation. Male green turtles also are known to join other mating pairs during copulation by latching onto other males for hours on end in attempts to dislodge the mating male. The reproduction process usually follows a system such as: male searches for a female mate, the male will visually examine and then approach the female, the female will either submit or reject the male, then possible copulation.

Females are known to revisit their natal beaches in 2-4 year intervals to breed from June to September. If they don't return to their natal beach, they will select a beach with similar sand texture and color.

Female green turtles can lay 1- 9 clutches in a single nesting season, but tend to average around 3. Each of these clutches can include 75-200 eggs. After nesting, it usually takes 45-75 days for the eggs to hatch. Once the eggs hatch, the hatchlings will begin their journey towards the ocean. From here the hatchlings will begin the juvenile portion of their life which can last 27-50 years before reaching full maturity. There is very little research regarding the lifespan of green turtles, due to lack of tagging. However, a maximum green turtle lifespan of 75 years is reported.

Green turtles travel in large groups that usually originate from the same natal beach. They spend a lot of their time swimming, traveling about 20-90 km/day. Juvenile green turtles are said to be faster swimmers than other sea turtles such as loggerheads (*Caretta caretta*) and olive ridleys (*Lepidochelys olivacea*) due to the way green turtle hatchlings stroke their foreflippers.

Green turtles primarily use vision to detect plants and other prey and use visual displays when communicating. Green sea turtles also use a sense of wave propagation direction to help them navigate under water. Magnetic channels are also used to assist the orientation of the turtle in deep waters. In one study, researchers found that the turtles' inner ear can detect the acceleration and direction of the wave which assists their sense of direction (Lohmann and Lohmann, 1992).

Green sea turtles begin their lives as omnivores and gradually shift to a more herbivorous diet. As juveniles, green sea turtles will feast on small marine invertebrates and neustonic material like Hydrozoa, Bryozoa), and Aplysia. They also consume large quantities of wetland plants such as api api (Avicennia schaueriana) and salt-water cord grass (Spartina alterniflora), which are commonly found in salt marshes. Their diet also consists of a variety of red and green algae. Because green sea turtles are highly mobile throughout their lives, their food choices are often opportunistic.

Green turtle hatchlings are at a higher risk of predation than adult green sea turtles. Multiple land

mammals, reptiles, and crustaceans prey upon eggs. The only defense mechanism of hatchlings is swarming in large groups toward the ocean. Once the hatchlings reach the water, they face a new group of predators such as tiger sharks (Galeocerdo cuvier) and whitetip sharks (Carcharhinus longimanus). Sharks also prey on juvenile and mature sea turtles. Mature green sea turtles' best form of protection from their predators is their large hard shell. When females come on land to nest, their head and limbs become vulnerable and easily accessible by predators. Humans for meat also hunt green turtles.

Green turtles play a role in their ecosystem by facilitating nutrient turnover and sea grass regrowth. As the turtles graze on sea grass, they provide nitrogen-rich fertilizer in the form of fecal matter.

Present distribution and abundance: Most clutches are laid in Turkey, Cyprus, and Syria. For the Mediterranean, the average number of documented nests is over 1500/yr. Green turtles frequent mostly the Levantine basin (Turkey, Syria, Cyprus, Lebanon, Israel, Egypt) as well as having foraging areas in Greece and Libya.

Some green turtles can be occasionally found in the Adriatic Sea (Italy, Croatia, and Albania), in Tunisia and very rarely in Malta and the western basin. No nesting sites are known on the French Mediterranean coasts.

On Mediterranean French coasts, the Green Turtle (Chelonia mydas) is very rare: only 5 catches have been reported.

- ***Dermochelys coriacea***

The leatherback turtle has been recorded from almost every area and country in the Mediterranean, but available data suggest that specimens concentrate in specific areas, probably for trophic reasons, along the Tyrrhenian and Aegean Seas and the area around the Sicily strait. Nesting is absent or exceptional (Laurent et *al*., 1999), therefore, the leatherbacks found in the region are likely to be of Atlantic origin.

Documented carapace lengths range from 112-190 cm, indicating that only large juveniles and adults frequent the basin, probably because small juveniles are restricted to tropical waters (Eckert, 2002). There are no records of small juveniles in the Atlantic as far north as the Straits of Gibraltar, which would be their entry point into the Mediterranean. In general, it seems that individuals enter the basin in small numbers. Average longline catch rates in the Mediterranean are 60-200 times lower than those observed in the Atlantic.

The leatherback turtle (*Dermochelys coriacea*) has been observed all along the French Mediterranean coastline. Its frequency and abundance are quite limited: nearly 1 specimen every two years. There have been 41 dated catches (Laurent et *al*., 1998). This species has been reported between May and December: 85% of sightings have been between these two months and 78% between June and September.

Threats: Most records from the region concern individuals incidentally caught in fishing gear, particularly set or drift nets. Thus, by-catch probably represents the main threat in the Mediterranean. Other threats may include collision with boats and ingestion of plastic material (Casale et al., 2003), although data are too incomplete to draw solid conclusions.

Sea Turtles Conservation status

There are several international conventions and supranational agreements which protect sea turtles in the Mediterranean region:

- African Convention on the Conservation of Nature and Natural Resources (1968) All marine turtle species are listed in Class A of the Convention.
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (1973). Under the Convention, parties must strictly regulate trade in species listed in its appendices and particularly Appendix I, where all marine turtle species are listed.
- Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) (1976)
- Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean. This protocol indicates species and habitats protection requirements that parties must incorporate into national legal frameworks. Obligations are particularly strong for species in the List of Endangered or Threatened Species (Annex II of the Protocol), which includes 5 marine turtle species: *Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*, *Lepidochelys kempii*.
- Convention on the Conservation of European Wildlife and Natural Habitats – Bern Convention (1979). Five marine turtle species (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*, *Lepidochelys kempii*) are listed in Appendix II (strictly protected fauna species).
- Convention on the Conservation of Migratory Species of Wild Animals (CMS) – Bonn Convention (1979). Six marine turtle species (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*, *Lepidochelys kempii*, *Lepidochelys olivacea*) are included in Appendix I of the Convention, which lists endangered migratory species.
- Convention on Biological Diversity (CBD) (1992). The Convention calls on parties to conserve biological diversity by several measures; e.g. by establishing a system of areas which are protected or where special measures are taken, to manage biological resources, to promote the protection of ecosystems and the maintenance of viable populations of species, and to promote the recovery of threatened species.
- Habitats Directive (1992). This is an instrument of the European Union to protect, manage and where appropriate restore to a favorable conservation status, in its natural range, biodiversity and to set up a coherent ecological network of special areas of conservation set up under the title of Natura 2000 (composed of sites hosting areas of the natural habitat types listed in Annex I and habitat of the species listed in Annex II). Five marine turtle species (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*,

Lepidochelys kempii) are listed in Annex IV (Animal and Plant species of Community interest in need of strict protection). Two species (*Caretta caretta* and *Chelonia mydas*) are also listed as priority species under Annex II of the directive. The conservation of the species in Annex II requires the designation of special areas of conservation.

- The French Ministry in charge of Environment, Nature and Landscape Direction started an Action Plan for the Conservation of Marine Turtles in 1993.
- Port-Cros National Park takes part in the rescue of Marine Turtles when it is necessary.
- "The National Agency for Hunting and Wild Fauna" (Office national de la Chasse et de la Faune sauvage, or O.N.C.F.S.) is entrusted with environment policy. Several agents of this office participate by collecting data and observations.
- The «French Mediterranean Marine Turtles network» (Réseau Tortues marines de Méditerranée française, or R.T.M.M.F.) constitutes a specialised group of the S.H.F. (Société Herpétologique de France); it is linked to the "National Strandings Network" (Réseau National d'Echouages or R.N.E.) and G.T.M.F. (Groupe Tortues marines France). This network collects data on events concerning Marine Turtles on French Mediterranean coasts.
- Some aquariums, such as those of Banyuls-sur-Mer (Pyrénées-Orientales), Agde (Hérault) or Institute Paul Ricard (Embiez Island, Var), participate in the rescue network when it is necessary. The Aquarium of Oceanographic Museum of Monaco (Monaco Principality) also collaborates with the French Mediterranean marine turtle network.
- At Le Grau-du-Roi (Hérault), a Rescue Center (CESTMED: Centre d'Étude et de sauvetage des tortues de Méditerranée), specially dedicated to marine turtles, was approved by an official decree (June 18th, 2007). Their close relationships with professional fishermen, have allowed them to collect several specimens incidentally captured and to rehabilitate and release them.

French legislation concerning Marine Turtles includes the October 14th 2005 decree which established the list of marine turtle species protected. In addition, quartering law n° 96-1139 from December 26th 1996 applies to the disposal of marine turtle carcasses, after a scientific examination. In addition to these French- specific laws, there are international documents ratified by France: C.I.T.E.S. (applicable in European Union though communal settlement n° 338/97 from December 9th 1977), Bonn Convention, Bern Convention, Barcelona Convention, Directive Habitat.

Professional fishermen are the principal providers of individuals for a rescue center. Coordination of the transfer of live animals from fishing boats to the rescue center could allow the rehabilitation of more individuals. On the other hand, methods or devices for reducing incidental capture at sea can protect marine turtles present in the area; but their number is low and the cost would be high.

3.2.6 Primary production

River-dominated continental margins are characterized by large supplies of inorganic nutrients and organic materials that support high biological productivity (Lohrenz et *al*., 2008). In such coastal zones, physical processes and plankton dynamics control the storage and trans- formation of terrestrial materials onto continental shelves towards the open sea (Dagg et *al*., 2008). Besides high organic carbon deposition that occurs on the continental shelf, physical processes also induce an organic carbon export to the open sea. Each river- shelf-ocean system differs from the others, depending on the river inputs variability, anthropogenic impact, and dynamic and topographic physical environment. Conceptually, the organic carbon buried in shelf sediments is made of living phytoplankton and organic detritus of both terrestrial and marine origin, such as dead planktonic cells and zooplankton fecal pellets. The Rhone River is the major freshwater source of the Mediterranean Sea with runoffs ~1750 m^3/sec on average (Naudin et *al*., 1997), which currently makes the Gulf of Lions the most river-impacted coastal area of the Mediterranean Sea.

The Rhone River freshwater plume forms an extended dilution zone (Estournel et *al*., 2001), which has been defined as a region of freshwater influence. Under specific wind conditions, low-salinity water (LSW) can, for instance, accumulate on the shelf to form confined structures (LSW lenses) propitious for high biological productivity and for blooms of large-sized phytoplankton (Diaz et *al*., 2008). Estimated for this area a mean primary production between 78 and 142 g C m^{-2} y^{-1} based on in situ and in vitro net community production. We therefore assumed an average primary production of 120 930 g C m^{-2} y^{-1} on the total surface of the Gulf of Lions (2.16 × 1010 m^2), which lead to a total POC produc- tion of about 260960×104 T y^{-1}. The production of algal biomass (PM), which can be estimated to be roughly 3 times the carbon production, amounts to about 7.8 9 1.8 × 106 T y^{-1}.

The average annual primary production measured in 1993 – 1994 at a single location on the upper slope off Marseilles was estimated to be about 140 – 150 g C m^{-2} y^{-1}.

The POC deposition on the Gulf of Lions shelf depends on the control exerted by zooplankton on the POM contents in the water column. Zooplankton is at the interface between river and marine environments and can be considered as a key energetic link in the food web of river plumes. The consumption of fresh marine phytoplankton, as well as organic detritus of terrestrial and marine origins, leads to increased zooplankton biomass in plume environments in agreement with previous observations (Dagg et *al*., 2004). In the Gulf of Lions, the spatial distribution of zooplankton biomass then appears mostly constrained by the enrichment effect of Rhone River inputs contrasting with the oligotrophic influence of the Northern Mediterranean Current (Gaudy et *al*., 2003). The observations of Gaudy et *al*. (2003) show a dominating trophic mode of herbivory near the coast for zooplankton (both micro- and mesozooplankton size classes) then evolving to omnivory in the offshore areas of the Gulf of Lions. Hence, in the Rhone River plume, zooplankton has been shown to consume mostly “fresh” carbon fixed by marine phytoplankton, rather than POM of marine and terrestrial origin. On the whole, phytoplankton could provide up to 90 % of the dietary carbon of mesozooplankton feeding in plume regions (Schlacher et *al*., 2009).

Then terrestrial organic matter would be of little direct nutritional importance to zooplankton in plume water. However, the study of Gaudy et *al*. (2003) also shows that zoo-plankton (both micro- and mesozooplankton) can punctually make an additional consumption of terrestrial POM to supply the necessary energy for its growth, especially during the spring period. Zooplankton is favoured by terrestrial POM inputs and high biological productivity within the plume. In turn, zooplankton reduces the phytoplankton and POC contents in the water column, and then the total POC deposition rates on the Gulf of Lions shelf. As already stated by Dagg et *al*. (2004), in marine areas under freshwater influence, the conversion of POM in living organisms through an omnivorous behaviour of zooplankton actually increases the retention of organic matter in the food web and bypasses the bacterial remineralization.

At the shelf scale, the organic carbon deposition is largely due to organic detritus (SPOC + LPOC) since their contribution is estimated to range from 82 to 92 %. The contribution of living organisms (microphytoplankton) finally remains limited at an average of 13 % with a maximum of 17 % under specific conditions.

Durrieu de Madron et *al*. (2000) assessed the contributions of river supply, atmospheric depositions, and primary production and estimated the total deposition of particulate or- ganic carbon on the Gulf of Lions shelf (depth <200 m) in the range 20–67 mg C m^{-2} d^{-1}. This range is assessed at a secular scale and cannot represent seasonality and extreme events such as peak discharges acting at a daily scale.

At first order, the time evolution of the organic carbon deposition follows the river runoffs. This could be especially true for the prodelta area where the organic carbon deposition is mainly constituted of terrestrial material. As highlighted by sedimentological data (Durrieu de Madron et *al*., 2000), terrestrial organic particles quickly sink on the prodelta area, remaining barely available for zooplankton consumption (Schlacher et *al*., 2009). For these reasons, the deposition of marine organic material is limited in this region.

The contribution of terrestrial POM inputs to the total POC deposition is lower than 17 % at the shelf scale. Thus, biological processes primarily enhanced by terrestrial inorganic matter inputs appear to mostly drive the POC deposition further on the Gulf of Lions shelf. The role of zooplanktons then likely to be significant. Nutrient loads induced by the Rhone River discharge first stimulate phytoplankton growth in the region of freshwater influence, enhancing high primary productivity and phytoplankton biomass (Naudin et *al*., 2001), as also observed in other plume regions (Dagg et *al*., 2004). This results in the sedimentation of living phytoplankton as well as organic detritus produced via phytoplankton senescence. Terrestrial POM inputs and primary production also enhance zooplankton biomass through grazing processes. Primary and secondary productions are then favoured by high river runoffs. In that case, the senescence of both phytoplankton and zooplankton cells could finally fuel the pool of POM and increase the organic carbon deposition on the shelf. However, zooplankton communities are also favoured by high river runoffs and can finally consume both terrestrial inputs and marine production of POM before their deposition on the seabed. The retention of organic carbon in zooplankton is relatively increased

during peak discharges, and biogenic elements from the Rhone River are then relatively more transferred in living organisms and less buried into shelf sediments.

Primary production and nutrient patterns in the Gulf of Lions

The Mediterranean Sea is known to have a negative water balance. To compensate the excess evaporation over precipitation and river runoff, surface Atlantic water flows into the Mediterranean basin whilst deeper Mediterranean water flows out at Gibraltar to balance the salt. Since fewer nutrients are contained in the inflowing surface Atlantic water than in the deeper outflowing Mediterranean water, the Mediterranean basin is relatively impoverished in nutrients with respect to the open ocean. As a consequence, the Mediterranean Sea is an oligotrophic system and particularly in summer.

The vicinity of the river Rhone, which is the largest one in the basin, delivers an important nutrient load. The general pattern of nutrient distribution and concentration in the area of the Gulf of Lions strongly dependents however on seasonal hydrographic conditions. During summer, the area is not influenced by the Rhône River water discharges; therefore, surface nutrient concentrations are extremely low, indicating strong nutrient limitation of phytoplankton growth. As a consequence, a strong nutricline extends between 50 and 100 m depth. Below these depths all the nutrient concentrations slowly increase downwards until they reach maximum values at depths between 100 and 800 m, depending on the nutrient and the season.

During winter, surface nutrient concentrations reach higher values. Deep vertical convective cells developing in the deep-water formation area and upwelling at the thermohaline frontal zone existing at the outer boundary of this area bring about this fertilization, which is little utilized by the winter light-limited phytoplankton.

Surface waters of the Gulf of Lions are enriched over the offshore concentrations due to the Rhône River discharge, forming a tongue of low-salinity seawater in the eastern part of the Gulf. The vertical distributions of nutrient concentrations in the area are dominated by the strong salinity gradients, which vary drastically according to the meteorological conditions. The wind plays an important role in controlling the vertical distributions of salinity and thus of nutrients. During calm weather conditions, a shallow layer 2-10 m thick, containing a very large proportion of freshwater, lies on top of a subsurface layer containing almost undiluted seawater. This stratification breaks down in winter, due to frequent wind events. Under these circumstances, the transition from the fresher surface water to the saline subsurface water is less sharp and, mixing of fresh and salt waters takes place to depths of 40 m and more.

The influence of the Rhône River water extends over a large part of the Gulf, being confined over the shelf by the density front, which is in dynamic equilibrium with the Liguro-Provençal Current. As far as water budget is concerned, the Gulf of Lions is a net exporter of water. Seawater moves horizontally into the Gulf from the open sea, mixes with the river water, flowing out along the southwestern coastal area. Taking into account the amounts of river water entering into the area (about 1500 m^3 s^{-1}) and the nitrogen concentrations in the river (about 100/µg-at. l^{-1}) of nitrate and

about the same amount of ammonium), the nitrogen contributions of the river to the fertilization of the area would be about 150.000 tm N y^{-1}. This amount of nutrients, using the Redfield molar ratio (C/N = 106/16), would support a primary production, averaged over the entire Gulf (about 15.000 km^2), of about 60 g C m^{-2} y^{-1} from the river. Assuming an average nitrogen concentration of about 4/µg-at. N l^{-1}in a period of 6 months, the flux of nitrogen into the euphotic zone of the Gulf of Lions should amount to a value similar to that contributed by the river, i.e. about 60 g C m^{-2} y^{-1}. This produces a total annual production of about 120 g C m^{-2} y^{-1}.

Zooplankton patterns in the Gulf of Lions

In the Gulf of Lions, the distribution of zooplankton biomass is rather heterogeneous despite its limited geographical extent (Gaudy et *al*., 2003). The enrichment effect of Rhone river input and the oligotrophic influence of the North Mediterranean Current are the main distribution factors of zooplankton biomass. Biomass increases according to an offshore–coastal gradient and an east-west gradient. The input of continental water (mainly the Rhone river) results in lower temperature and salinity conditions near the coast, and in richer food conditions for zooplankton increasing the total particulate organic Nitrogen and Carbon. In winter, the general potential food enrichment is limited to the area close to the Rhone discharge, but in spring, when the freshwater input is more important, it influences all the central and western part of the Gulf. On the contrary, offshore regions display poorer food conditions due to the oligotrophic character of the North Mediterranean Current.

Associated to river low salinity waters, high copepod and other zooplankton group densities have been recorded in the Gulf of Lions along with an increase in zooplankton biomass and feeding activity in the outflow plume of the Rhône River (Pagano et *al*., 1993). These rich zooplankton production areas have been reported to be important spawning grounds of anchovy in the northwestern Mediterranean, favoring larval fish survival (Palomera et *al*., 2007) as well as the diet and condition of the adults (Banaru and Harmelin-Vivien, 2009). Furthermore, over the shelf, topographic irregularities can greatly modify circulation producing complex plankton distributions (Alvarez et *al*., 1996). Hence, submarine canyons at the continental margin of the NW Mediterranean can interact with the Northern Mediterranean Current and modify the general circulation, generating topographically controlled up- and downwellings and affecting the shelf-slope water exchange (Durrieu de Madron et *al*., 1994). All these processes favour high concentrations of zooplankton and fish larvae along all Gulf of Lions shelf and near the coast.

The geographical and temporal variations of zooplankton biomass are positively linked to the level of the primary production but also depend on the quality of food. In spring, the increase of food energy necessary to account for the seasonal enhancement of the zooplankton biomass needs a complement of phytoplankton food by another source of food, of animal nature, mainly organic particles and pico and nanoplankton. On the contrary, in winter, plant food seems sufficient for the maintenance of the lower zooplankton biomass observed at this season. The average secondary production was 54 mg C m^{-2} d^{-1} in spring and 19 mg C m^{-2} y^{-1} in winter, which represents 11% and 12% of the primary production, respectively (Gaudy et *al*., 2003).

3.2.7 Benthos

Sedimentation processes in the Gulf of Lions

The Gulf of Lions presents the highest density of submarine canyons in the entire basin, some of which extending for more than 100 km, cutting the entire continental slope and reaching depths deeper than 2000 m. Hydrological measurements collected since 1950 in the Lacaze-Duthiers canyon, which is located at the SW outlet of the crescent-shaped shelf, revealed the spreading of dense shelf water plumes that reached equilibrium depths between 170 and 800 m depth. Continuous temperature measurements carried out since 1993 in the same canyon revealed that dense shelf water cascading reached 500 m depth almost every winter.

Moreover, intense and dense shelf-water cascading occurred triggered by abnormally cold, strong and persistent winds. During these years of intense cascading dense waters flows down-slope over the bottom reaching the lower continental slope and basin at depths in excess of 2000 m. These sinking water phenomena in the Gulf of Lions are an annually recurrent phenomenon that peaks at decadal to sub-decadal time scales. In the last years several studies conducted in this region aimed at identifying the consequences of cascading on the sediment and organic matter transported to the deep sea during these episodic though recurrent events.

Several signals of ecosystem change were documented in the south westernmost canyons (Lacaze-Duthiers and Cap de Creus) during the major flushing events observed in recent years (Pusceddu et *al*., 2010): a rapid drop in deep water temperature, the raise of down- canyon currents (peaks up to 1 m s^{-1}), the concurrent increase of bottom water turbidity, and a dramatic increase in downward fluxes of material exported from the shelf and upper slope (Canals et *al*., 2006). These events were able to resuspend and transport several million tons of fine sedimentary particles down canyon, a mass comparable to the mean annual solid transport of all rivers opening into the Gulf of Lions.

During the cascading, both fine and coarse shelf and upper canyon sediments contributed to the mass flux, whereas advection of fine material via nepheloid layers dominated down-slope fluxes during pre- and post- cascading. The resulting change in grain-size affected the flux of mineral-bound terrigenous organic carbon, indicating that the down-canyon transport of land-derived organic matter did not occur as bulk but rather its composition are driven by sediment sorting associated with different transport mechanisms. While export of degraded sedimentary organic matter dominated during the early stage of water sinking, export of more labile marine organic Carbon took place during the last stage of this sinking event due to the phytoplankton bloom that occurred in late winter on the shelf (Pusceddu et *al*., 2010). Hence, the significant export of modern marine organic Carbon observed in the canyons after the pulsed input of terrigenous organic Carbon, suggests that the off-shelf marine export during the cascading season refuels the adjacent deep-sea basin with fresh organic matter (Pusceddu et *al*., 2010).

The dense shelf water cascading events can represent one of the most important processes fuelling the deep sea with fresh resources that are able to sustain high levels of ecosystem

functioning in the Gulf of Lions. These episodic events, especially those of high intensity, have positive or negative effects on the benthos, by fuelling the deep-sea floor with large amounts of bioavailable particles or by disrupting the benthic habitats, respectively. Results from a multidisciplinary investigation carried out in the Gulf of Lions revealed that meiofaunal abundance in canyon sediments during several years of high sinking water events were up to one order of magnitude lower than during periods characterized by the lack of dense shelf water formation (Pusceddu et *al*., 2010). However, whether meiofauna almost disappeared due to cascading (i.e. flushed away entrained with seafloor erosion under the effect of sediment-laden turbulent flows. or was diluted by the 'azoic' sediments brought in by the cascading remains still unclear.

The general sediment transport in the Gulf of Lions is also, a consequence of the different forcing events and is shown by the along-canyon cumulative transport (Palanques et *al*., 2006). The early winter events were produced by a strong eastern storm accompanied by a very significant flood and high river sediment discharges (5 Mt in the Rhone River). These events generated intense sediment resuspension and downwelling of warmer shelf water, with sharp increases in near-bottom down-canyon sediment fluxes in the western submarine canyons and less sharp increases in the central canyons along the Gulf of Lions continental shelf break. The canyons head have recurrent sediment transport events during shelf water cascading events and sporadic strong sediment transport events during strong eastern storms. Storm-induced downwelling can be combined with cascading, thus enhancing the sediment transport.

When these processes are very intense and occur at the end of or after the flood season, they can flush the sediment stored on the shelf, mainly though the Cap de Creus Canyon, at the southwestern end of the Gulf. Thus, the western and central submarine canyons show a sporadic sediment flush transport pattern, fed by river floods and controlled by strong storms combined with cascading. In the easternmost submarine canyons, sediment transport events are smaller and mainly associated with shelf water cascading (Palanques et *al*., 2006). River floods by themselves do not generate strong sediment transport through canyons, but they generate temporal deposits on the shelf that are winnowed and transferred offshore during sporadic strong eastern storms and seasonal cascading events. Similar behavior has been observed in the other central canyons, where sediment is stored temporarily in shelf depocentres until a strong storm reaches the area (Puig et *al*., 2003). Other canyons probably also follow this pattern.

The sands of the inner shelf display a seaward-fining texture and merge, in water deeper than 20-30 m, with mid-shelf muds. Jago and Barusseau showed the qualitative correspondance between the grain size gradient and the seaward-attenuating wave power. The only noticeable exception is the prodeltaic accumulation zones found near the river mouths, which are composed of silty muds. Pelitic deposits predominantly compose the middle shelf and the slope sediments. Muddy sands that outcrop on the outer shelf between 90 and 200 m represent littoral relict formations from the last eustatic low stage, that were reworked during the first phase of the eustatic sea-level rise.

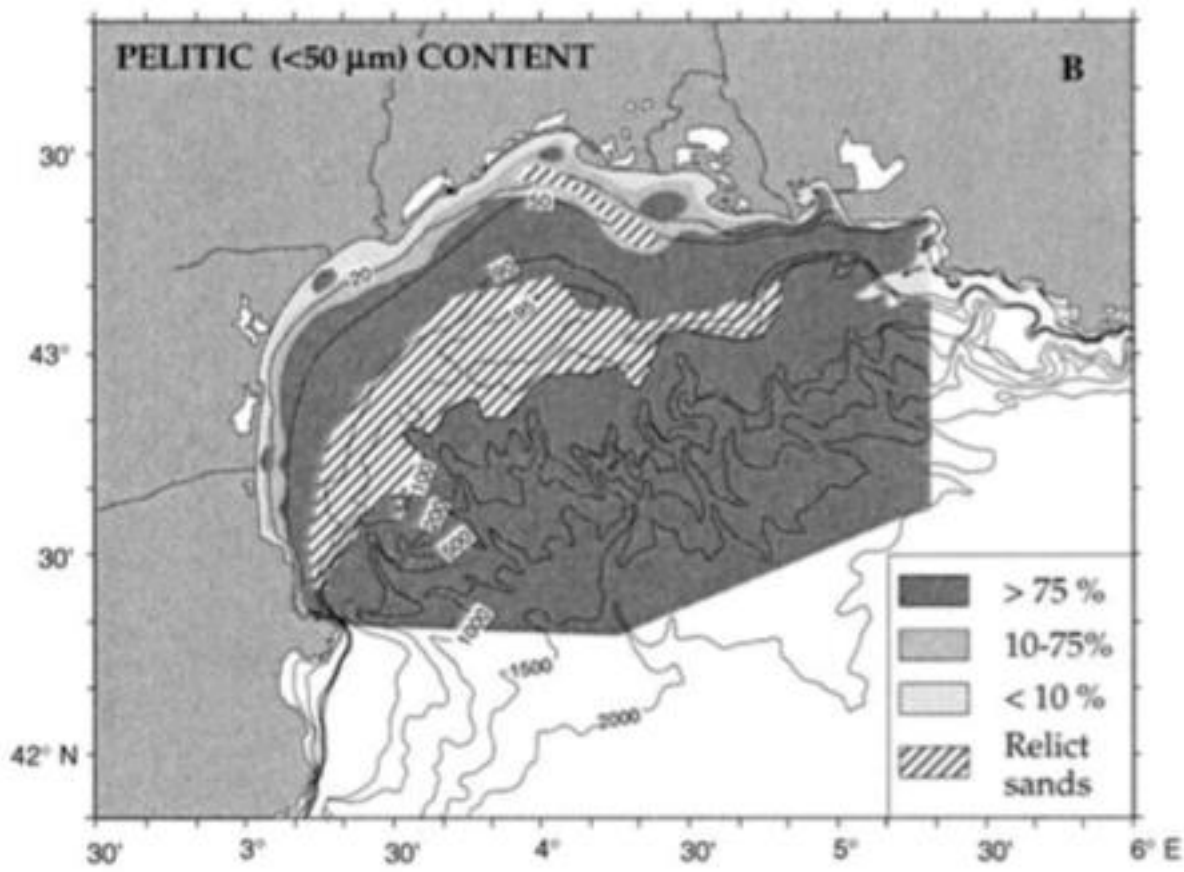


Figure 44: Percentage of pelite in sediments, from Durrieu de Madron et al., 2000

Organic carbon

Organic carbon content in surficial sediments is generally low in the sandy deposits of the outer shelf (0.25 - 0.5 %) and especially those of the inner shelf. It increases (0.6 %) in the mid-shelf muddy deposits, where the pelitic fraction exceeds 75 %. The highest values are found in the Rhone prodeltaic deposits, which are, enriched with organic carbon (1 - 2 %) due to the presence of coarse lignin-rich plant debris. Surficial sediments of the slope down to 1700 m depth present intermediate organic carbon contents (0.4 - 1.0 %), due to the very fine texture of the sediment. The highest contents on the slope are observed in muddy deposits from the various canyons (0.6 - 1.0 %), with northeastern canyons being richer (average 0.8 %) than southwestern canyons (average 0.7 %). Organic carbon contents on the open slope are significantly lower (0.4 - 0.5 %).

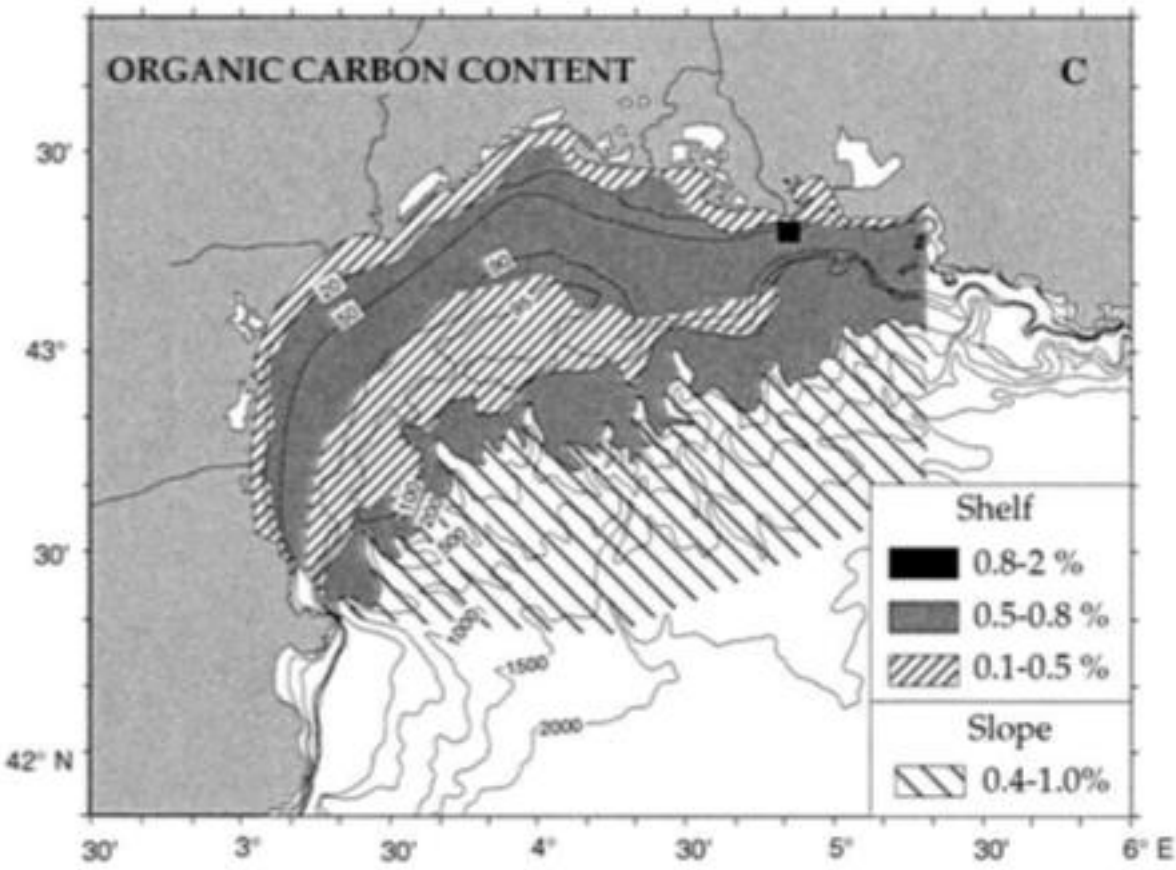


Figure 45: Organic carbon content in sediments, from Durrieu de Madron et al., 2000

Mass accumulation rates

Mass accumulation rates are highest in the immediate vicinity of the Rhone river mouth where they range from 30 to 50 g cm^{-2} y^{-1} (average 40 g cm^{-2} y^{-1}). Rates decrease rapidly seaward and gradually along-shore. On the distal part of the Rhone prodelta (20 km off the coast of Camargue), they range from 0.2 to 0.6 g cm^{-2} y^{-1} (average 0.4 g cm^{-2} y^{-1}). The rest of the shelf exhibits low rates, between 0.1 and 0.3 g cm^{-2} y^{-1}. The average accumulation rate is about 0.15 g g cm^{-2} y^{-1} on the mid-shelf mud belt and 0.14 g cm^{-2} y^{-1} on the outer shelf. As mentioned by Zuo et *al.*, sedimentation on the slope is less variable and generally decreases with increasing depth. Accumulation rates for the upper slope (200 - 1000 m depth) are in the range of 0.05 - 0.12 g cm^{-2} y^{-1}, with the highest values generally found in the canyons. The average rate is 0.09 g cm^{-2} y^{-1}. The rates on the lower slope (1000 - 2000 m) range from 0.01 to 0.08 g cm^{-2} y^{-1} (average 0.03 g cm^{-2} y^{-1}).

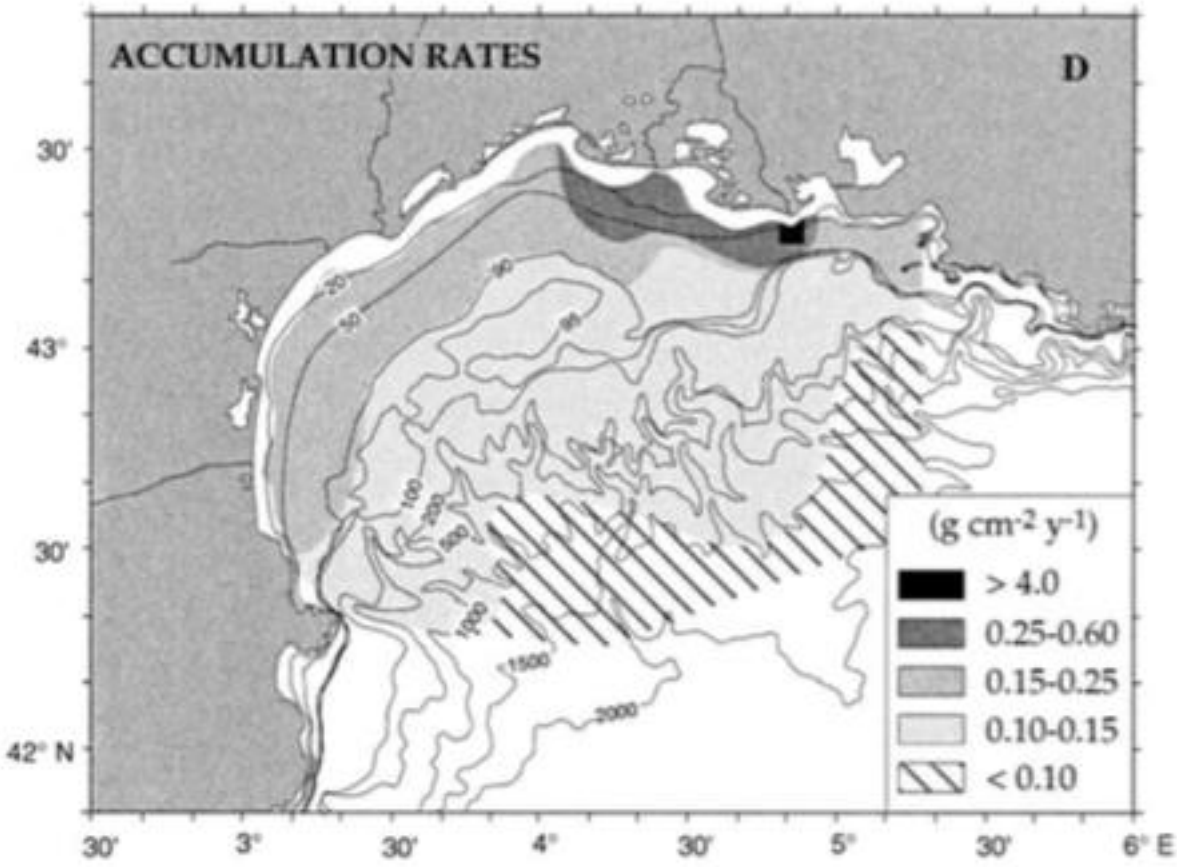


Figure 46: Depositional rates, from Durrieu de Madron et al., 2000

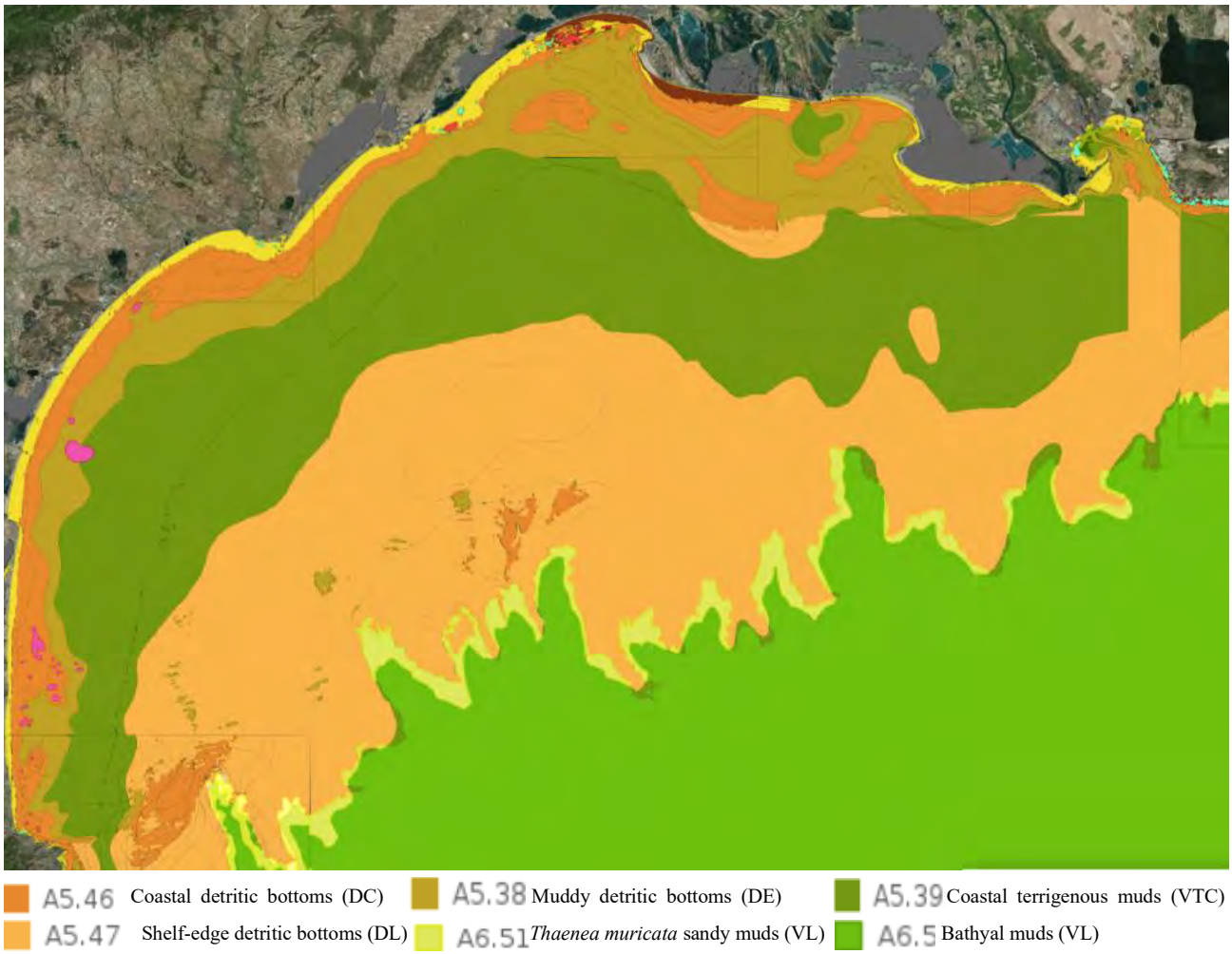


Figure 47: Benthic communities' map, from EMODnet, www.emodnet.eu

Along an ideal trasect moving from the Rhone mouth to the abyssal plain, passing trough the BGF location point, the benthic communities' encoutered are, from coastline to open sea:

- Well-sorted infralittoral sands, coded as SFBC in Peres & Picard 1965 and as A 5.23 in EUNIS 2019;
- Coastal detritic bottoms, coded as DC in Peres & Picard 1965 and as A 5.46 in EUNIS 2019;
- Muddy detritic bottoms, coded as DE in Peres & Picard 1965 and as A 5.38 in EUNIS 2019;
- Coastal terrigenous muds, coded as VTC in Peres & Picard 1965 and as A 5.39 in EUNIS 2019;
- Shelf-edges detritic bottoms, coded as DL in Peres & Picard 1965 and as A 5.47 in EUNIS 2019;
- Sandy muds at Thaenea muricata, facies of the coded VB in Peres & Picard 1965; coded A 6.511 in EUNIS 2019;
- Bathyal mud, coded as VB in Peres & Picard 1965 and as A 6.51 in EUNIS 2019;

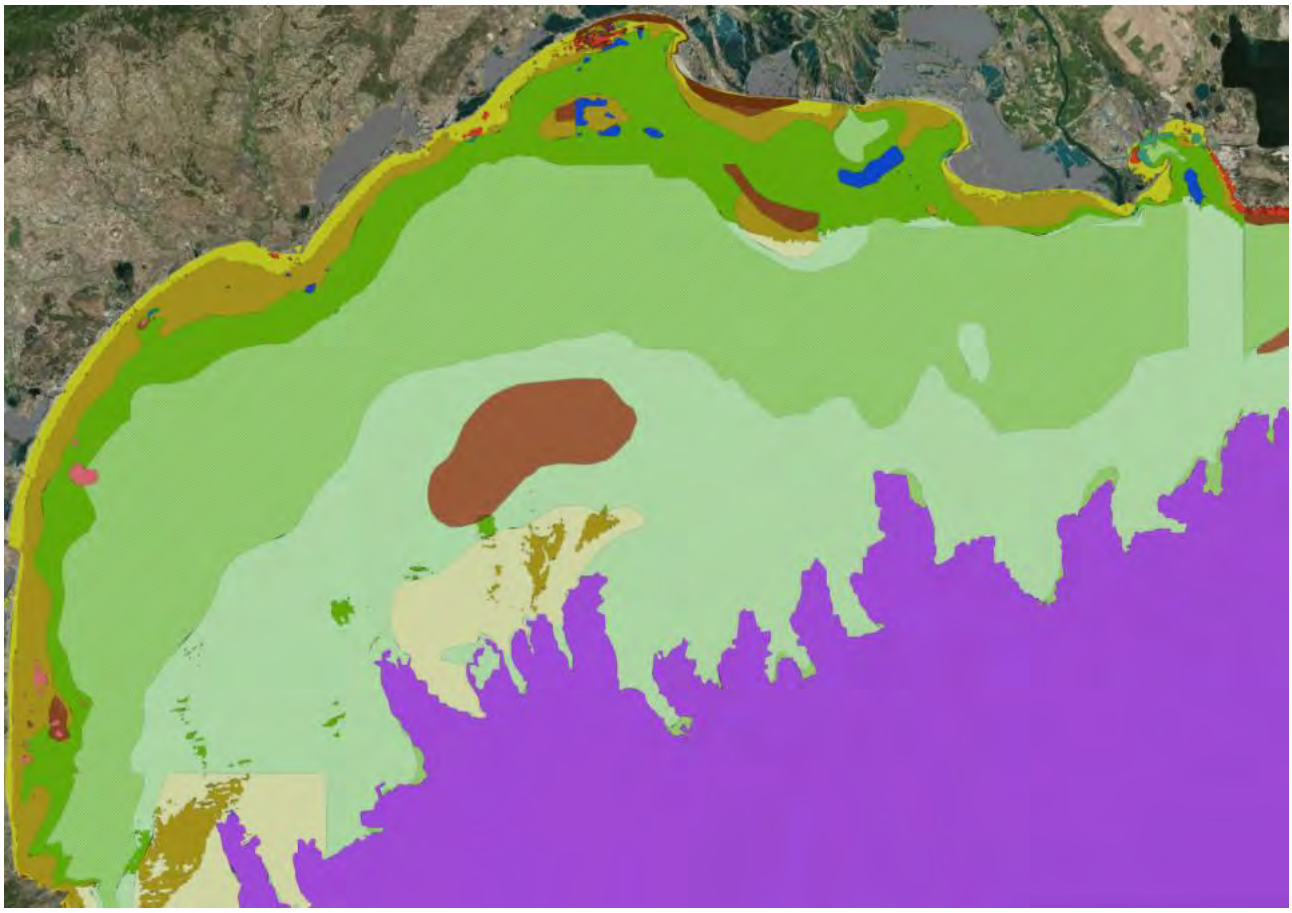


Figure 48: Broad habitat map, from EMODnet, www.emodnet.eu

Infralittoral plan: Biocenosys of well-sorted fine sands (SFBC)

Correspondance with the EUNIS classification: A 5.236, Infralittoral fine sands.

- Bionomic plan: Infralittoral
- Nature of the substrate: Sand
- Bathymetric distribution: 2 to 25m
- Location: Open Sea
- Hydrodynamics: Medium
- Salinity: Normal, being able to support a slight desalination
- Temperature: Normal
- Light: The light can reach the whole of the bathymetry of the habitat, but can also be restricted according to the presence of particles brought by the rivers and the anthropic rejections.

Figure 49: *Cymodocea nodosa*

Stationary features

Extensions of fine sand following in depth the biocenosis of high-level fine sands (SFHN), the sediment is generally of homogeneous granulometry and of terrigenous origin (transported by rivers to the sea or brought by ravines along the coast line during rain events). The biocenosis begins at 2-2.5 m and can reach 25 m depth, sometimes occupying very large areas along the coast or in large bays. The biocenosis of well-sorted fine sands tolerates locally a slight desalination of water, in the vicinity of estuaries and on the perimeter of certain Mediterranean ponds. It then presents a certain impoverishment, compensated by the presence of some species euryhaline. When the mode is too beaten, the biocenosis can also be impoverished. Locally, the phanerogam *Cymodocea nodosa* is likely to settle and constitute a facies of epiflora. The presence, rather localized on the French coasts, of Caulerpa prolifera determines the formation of a particular facies.

Dynamics of population are seasonal. During periods of strong hydrodynamism with storm surge, the sand is strongly reworked up to several meters deep.

Characteristic species

The polychaete annelids: *Sigalion mathildae, Onuphis eremita, Exogone hebes, Diopatra neapolitana.*

Bivalve molluscs: *Acanthocardia tuberculata, Mactra stultorum, Fabulina fabula, Tellina nitida, T. pulchella, Donax venustus*. The gastropod molluscs: *Acteon tornatilis, Nassarius mutabilis, N.*

pygmaea, Neverita josephinia.
Decapod crustaceans: *Liocarcinus vernalis,* amphipods: *Ampelisca brevicornis, Hippomedon massiliensis, Pariambus typicus,* Isopod *Idotea linearis*.
Echinoderms: *Astropecten spp., Echinocardium cordatum, E. mediterraneum.*
Fish: *Pomatoschistus microps, Callionymus risso.*

Associated species

Ditrupa arietina is a polychaete annelid of the family Serpulidae living on shallow soft substrates. This species can reach densities higher than 10000 ind.m2. The inter-annual variation in densities of this species is probably related to the frequency of resuspension events (Labrune et *al*., 2007).

Geographical distribution

Habitat present in all the coves and sandy beaches of Languedoc-Roussillon, where it is widespread, on the coasts of Camargue, in the coves of the eastern part of the coasts of Provence and Corsica, especially on the east coast of the island.

Structure and functions

Large expanses of fine sand with, in the deepest part, granulometric elements announcing the biocenoses of the circalittoral. Normal presence of epigee plant species that can lead to structured formation of phanerogamous association. The endogenous fauna is particularly diversified.

This diversity allows the presence of many species of fish and, possibly, crustaceans particularly sought after by professional local fishermen closer to the coast and by trawlers further offshore.

Interest in conservation

Habitat involved in maintaining the balance of the beaches: its removal during the formation of return currents endangers the submerged and the high beach.

It represents a feeding area for flatfish (*Solea solea, S. senegalensis, Bothus podas*, etc.) and many burrowing fish such as red mullet (*Mullus surmuletus*) and marbled (*Lithognathus mormyrus*). It is also home to many species that hide themselves by sinking entirely like the irregular sea urchins (*Echinocardium cordatum*), the sea stars of the genus *Astropecten,* bivalves and fish (the great live *Trachinus draco*, fish dishes, rason *Xyrichtys novacula*, etc.). Like some other seagrass meadows, *Cymodocea nodosa* and *Zostera noltii* meadows play a vital role in the recruitment and installation of a large number of species, thanks to an enrichment in the organic matter of the stand and a role of support for a microflora and a microfauna that constitute a food source that can be used throughout the local food web.

Potential threats

The habitat is subject to the inflow and sedimentation of fine particles from rivers. Hydrodynamics are generally not strong enough to prevent sedimentation. The habitat is directly subjected to human activity on the coast: emission of pollution, turbid water, poorly managed developments, macro

debris. Artisanal fishing is practiced on this habitat and can be a pressure. Trawling is a major pressure on this habitat. The reflourishment of the beaches can also constitute a strong pressure, modifying the dynamics and the composition of the biotope and therefore of the habitats.

Circalittoral Plan: Biocenosis of coastal terrigenous muds (VTC)

Correspondance with the EUNIS classification: A 5.39, Mediterranean communities of coastal terrigenous muds.

- Bionomic plan: Circalittoral
- Nature of the substrate: Muds
- Bathymetric distribution: 35 m (or 25 m) up to about 90 m depth
- Location: Open Sea
- Hydrodynamic: Low to very low. During storms, shallow fluid muds may be affected.
- Salinity: Normal
- Temperature: Normal
- Light: Low brightness

Stationary features

This biocenosis is characterized by fine, rapid and abundant sedimentation. The sediment is composed of a pure mud of fluviatile origin in which are quickly buried all the coarse debris (shells, slag, etc.). In the estuary areas, it follows the infralittoral stage from 35 m or even less (25 m) off the major rivers bringing a considerable mass of sediment and up to about 90 m deep, but which can, near of the Rhone delta, exceed 100 m depth (Salen-Picard, 1982). The sediment is a fluid, water-rich, sometimes thixotropic, mud whose pelite rate is always greater than 50%. In the area subject to the Rhone, Salen-Picard, (1982) has shown the existence of several concentric rings in a decreasing gradient of these pelites. In an area between 3 and 10 miles south of the mouth, the pelite content exceeds 90% in the sediment. In particular areas such as the Gulf of Fos, the biocenosis VTC is present from 10 m depth, due to local hydrodynamism allowing more fast sedimentation. (Pérès and Picard, 1964, Bellan-Santini et *al*., 1994)

Dynamic

The dynamics of the biocenosis of the coastal terrigenous mud is a function of the quantitative and qualitative contribution in fine sedimentary elements. The flow of rivers and the nature of its inputs, especially organic matter, play a major role. This leads to rapid changes in the structure of the community with sudden appearances and disappearances of some "opportunistic" species with a short life cycle. The base population is much more stable (Hermand et *al*., 2008).

Characteristic species

This biocenosis is characterized by the species: *Oestergrenia digitata, Labidoplax digitata, Leptopentacta tergestina* (Echinoderms), *Thyasira croulinensis, Abra nitida, Mysella bidendata, Axinulus croulinensis, Abra nitida, Turritella turbona f. communis* (molluscs), *Nephthys hystricis, Ninoe kinbergi, Sternaspis scutata, Lepidasthenia maculata, Eunereis longissima, Ninoe cf.*

Armoricana, Prionospio ehlersi, Prionospio steenstrupi, Paraprionospio pinnata, Poecilochaetus serpens, Magelona alleni, Pectinaria belgica, Ampharete acutifrons (polychaete annelids), *Leptocheirus pectinatus, Medorippe lanata, Goneplax rhomboides* (crustaceans).

Associated species

Characteristic species are accompanied by other species, notably vasicoles, species common to all circalittoral biocenoses of soft substrate, especially in the biocenosis of silted detritic (Picard, 1965). These species include *Glycera rouxii, Goniada maculata, Lumbrineris fragilis, Clymene gracilis, Thyasira flexuosa, Apseudes echinatus, Alpheus glaber*. During the years 1970-1990, abundance and dominance of vasicole species increased significantly, in the area between the Rhone delta and the northern harbor of Marseilles according to Salen-Picard (1982) and Hermann et *al*. (2008). Many of these species have been considered by Bellan and Bourcier, (1990) and Picard (1976) as indicators of the progressive degradation of benthic settlements linked to anthropogenic disturbances (chemical pollution, excessive inputs of organic matter, instability of the superficial layer of sediment).

Geographical distribution

Present in front of the estuaries and deltas of the coastal rivers. As a rule the most general, the soft vases of the VTC are closer to the coast and sticky vases, further offshore. But depending on the hydrodynamic conditions influencing the direction of the currents with respect to the course of the coast, we can observe an inverse succession.

Structure and functions

Homogeneous community with generally only few epibionts, linked to large mud extensions. Rich invertebrate fauna that can be used to feed benthic and epibenthic fish.

Interest in conservation

The major conservation interest for in fishing activities, most often by trawling with high economic value. This economic importance is directly related to the preservation of the overall ecological quality of the habitat. Repetitive trawling alters the nature of the physical environment (upper layer of sediment) leading to the quantitative depletion or even the disappearance of invertebrate species consumable by fish and consequently the rarefaction or monotonisation qualitative of catches.

Potential threats

Since this biocenosis is established on bottoms on which fine sediments are deposited by nature, it is therefore particularly exposed to all sorts of deposits: debris, garbages, pollutants associated with sedimentary particles, organic matter, pesticides, heavy metals, resulting in a strong pollution of funds. This results in a drastic decrease in the characteristic species of the biocenosis and their replacement by more widely distributed species in all loose substrates rich in fine particles. It can happen (mouth of the Rhone) that the number of species present is reduced, as it is at the outlet of the emissaries at sea sewage collectors (Salen-Picard, 1982).

Facies with *Turritella tricarinata communis* (Mollusca, Gastropoda)

Correspondance with the Eunis classification: 5.391

This facies is found on coastal muds, and is characterized by the high number of specimens and biomass of *Turritella tricarinata communis*. Gamulin-Brida, (1974) noted that in some areas this gastropod was so abundant that it represented about 95% of the total macrobenthos abundance. This facies has not been systematically researched in recent years.

Figure 50: Facies with *Turritella tricarinata communis*

Facies of sticky muds with *Virgularia mirabilis* and *Pennatula phosphorea*

Correspondance with the Eunis classification: 5.392

This facies is found on coastal mud, on terrigenous rather incoherent mud in areas with low sedimentation rates and reduced hydrodynamism down to 400 m depths. This habitat is dominated by the sea pens Virgularia mirabilis, Pennatula (phosphorea), and sometimes Veretillum cynomorium is also often associated to them. Brittlestars such as Amphiura spp. are particularly characteristic of this habitat, whilst infaunal species include tube building polychaetes and deposit feeding bivalves. Burrowing megafauna including Nephrops norvegicus are common in deeper

muds.

Figure 51: Facies of sticky muds with *Virgularia mirabilis*

Facies of sticky muds with *Alcyonium palmatum* and *Stichopus regalis*

Correspondance with the Eunis classification: A5.393

This facies occur in areas with low sedimentation rates and is characterized by the dominance of Alcyonium plamatum and the bivalve Pteria hirundo, ascidians (e.g. Diazona violacea) and the large holothurioid Stichopus regalis. In the Cap the Creus canyon, two different facies can be distinguished in the upper canyon rim and canyon head, those with shared dominance between sea pens and ceriantharians, and those dominated by sea pens and hydrozoans (Gili et *al*., 2011).

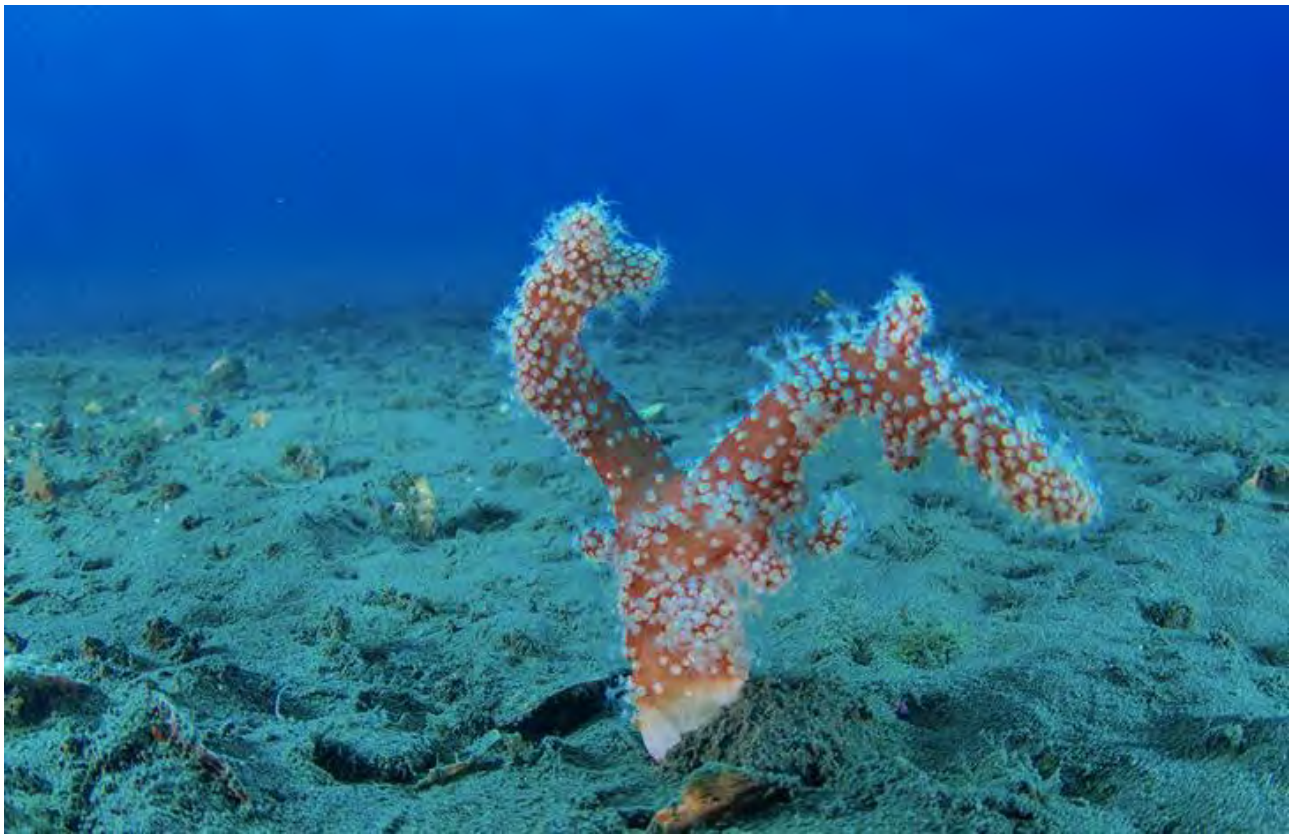


Figure 52: Facies of sticky muds with *Alcyonium palmatum*

Detritic bottoms

Communities of coastal detritic bottoms (DC)
Correspondance with the Eunis classification: A 5.46

- Bionomic plan: Circalittoral
- Nature of the substrate: Organogenic gravel with sandy-muddy filling
- Bathymetric distribution: 30-35 m at 90-100 m
- Location: Large bays and open sea
- Hydrodynamism: Generally weak, some currents can condition the appearance of facies. During storms, the funds up to 60-70 m can be impacted, with exceptionally alteration or even disappearance of some facies.
- Salinity: Normal
- Temperature: Normal
- Light: Low intensity

Figure 53: Detritic bottom

Stationary features

Extents of gravel and organogenic coarse sands more or less clogged with sandy-silty sediments, generally following the biocenosis of well-calibrated fine sands SFBC. The sediment is of heterogeneous granulometry and of mixed origin: terrigenous and organogenic. Gravel and sand may be derived from nearby rocks (infralittoral and circalittoral), or consisting of mollusc shell debris, large calcified bryozoans, echinoderm tests, or dead melobates. These coarse sands and gravels have their interstices filled by finer elements, sandy-muddy. The silty fraction is generally less than 20% (various types more or less silted exist), but it can undergo rapid and significant increases, unbalancing the entire biocenosis. The fragmentation of the debris is not the result of always-weak hydrodynamic factors, but results from the action of organisms attacking limestone (*Cliona spp., Polydora spp., lithophagous pelecypods*, etc.). However, the regular or intermittent existence of background currents has been frequently emphasized.

Characteristic species

Several dozen species belonging to many groups of phytobenthos and zoobenthos can be considered as characteristic of this particularly rich biocenosis.

Phytobenthos: *Cryptonemia tuniformis**, branched limestone rhodophytes (*Phymatolithon*

calcareum, Lithothamnion corallioides, Spongites fruticulosa), Peyssonnelia spp.

Zoobenthos: *Bubaris vermiculata*, Suberites domuncula** (sponges); *Sarcodictyon catenatum** (cnidarian); *Astropecten irregularis*, Anseropoda placenta*, Genocidaris maculata*, Luidia ciliaris, Ophioconis forbesi*, Psammechinus microtuberculatus*, Panningia hyndmani** (echinoderms); *Limaria loscombi*, Palliolum incomparabile*, Flexopecten flexuosus*, Laevicardium oblongum*, Acanthocardia deshayesii*, Moerella donacina*, Melanella polita*, Turitella triplicata*, Cardiomya costellata, Turritella communis (molluscs); Laetmonice hystrix*, Petta pusilla** (polychaetes); *Conilera cylindracea*, Paguristas eremita*, Anapagurus laevis*, Ebalia tuberosa*, Ebalia deshayesi** (crustaceans); *Molgula oculata*, Microcosmus vulgaris*, Polycarpa pomaria*, Polycarpa gracilis** (ascidians).

Species with a * are mentioned as exclusive features of the biocenosis by Picard (1965).

Given the heterogeneity of the sediment, a number of species can be abundant in the biocenosis of coastal detritic. They are indicative of more specific conditions of the environment. These include, for example, gravellicolles (*Echinocyamus pusillus, Spatangus purpureus, Astarte fusca*), mixticoles (*Parvicardium minimum, Timoclea ovata, Antalis inaequicostata*), sabulicoles (*Philine aperta*) or species with broad ecological furniture substrates.

The biocenosis of coastal detritic is strongly structured by a large number of characteristic species. Picard (1965) quotes 49. These species are found, for the most part, in later works (Falconetti, 1980; Salen-Picard, 1982) for the sectors east of the Rhone delta.

Associated species

Picard, (1965) recorded some 60 gravellicolous and mixtic species, indicative of the particular quality of the sediment and more general distribution in the soft substrates, as long as the fine particles (vases) are little or not present.

Geographical distribution

Part of the continental shelf of the French Mediterranean coast.

Structure and functions

Large stretches of detrital sands with coarser elements, normal presence of epigal algal and animal species. The endogenous and epigee fauna is particularly diversified.

This diversity allows the presence of many species of fish and, possibly, crustaceans particularly sought after by professional fishermen in "small trades", closer to the coast, and by trawlers, further offshore.

Interest in conservation

The biocenosis of coastal detritic occupies considerable areas on the continental shelf throughout

the Mediterranean. It is a biocenosis with a very high specific diversity. Under the influence of various environmental factors, many facies are developed, linked to the sometimes-exuberant extension of particular species. It is an important fishing area, especially for "small trades", and thus represents an essential fraction of the Mediterranean fishery resources.

Potential threats

The coastal detritic bottoms are subject to a variety of sediment inputs from both permanent and intermittent rivers that cyclically increase fine sediment and organic matter contents. There is a possibility of natural evolution towards the biocenosis of silted detrital, or even, in depth, towards altitudinal transgressions of the biocenosis of offshore detritic. The hydrodynamism affecting the biocenosis of coastal detritic is only exceptionally strong enough to avoid the sedimentation of fine particles of terrigenous origin.

However, this natural variability is currently overshadowed by the increase in anthropogenic actions, which pose a considerable threat. These anthropogenic actions can be direct by the generalized siltation of the continental shelf, whose main causes are unpurified urban discharges, major works in the maritime field, and the leaching of soils denuded during large fires. This hypersedimentation eventually increases the extension of the other circalittoral detrital funds. In addition, these contributions of fine particles are generally loaded with various pollutants, especially in wastewater, pollutants that have a direct effect on the characteristic species of the biocenosis. Trawling as it has been done for several decades has particularly destructive effects on the epigee flora and fauna. This results in addition to a physical alteration of the superficial part of the sediment. The most harmful induced effects cause the disappearance of numerous facies (Lithothamnies, large Bryozoans, Ascidian bottoms, etc.), the progressive dominance of species with wide ecological distribution, the generalized monotonization of the funds, the loss of the biodiversity, and to term, it is necessary to consider the reduction of living resources

Evolutionary trend

The biocenosis of coastal detritic is theoretically a stable biocenosis in time and space. This is linked to the strong structuring of its specific composition. However, it appears that for about 4 decades the stands have evolved significantly. Salen-Picard (1982) has clearly highlighted two modalities of this evolution:

1) in the case of the extension, whether anthropogenic or not, of fine sediments, muddy or sandy-silty, there is a change, possibly rapid, in the faunistic composition due to the arrival of the biocenosis of silty detritic which eventually becomes dominant with progressive elimination of characteristic species of coastal detritic. Detritic species are replaced by vasicole species, while the stock of species with a wide ecological distribution may remain;
2) in the case of disturbances of known anthropogenic origin (chemical pollution, excess of organic matter, natural or induced instability of the superficial layer of sediment, etc.), a certain number of species, generally with wide ecological potential, tolerant, or

demanding with respect to their sensitivity will develop according to the nature of the disturbing factors. There is then a qualitative and quantitative reduction of the coastal detritic structural species, replaced by the indicator species of disturbances which will end up causing the biological monotonization of space, resulting through a succession of facies to a general pattern of degradation of benthic biocenoses of soft substrates and not just the biocenosis of coastal detritic. The ultimate stage is none other than the disappearance of the impacted biocenosis and the appearance of an unstructured paucispecific stand (Bellan and Boucier, 1990, Picard, 1976).

Biocenosis of silty detritic bottoms (DE)
Correspondance with the Eunis classification: A5.38

- Bionomic plan: Circalittoral
- Nature of the substrate: Gravel, sand and silt in varying amounts with a dominant proportion of silt
- Bathymetric distribution: 30 - 35 m up to 95 m depth
- Location: Open Sea
- Hydrodynamic: Low
- Salinity: Normal
- Temperature: Normal
- Light: Low brightness

Stationary features

These biocenoses develop in areas where the detrital bottoms are covered by mud of terrigenous origin (deposits of rivers). The sediment consists of sandy loam or muddy sand, and sometimes of indurated mud, rich in shelly debris. Sedimentation is slow enough to allow the development of sessile epifauna. Gravel, sand and silt are mixed in varying amounts but the proportion of silt is still dominant.

The renewal of the water masses is relatively little active in this biocenosis, which is found elsewhere in the bays, deeper than the biocenosis of coastal detritic bottoms.

Characteristic species

The exclusive features of this biota are the anemone *Anemonactis mazeli* the cnidarian *Alcyonium palmatum*, the bivalve *Serratina serrata*, polychaetes *Aricidea (Acmira) assimilis*, *Aphrodita aculeata, Polyodontes maxillosus, Eupanthalis kinbergi, Inermonephtys inermis, Leiocapitella dollfusi* and the isopod *Natatolana neglecta*. This biocenosis is also characterized by the sipunculid *Golfingia (Golfingia) elongata* and the echinoderm *Pseudothyone raphanus. Serratina serrata* is both a pioneer and a residual species when the biocenosis sets in or disappears.

Figure 54: Biocenosis of silty detritic bottoms

Geographical distribution

Muddy and sandy-muddy surfaces present on the continental shelf between thirty meters (possibly less) to the edge of the continental shelf, which can occupy large areas. The biocenosis of muddy detritic bottoms is found in the zones of influence of the terrigenous supply of coastal rivers, in particular, in the whole Gulf of Lion (Pérès and Picard, 1964, Salen-Picard 1982, Bellan-Santini et *al*., 1994).

Interest in conservation

Major ecological value, at the heart of the modalities of evolution of coral communities of circalittoral soft bottoms. Accessible biomass production as food for consumable species (fish and crustaceans). Great fishing sector.

Potential threats

Like the coastal terrigenous vases, this biocenosis is subsequent to sedimentary bottoms and is therefore particularly exposed to all sorts of deposits: macro-waste, pollutants, organic matter, pesticides, heavy metals, resulting in polluted or even azoic bottoms. The vasicole tolerant species often abundant within this biocenosis, constantly subject to the sedimentation of fine elements, such as the bivalve *Corbula gibba,* polychaetes *Glycera unicornis, Lumbrineris latreilli, Notomastus latericeus* and, sporadically *Ditrupa arietina*, the sipunculid *Aspidosiphon muelleri* take considerable quantitative extension in disturbed areas by anthropogenic inputs of domestic or

industrial origin.

Evolutionary trend

The Rhône plays a major role in the presence and extension in time and space of the biocenosis of muddy detritic bottoms, at the expense of coastal detritic especially in the entire Gulf of Lion, between the Bay of Marseille and that of Banyuls (Salen-Picard, 1982, Grémare et al., 1998). This trend has been widely documented by the authors cited. It is related to sedimentary inputs, both in volume and in their granulometric nature.

The contribution of the small rivers of the western part of the Gulf of Lion, can accentuate these phenomena on the scale of the gulf. More locally, the biocenosis of muddy detritic bottoms has progressed by subsequent invasion of the biocenosis of coastal detritic in the area east of Marseille (Riou archipelago, Cortiou basin and Cassis bay) submitted since the end of the 1960s to joint discharges of the great sewer collector of Marseille and the diversion of the small coastal river Huveaune diverted into the collector.

The biocenosis of silt detritic bottoms is the central element of the overall evolution of the circalittoral soft bottoms of the continental French Mediterranean coasts.

Facies with *Ophiotrix quinquemaculata*

Correspondance with the Eunis classification: A 5.381

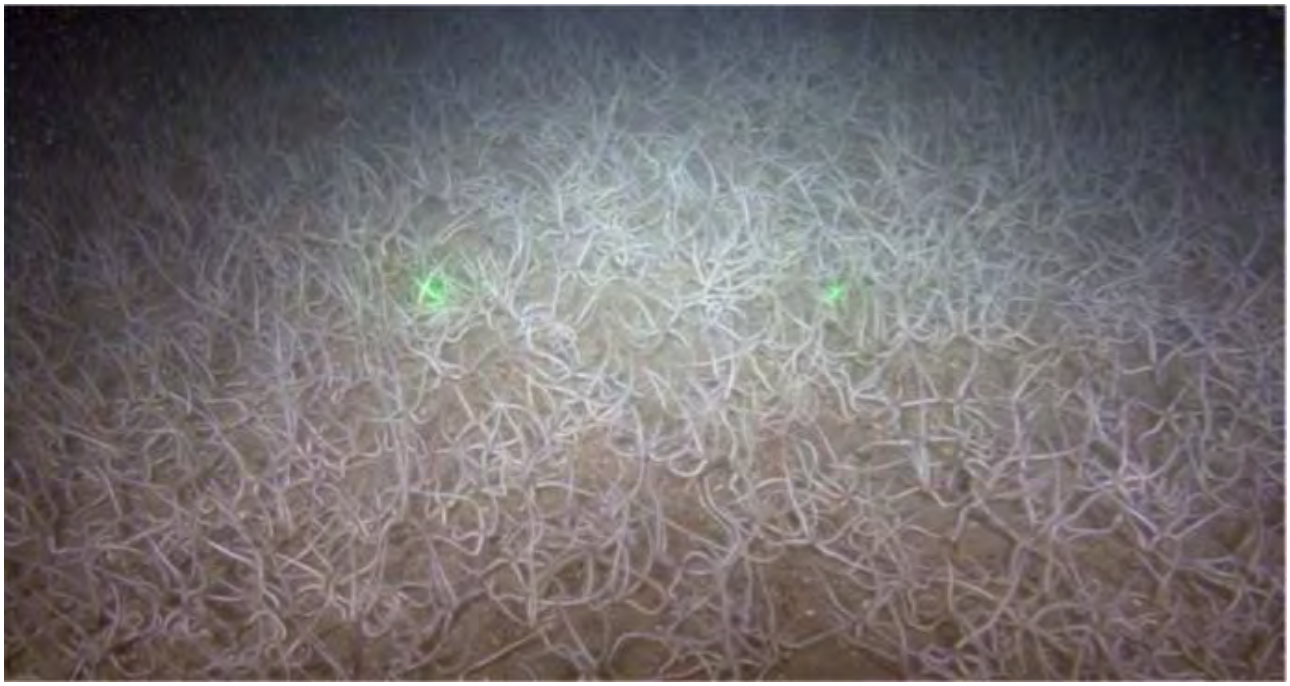


Figure 55: Facies with *Ophiotrix quinquemaculata*

This facies are found on muddy sand with a mixture of broken shells. Because of the low sedimentation rates, small hard substrates such as shells remain on surface and allow the development of sessile epifauna. Sometimes, the brittle star Ophiothrix quinquemaculata can be found in fairly abundant densities.

Biocenosis of shelf-edge detritic bottom (DL)
Correspondance with the Eunis classification: A 5.47

- Floor: Circalittoral
- Nature of the substrate: Organogenic gravel with sandy-muddy filling
- Bathymetric distribution: from 90 to 200 m approximately
- Location: Open Sea
- Hydrodynamic: Slow to nonexistent (currents at the slope of the continental slope)
- Salinity: 38
- Temperature: 13 °C
- Light: Low brightness
- Trophic diet: Oligotroph

Stationary features

The biocenosis of offshore detrital bottoms (DL) is found between 80-90 m and 120-130 m. The lower limit of this biocenosis is well marked and corresponds to the slope break of the continental slope. The coarse fraction of the LS biocenosis substrate consists of a mixture of small gravels from fluvial input and large shell debris. These debris are generally considered to belong to quaternary thanatocenoses. A sandy-muddy part is also observed. This biocenosis is located just below the 95 m isobath, following the biocenosis of coastal detritic (DC). Most of the population of the edge of the continental shelf is found in this biocenosis.

Dynamic

Salen-Picard, (1982) was able to study the evolution of the biocenosis of DL in the siltation front sector linked to the eastward progression of rhodanian vases. The active settling of the pelites leads to the replacement of detritic offshore by the biocenosis of silted detritic. The author emphasizes that the fundamental difference between these two biocenoses is sedimentological and non-bathymetric.

Characteristic species

This biocenosis is characterized by *Leptometra phalangium, Thyone gadeana, Ophiura (Dictenophiura) carnea* (echinoderms), *Antalis panorma (scaphopod), Astarte (bivalve), Haploops dellavallei (amphipod), Natatolana borealis (isopod), Pitaria mediterranea (bivalve*) and *Atrina fragilis* (pelecypods) (Pérès and Picard, 1964, Falconetti, 1980, Bellan-Santini et *al*., 1994).

Associated species

Other species mixed with species characteristic of the biocenosis of offshore detritic can be observed as:

- Species common to all the circalittoral stage, and also some species of coastal detritic bottoms, especially when these are in topographical continuity with the offshore detritic bottoms. Thus, the small teleostian *Deltentosteus quadrimaculatus* is common, as in the

shallower sand bottoms.

- At the level of the continental slope break, a reinforcement of hydrodynamism and observed. Two species favoring these bottom currents will be observed in this biocenosis: *Venus casina* and *Spatangus purpureus*. The crinoid *Leptometra phalangium*, often in dense population in this biocenosis, is also conditioned by these currents.
- Species from the immediately lower stands: large brachiopod stand and biocenosis of the deep chambers of the bathyal floor.
- Species with various ecological requirements, such as the *Ophiacantha setosa* that lives on all hard substrates (rocks, slag, isolated shells, large sponges) in the lower part of the circalittoral layer (Pérès and Picard, 1964).
- Bryozoans and free cyclostomes on sediment or attached to *Gryphus vitreus* or *Leptometra phalangium* cirri (Harmelin, 1978).

Geographical distribution

This biocenosis is present throughout the Mediterranean coast.

Structure and functions

The biocenosis of offshore detritic bottoms is an area where demersal trawling can be quite common. Thus, it is home to a high density of benthopelagic teleosts mainly associated with the *Leptometra phalangium* facies.

Interest in conservation

The funds of this biocenosis are places of fishing by demersal trawl. This fishing technique alters the structure of this biocenosis (destruction of the *L. phalangium* facies) and leads to rarefaction of large breeders.

Potential threats

Mainly continental threats are impacting the biocenosis of offshore detritic bottoms locally. Quite exceptionally, offshore detritic bottoms close to the coast may be altered by anthropogenic inputs linked to discharges at sea from sewer collectors in large cities (for example in Marseille), or even direct discharges through pipelines (Nice). In Corsica, direct sedimentation of fine particles from fires in the large forests of the center of the island has been observed locally when the continental shelf is narrow.

Evolutionary trend

The increase in siltation of the zones, by point discharge or frequent discharges, could lead to a modification of this biocenosis and tend towards more silty biocenoses.

Facies with *Leptometra phalangium*
Correspondance with the Eunis classification: A 5.472

This facies, found on the shelf in the western Mediterranean, is characterized by the high abundance of the crynoid *Leptometra phalangium*. This species is a suspension-feeder that inhabits

areas with a high hydrodynamics and high input of organic matter and plankton. The presence of *L. phalangium* enhances habitat heterogeneity by developing three-dimensional communities. Leptometra beds, hosting large biomasses of benthopelagic fish and recruits, are mainly characterized by a high abundance of spawners of commercially important species, eg red mullet *Mullus barbatus, Merluccius merluccius* hake, blue whiting *Micromesistius poutassou* and *Trisopterus minutus capelanus* (Bellan-Santini et a*l*., 2002).

Figure 56: Facies with *Leptometra phalangium*

<u>Hard beds and rocks</u>

Biocenosis of shelf-edge rock (RL)
Correspondance with the Eunis classification: A 4.12

A fairly specific assemblage on the shelf break and the upper part of the slope, with poorly developed calcareous red algae characteristic of the coralligenous biocenosis. This biocenosis is mentioned in the reference list of Marine habitat types (UNEP-MAP-RAC/SPA 2006), however it is not well defined. Here it corresponds to the offshore rocky-bottom assemblage defined in Pérès, (1984) and “Roche du large” in Pérès and Picard, (1964). This biocenosis is found from 90 to 300 m depth, on rocky areas, however it is usually covered with a very thin layer of sediment. The

predominant components of this biocenosis are suspension-feeders as expected in areas with strong currents and high turbidity. This type of biocenosis is dominated by large-sized sponges (e. *Poecillastra compresa, Rhizaxinella pyrifera, Phakellia ventilabrum, Axinella spp.),* the yellow scleractinian *Dendrophyllia cornigera*, the black coral *Antipathes fragilis,* many bryozoans, brachiopods, polychaetes and echinoderms, which are also well represented. Decapods like *Palinurus elephas* and *P. mauritanicus* are also common. The biocenosis of the "Roche du large" may play an important role in controlling the benthic biodiversity of the Mediterranean circalittoral (Bo et *al*., 2012).

Figure 57: Biocenosis of shelf-edge rock

To date, there are no facies described for this type of biocenosis, however recent experimental surveys reported the presence of several dominant components:

Gorgonians: *Eunicella spp. and Paramuricea clavata*
Oyster bancs with *Neopycnodonte cochlear*
Sponges: *Aplysina cavernicola, Spongia lamella and Desmacidon sp.*

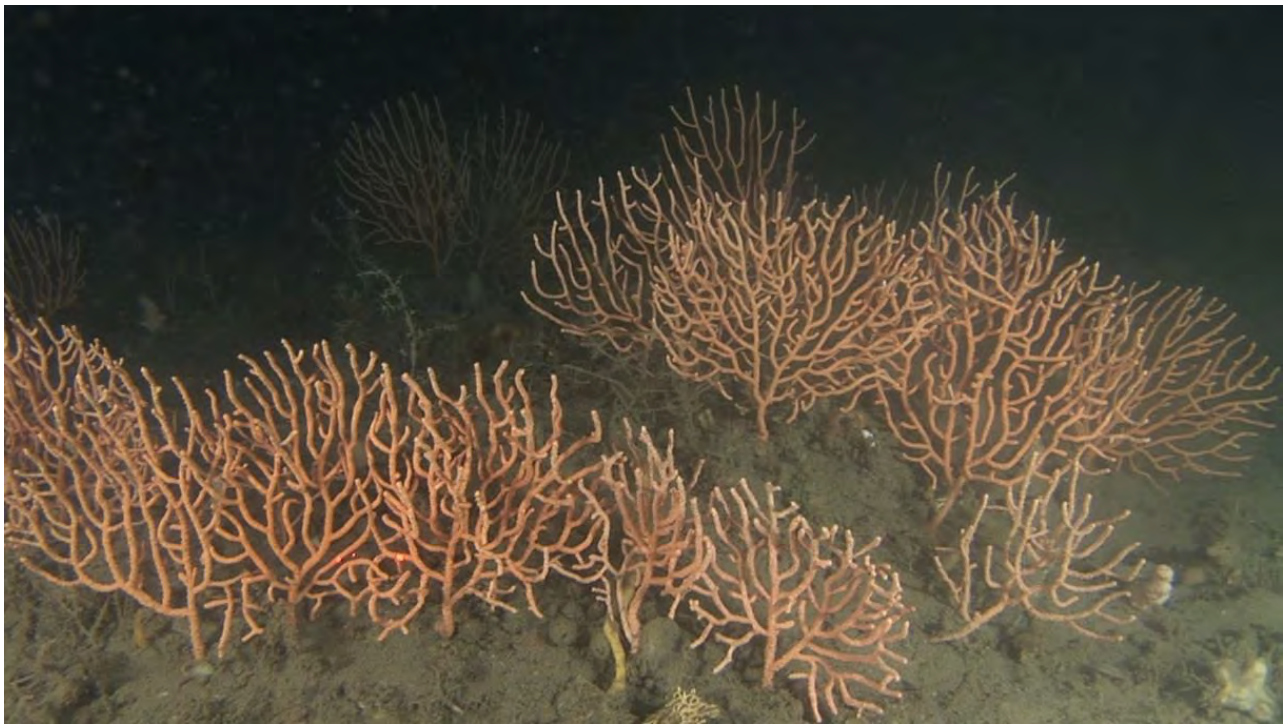


Figure 58: Biocenosis of shelf-edge rock, *Paramuricea clavata*

Bathyal muds

Biocenosis of bathyal muds
Correspondance with the Eunis classification: A 6.51

This biocenosis is characterised by a constant homothermy of around 13 °C and an almost total absence of light. The granulometry and thickness of the sediment is not homogeneous. It is present, generally, at depths of 150 - 250 meters. The faunal composition is characterised by foraminifera, sponges, polychaetes, echinoderms and crustaceans.

Facies of sandy muds with *Thenea muricata*
Correspondance with the Eunis classification: A 6.511

This facies is found on sandy muds populated mainly by the small sponge *Thenea muricata.* This facies is poorly described in the original description from (Pérès and Picard, 1964). Experimental surveys from MEDSECAN canyons show that some commercial fishes and decapods (e.g. *Gadiculus argenteus, Merluccius merluccius, Nephrops norvegicus*) and the sponge *Rhizaxinella* sp. are frequently found. This facies in the Gulf of Lions was mainly observed between 250 and 350 m depth.

Figure 59: Facies of sandy muds with *Thenea muricata*

Facies of soft muds with *Funiculina quadrangularis* and *Aporrhais serresianus.*
EUNIS A 6.513

Figure 60: Facies of soft muds with *Funiculina quadrangularis*

This facies, present on the shelf edge and upper slope up to a depth of 350 m is characterized by sandy muds, in which the cnidarian *Funiculina quadrangularis* and the gastropod *Apporhais serresianus* are dominant. On gently inclined bottoms the sea pen Kophobelemnon leuckarti is also

abundant. These suspension feeders presumably increase the three-dimensional complexity of soft-bottoms, and can contain abundant populations of some commercial crustaceans, such as *Parapenaeus longirostris* and *Nephrops norvegicus* and cephalopods (*Eledone cirrhosa, Illex illecebrosus coindetii and Todaropsis eblanae*).

Facies of compact muds with *Isidella elongata*
Correspondance with the Eunis classification: A 6.514

This facies is present on deeper grounds (mainly 400-800 m depth) over bahtyal muds, at the base of the continental slope and bathyal plain (with little or no slope) and is characterised by compact muds in which the cnidarian Isidella elongata is present. Isidella elongata usually presents epibionts like the actinia *Gephyra (Amphianthus dohrni*), the crustacean *Scalpellum scalpellum*, the bivalvia *Chlamys* and *Scyliorhinidae* eggs. Some commercial fishes, decapods and cephalopods (e.g. *Merluccius merluccius, Micromesistius poutassou, Parapenaeus longirostris, Aristaeomorpha foliacea, Aristeus antennatus, Bathypolypus sponsalis*) are found in high abundances in this facies. This facies in the Gulf of Lions was mainly observed between 350 and 620m depth.

Figure 61: Facies of compact muds with *Isidella elongata*

Facies with Ceriantharia

These facies have been observed in soft muddy bottoms in several canyons from 250 to 400 m depths. They are characterized by the high abundance of large Ceriantharia (species not identified).

In Algerian waters, the big cerianthid *Branchiocerianthus norvegicus* is common (Pérès, 1984). Also dominant in this type of community are fish and cephalopods of commercial interest (e.g. *Helicolenus dactylopterus*, *Merlucccius merluccius*, *Eledone cirrhosa*).

Figure 62: Facies with Ceriantharia

Deep hard beds and rocks

Biocenosis of deep-sea corals
Correspondance with the Eunis classification: A 6.61

These facies appear below 200 m, generally on steep rocky areas in the shelf break and canyons, where strong currents and steep slope prevent sedimentation (Bellan-Santini et *al*., 2002, Zibrowius, 2003). Deep-sea or cold-water corals from complex three-dimensional habitats, creating biodiversity hotspots, increasing densities of associated species, accumulate suspended detritus and influence the local hydrodynamic flow field (Zibrowius, 2003; Taviani et *al*., 2011). Mainly two species of scleractinians Lophelia pertusa and Madrepora oculata are characterizing these facies. The associated fauna on alive and dead skeletons include: sponges, polychaetes, echinoderms and bryozoans. Cold-water corals are also considered an important habitat for larval fish and crustaceans (D'Onghia et *al*., 2010). These communities are still poorly known in the Mediterranean, highlighting its conservation interest (Bellan-Santini et *al*., 2002; Zibrowius, 2003; Taviani et *al*., 2011).

Figure 63: Biocenosis of deep-sea corals

Facies of *Neopycnodonte zibrowii*

A large number of subfossil oysters (*Neopycnodonte zibrowii*) were localized in several canyons, on rocky bottoms up to depths of 500m. This species might live up to 500 years old (Wisshak et *al*., 2009) and are testimonial of ancient shallow sublittoral environments. A living specimen of *Neopycnodonte zibrowii* might have been found (Fourt and Goujard, 2012), confirming the presence of a live specimens in the Gulf of Lions. From the existing reports, it seems that this species succeeds on vertical cliffs and underneath bedrock (Wisshak et al., 2009).

Figure 64: Facies of *Neopycnodonte zibrowii*

Facies of *Callogorgia verticillata* and *Viminella flagellum*

The gorgonian *Callogorgia verticillata* has been observed in large numbers on rocky substrates at depths of ca. 350-450m. This species seems to appear accompanied by other gorgonians (e.g. *Viminella flagellum*) and antipatharians (e.g. *Leipathes glaberrima, Antipathes dichotoma*) and deep-sea sponges. Large benthic cnidarians can play an important role since they create complex tree-dimensional habitats, allowing for high diversity levels and producing biodiversity hotspots.

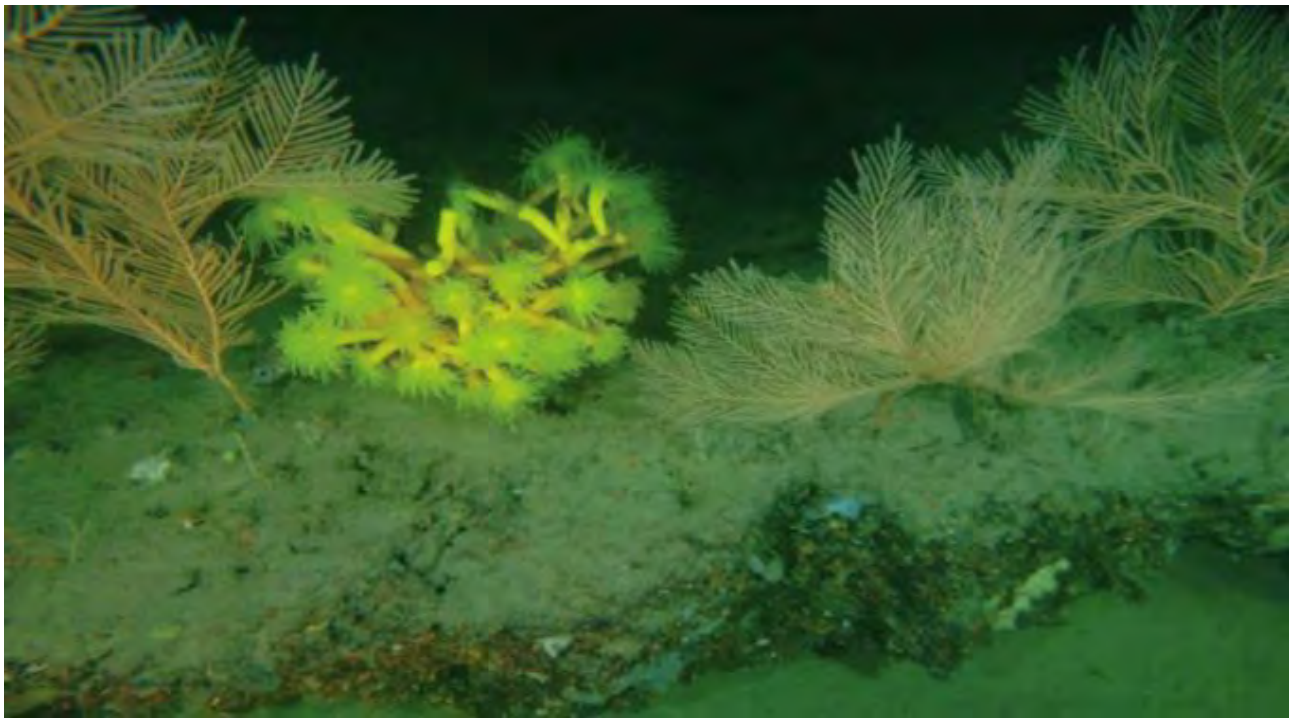


Figure 65: Facies of *Callogorgia verticillata* and *Viminella flagellum*

3.3 HUMAN ASSETS

3.3.1 Fishery

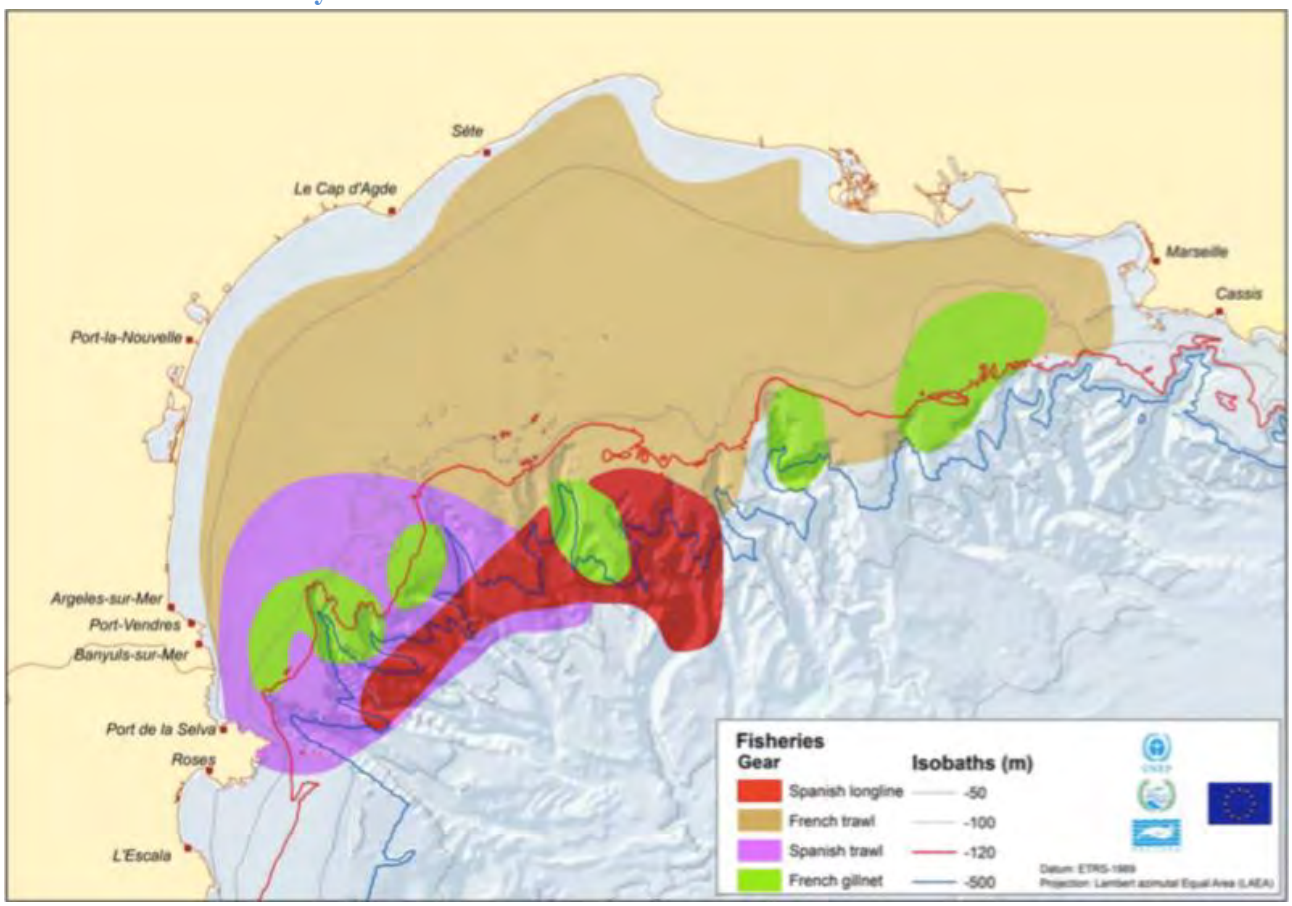


Figure 66: Fishery areas by gear (*Source: UNEP-MAP-RAC/SPA, 2013*)

The Gulf of Lions supports fisheries including bottom and pelagic trawls, purse seines, gill nets and longlines, and is also an important spawning area for many pelagic and demersal species. The demersal fisheries are multi-species and multi-gears fisheries. The marine living resources of the Gulf of Lions are a “shared stock”, both exploited by French and Spanish fishing boats. The main part of the fishing grounds exploited by these boats cover the entire continental shelf from the coastline to the 200 metres isobath, with an area of some 14 000 square kilometres covered by sedimentary deposits. This particular geomorphology has been conducive to the development of trawling there.

Off the French coasts, the Spanish fishing activity was confined at first in a restricted zone included between 6 and 12 miles, from the French-Spanish border up to Cap Leucate (the so called "zone of the border treaty" 1967-68). At the beginning of the 80s this activity extended offshore and to the east of the continental shelf.

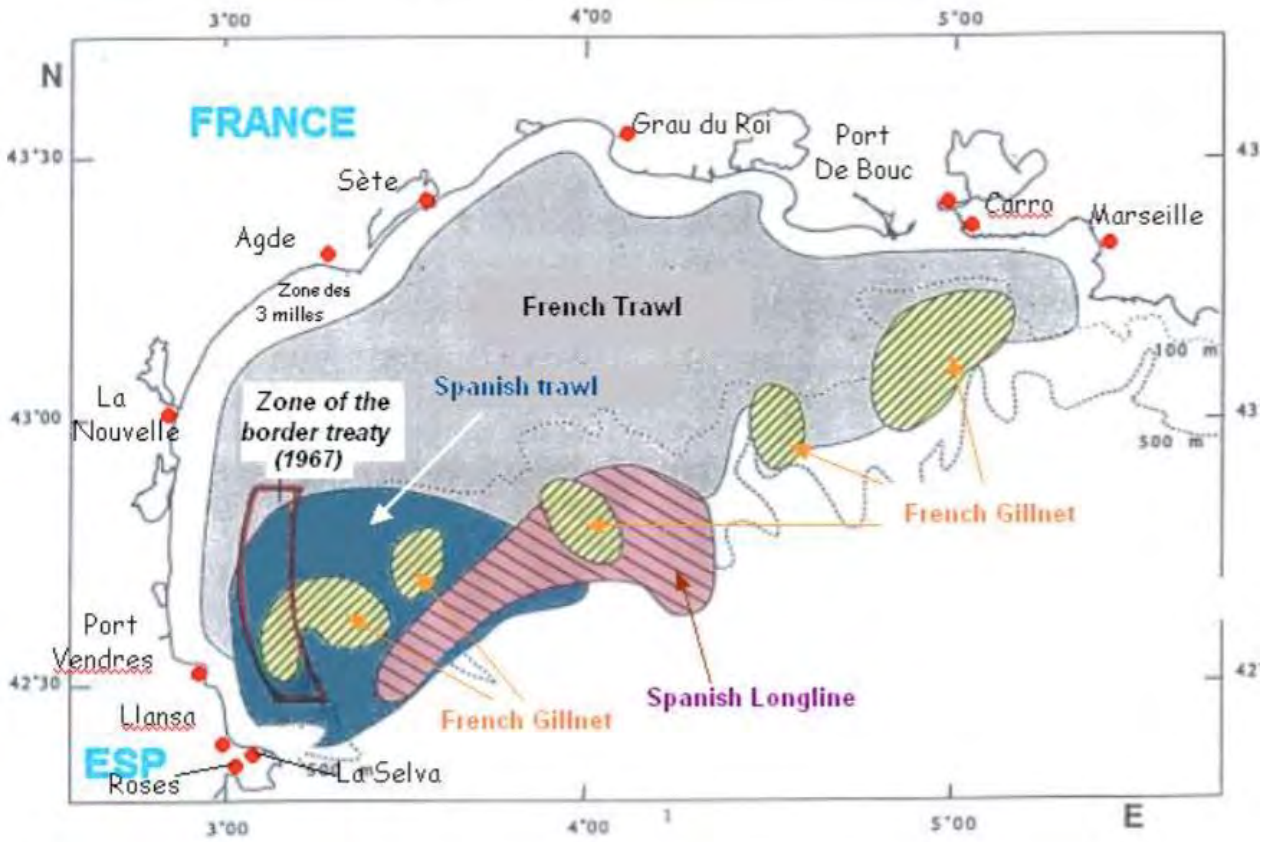


Figure 67: Fishing grounds by fleets nationalities (*Source: UNEP-MAP-RAC/SPA, 2013*)

The fishing Fleet

The boats exploiting the marine resources of the Gulf of Lions are mainly based in the French ports of Sète and Le Grau du Roi which group more than 60 % of the boats and insure about 70 % of the halieutic production of the Gulf of Lions and in the Spanish ports of Roses and Port de la Selva. In 2010, 220 boats were involved in the demersal fishery: 111 French bottom trawlers, 67 French gillnetters, 27 Spanish bottom trawlers and 15 Spanish long-liners (tab.1), while 14 French purse seiners and 6 Spanish ones where fishing small pelagics in 2007-2008. Both fleets are subject to the rules of the EC Common Fisheries Policy, concretely to the management framework established by Council Regulation No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea.

Table 13: Composition of the French-Spanish fleet in 2010

Country	Gear	Target sp	N° of boats	%
FR	Trawl	Demersal	111	50,45%
FR	Gillnet	Demersal	67	30,45%
SP	Trawl	Demersal	27	12,27%
SP	Longline	Demersal	15	6,82%

French trawlers are the main component of the fleet exploiting the marine resources of the Gulf of Lions. This fleet can be divided into two main components, one (around 50 boats) directed to the catch of small pelagic species (mainly anchovy Engraulis encrasicholus and sardine Sardina pilchardus), the other characterised by the exploitation of a great diversity of demersal species.

In 1998 the French fleet was composed of 140 trawlers of 2 types: approximately three quarters of these ships practiced only the bottom trawling catching various species (hake, red mullets, gurnards, angler fishes, lines), between 10 and 150 m of depth, during daily trips of about 12 to 15 hours. The remaining quarter has a mixed activity of bottom trawling and pelagic trawling targeting mainly the sardine and the anchovy on the whole continental shelf. During the last decade the number of French trawlers decreased until 90 units in 2010 with a total tonnage of 8900 GT and an overall power of 28000 KW. About half of these trawlers operate out of Sète.

In 2010 eleven small French purse seine boats with a total tonnage of 374 GT and an overall power of 2600 KW where still using the "lampara" technique (light attraction) to fish the anchovy. However, this fishing technique is in decline. Three quarters of the remaining seiners equipped with lampara nets operate out of Port-Vendres and the remainder operates out of Marseille

Small-scale fleet

The part of the fleet devoted to small-scale fisheries is defined by default as all fishing vessels except licensed trawlers and tuna and sardine vessels licensed to catch pelagic fish. Vessels that can catch pelagic fish with lampara nets are also excluded when they use those nets but are included when they pursue a different métier.

The small-scale boats operating in the Gulf of Lions are essentially French ones. They are split over 45 sites along the coastline of the Languedoc-Roussillon region. The fleet is very diversified and composed from boats of 3-4 m until units from 10 to 16 m. There are almost 50 different "métiers", among which most are very specific in certain sectors. The gillnets and the trammel nets are the most used gears, along with trolling lines, longlines and many other gears. About 60 % of the activities of the small-scale boats are operating in the shallow waters of the coastal zone, between 0 and 20 m depth. Some of the biggest boats also fish at depths of more than 100 m and even in the canyons of the continental slope, in particular the gillnetters targeting the hake.

In general, the small-scale fleet of the Gulf of Lions is declining as it decreased about two thirds during the last decades. However, this activity is still much to the fore, with 769 registered active entities and 81% of total manpower in 2008. A total of 171 boats where registered in Port- Vendres, 222 in Sète, 175 in Martigues and 201 in Marseille. In 2010 the small-scale fleet of the Languedoc-Rousillon was composed of 897 boats (table 14)

Table 14: Composition of the 2010 small-scale fleet of the Languedoc-Rousillon

Type	N° boats	ratio	total GT	total KW
Gill& Trammelnetters	669	74,58%	2 077,10	49 510,00
Lonliners	180	20,07%	247,3	8 499,00
Dredges	45	5,02%	116,2	3 143,00
Beach seines	2	0,22%	3,9	220
Liners	1	0,11%	40	316
Total	897		2484,5	61688

Type	N° boats	Ratio	Total GT	Total KW
Trawlers	90	89,11%	8 914,10	27 957,00
Purse seiners	11	10,89%	374	2 603,00
Total	101		9288,1	30560

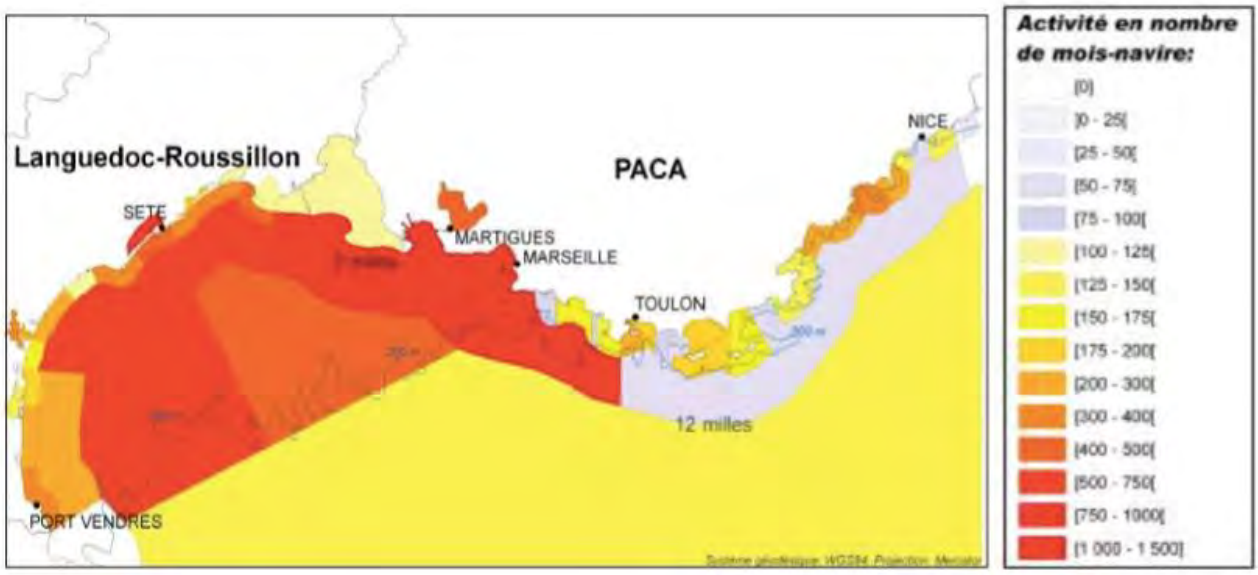


Figure 68: Average fishing effort (*Source: from UNEP-MAP-RAC/SPA, 2013*)

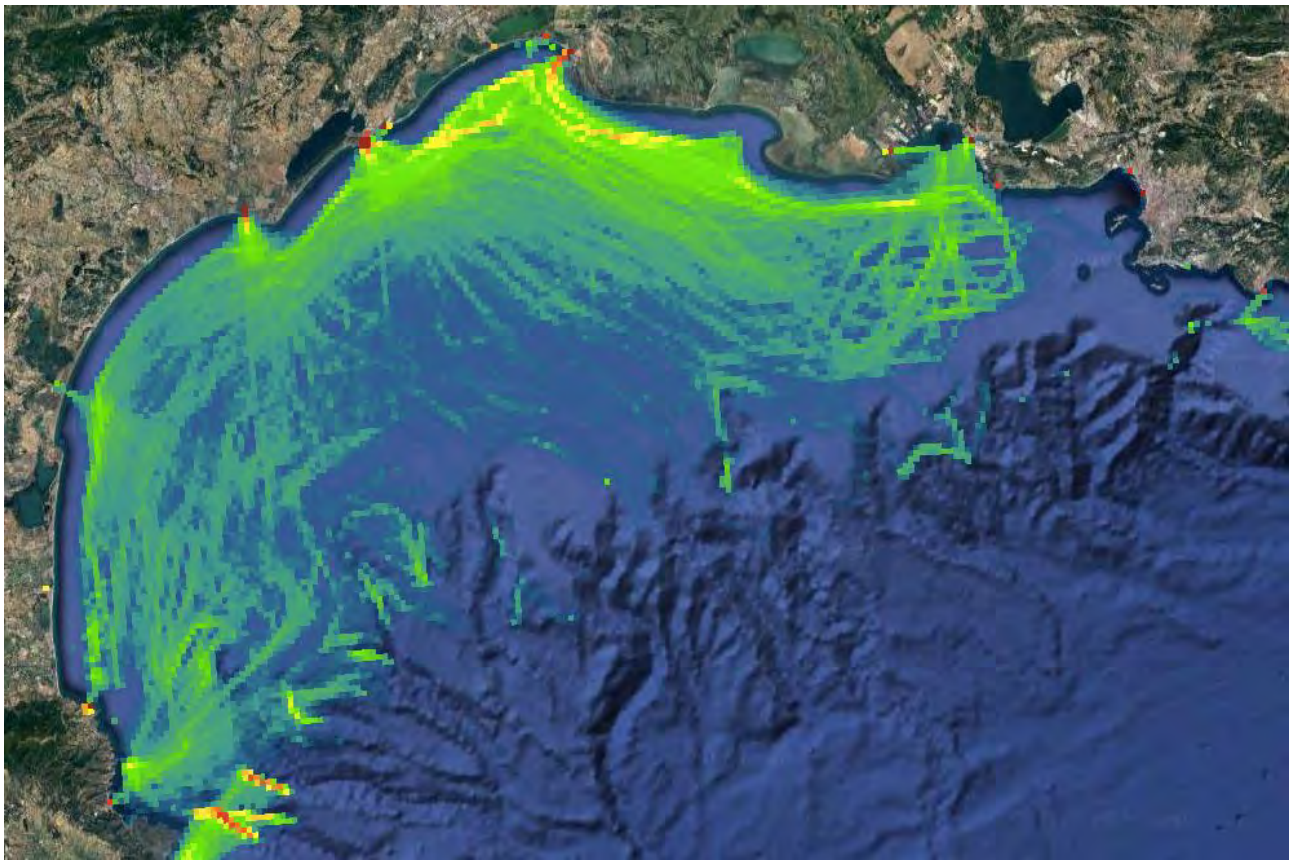


Figure 69: Fishing fleet tracks by AIS (*Source: EMODnet, www.emodnet.eu*)

Small pelagics stocks

Most of the small pelagic species are in general distributed close to the coast, over the continental platform. The majority of these species undertake rather well defined seasonal migrations, which explains the seasonal character of their fisheries. Sardine, anchovy, mackerel and horse mackerel move close to the coast during the summer months, which corresponds to the main fishing period of these species. During the winter they move away from the coast and shift to more or less deeper waters.

On the basis of the available data, most of the demersal stocks are either fully exploited, or overexploited. This conclusion has been first supported by global assessments (GFCM 1988) and more recently by single stock assessments using analytical models (VPA, cohort analysis). Indeed, most of the diagnoses available referring to single stocks has concluded to a high fishing pressure and at a status of full exploitation or overexploitation.

The available models can only lead to foretell a passage to a state of overfishing, in the best case, if the general tendency to a growing effort of the various segments of the fleet was carried on according to the pattern prevailing during the recent past. A decreasing trend in the catches per unit of effort of the trawlers can be observed; furthermore, in most of the cases a situation of "growth overfishing" leading to low average ages in the stocks is confirmed in an evident way by the observation of a decreasing trend in individual lengths of fishes in the landings. In general, the

juveniles are under the most important fishing pressure. This situation results essentially from the fact that the sizes at first catch are very often similar to those at which fishes appear in the fisheries (recruitment) in particular on the continental shelf where the trawling activity is the most intensive. However, the concerned stocks do not seem threatened by a "recruitment overfishing" which could affect their capacity to be renewed at the current levels.

The artisanal fleets affect more the adult population, even though there is some degree of overlap.

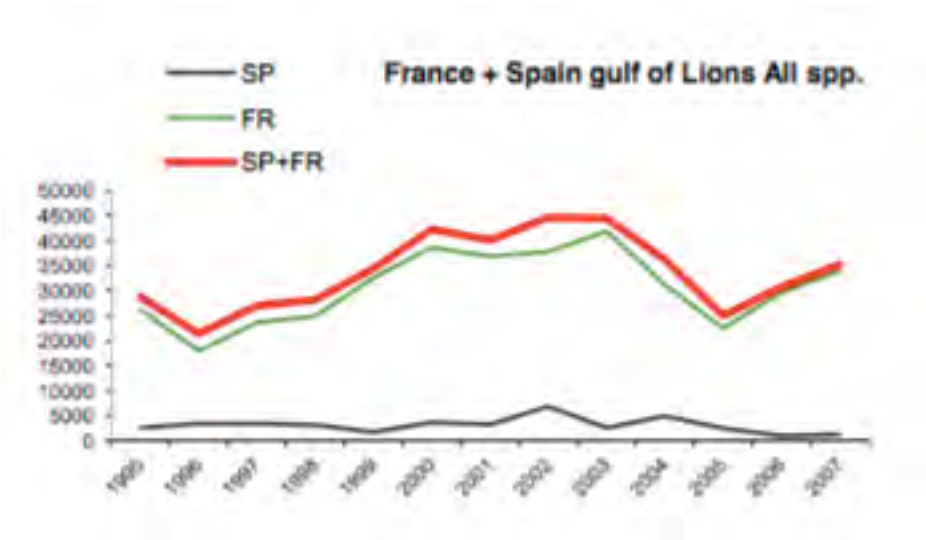


Figure 70: Landings of demersal and small pelagic from 1995 to 2007 (*Source: UNEP-MAP-RAC/SPA, 2013*)

Economic elements

In 2008, 19 % of the revenue of the bottom trawlers fleet resulted from landings of hake. The rest of the turnover resulted mainly from captures of octopuses (11 %), and from sea bass (8 %), squids (7 %) sole (6 %), sea bream (5 %) other species (44 %). Regarding the pelagic trawlers, this fleet depended mainly on the anchovy (44 % of the revenue) and of the sardine (31 %) while10 % of their revenue resulted from landings of hake.

The revenue of the French gillnetters operating offshore (> 3 miles) in 2008 were composed of hake (10 %), sea breams (7 %), bonitos (7 %), scorpion fishes, congers (5 %) and miscellaneous (71 %). For the gillnetters operating in the coastal zone (<3 miles) 38 % of the revenue came from hake. The rest resulted mainly from gilthead sea bream (11 % of captures in weight), of sea bream (6 %), sole (6 %), horse mackerel (5 %), mackerel (7%) and other species (27%).

The yearly landings of Hake by the French-Spanish fishery of the Gulf of Lions have fluctuated between 1300 to 3800 tons following however an overall 20% decreasing trend during the period. As indicated before the overall fishing capacity of the trawlers fleet has shown in these last 10 years a progressive decrease; the number of French trawlers decreased of about 30% on the period. Most

of the catches (70%) correspond to French trawlers with an average size of 20 cm, followed by French gillnetters (15%, average size 39 cm), Spanish trawlers (8%, average size 25 cm), and Spanish long-liners (7%, respectively, average size 54 cm).

Small pelagic species

Before 1960, the landings of small pelagic species by the French fleet were of the order of 2000 tons / year. This production which consisted in 90 % of sardines (fished almost at night with "lampara" nets) increased then quickly up to around 20000 and remained at this level during about twenty years, with some interannual fluctuations.

From 1973 took place a progressive replacement of the lampara purse seiners by trawlers using big vertical opening nets. From 1987 the production of anchovy increased regularly during ten years; indeed, the cumulated French-Spanish fishing effort practically doubled during this period as a result of the arrival in the Gulf of Lions of a group of 80 Spanish boats from Catalonia, from the province of Murcia, Andalusia and the region of Valencia. This fleet left the area after some years and since 1997 the production of anchovy and sardine of the Gulf of Lions followed a decreasing trend as a result of the size of the fleet and the biomasses of the stocks.

Discards and Waste Accumulation

There is no reliable quantitative information on the nature and quantities of discarded animals by the trawlers operating in the Gulf of Lions. However, some field observations are on progress in the frame of the achievement of the data collection framework of the EU the scientists participating to this sampling on board the professional fishing boats indicate that the discards of non-commercial species or undersized fishes by the trawlers are very low in the area. The artisanal fishery does not produce significant discards due to the higher selectivity of their gears.

The discharge of offshore waste can have more important ecological consequences: mortality of plants or animals by constrictions or drowning captures in the lost nets ("ghost fishing"), physical damage by ingestion, liberation of associated chemicals and alteration of certain benthic communities.

The distribution and abundance of large marine debris have been investigated on the continental slope and bathyal plain of the northwestern Mediterranean Sea during 3 oceanographic cruises undertaken in June 1994, July 1995 and April 1996, different types of debris were enumerated, particularly pieces of plastic, plastic and glass bottles, metallic objects, glass and diverse materials including fishing gear. The results showed considerable geographical variation, with concentrations ranging from 0 to 78 pieces of debris/ha most stations sampled, plastic bags accounted for a very high percentage (more than 70%) of total debris. In the Gulf of Lions, only small amounts of debris were collected on the continental shelf. Most of the debris was found in canyons descending from the continental slope and in the bathyal plain, with high amounts occurring to a depth of more than 500 m. Sixteen dives were conducted in canyons off Marseille and Nice (France) ranging from 40 to 1448 m in depth.

For a total continental shelf area of 12000 km^2 (from 0 to 200 m in depth), the data collected allowed an estimation of 1.188 million pieces of debris, 77% of which were plastics, including 92.8% bags. For 1995, the estimated amount of debris for the Gulf of Lions was 1.334 x 10 e^6. The 1994 and 1995 cruises yielded estimated total amounts of 26.84 t (1994) and 30.16 t (1995) of plastics on the continental shelf of the entire gulf. In comparison with the total quantity collected in the entire continental shelf from the northwestern Mediterranean Sea, these amounts were very low. However, these results concern only those areas in which trawling operations could be carried out.

The average abundance of the waste in the Gulf of Lions can be compared with the values of abundance for certain demersal species: these quantities of waste exceed the biomass of certain species. On the other hand, the evolution of the quantities of waste in time in the Gulf of Lions shows a significant decreasing trend.

Regulations, Management

The Mediterranean French and Spanish fisheries are managed through licensing systems and they are subordinated to a large number of specific technical measures: characteristics and conditions of use of the fishing gears, minimum legal sizes of the species, fishing seasons and sectors. These regulations are more or less respected. Besides, the European Union adopted recently a regulation concerning the harmonization of the technical measures applicable to all the EU Mediterranean fleets.

French Management measures for trawlers and purse seiners

To control the fishing effort the French Administration established in 1988 the "Permis de Mise en Exploitation" (PME). It is delivered by the Direction des Pêches Maritimes et de l'Aquaculture (DPMA) for the ships of more than 25 meters and by the Direction Inter Départementale des Affaires Maritimes for those of less than 25 meters.

The licensing system limit the number of ships authorized to fish. For the trawlers these licenses are managed at the national level by the DPMA. The same license allows practising the pelagic trawling and the demersal trawling. For the purse seiners targeting the small pelagics the licenses of the ships of more than 24m are managed at the national level by the DPMA. The licenses for the smaller purse seiners are managed at the regional Fisheries Committees level.

Technical measures:

- Trawl net with 4 panels: netting with 20 mm rhombohedric mesh size. Operate beyond the 3 nautical miles coastal area, between surface and bottom and target mainly the sardine and the anchovy, with secondary catches of other pelagic and demersal species (mackerels, hake etc.).
- Bottom trawl net: two panels of opening. Netting with 50 mm rhombohedric mesh size. Target the demersal species and capture additionally small pelagics. Trawling is prohibited at less than 3 nautical miles from the coastline.

Trawling operated by two boats dragging one single net ("chalutage en boeuf") prohibited.

- Duration of the fishing restricted to the period from 3 am to 7 pm. Fishing operation prohibited on Saturdays and Sundays (except for the lampara purse seiners that have a very short fishing season). No fishing during some particular holidays.
- Number of fishing days limited at 250 days/year
- Engine power of the trawlers limited to 316 kW, overall boat length limited to 25m.
- Trawling prohibited at depth greater than 1000m
- Purse seine for small pelagics: night fishing with attracting lights ("lampara"), or fishing during the day using echo sounders. 500 to 800 m nets with 14mm meshsize. Target mainly the sardine.
- Minimum legal sizes for the main commercial species.

3.3.2 Aquaculture

French marine aquaculture is mainly based on two sectors: shellfish farming and fish farming, representing respectively 153.200 and 5.700 tonnes per year in 2010 (source: France Agrimer 2013).

Shellfish farming in France, the largest producer in Europe, represents around 10,000 jobs for about 3,000 farms. The majority of production concerns oysters (around 100 000 tonnes in 2009) and mussels (around 83 000 tonnes in 2009). Shrimp farming and seaweed farming activities are also developing in the diversification of shellfish production, but they remain confidential.

French marine fish farming concerns 35 companies for about 600 jobs. It is essentially based around two sectors: the hatchery with more than 70 million fry of which 72% are exported, and the fattening, mainly of seabass (*Dicentrarchus Labrax*), sea bream (*Sparus aurata*), turbot (*Scophthalmus maximus*) Salmon (*Salmo Salar*) and Meagre (*Argyrosomus regius*). This activity, which started in the early 1980s, has struggled to develop given the unfavorable regulatory and political context (conflicts with tourism, in particular). Regulatory constraints on access to sites and competition from other producing countries (Greece, Turkey, etc.) are holding back the expansion of the sector.

State of market on the French Mediterranean coast and in Provence-Alpes-Côte d'Azur

In 2009, the shellfish farming enterprises of the Mediterranean coast represented, compared to the national level:

4 12% of the sales volume of shellfish for consumption (7% for oysters, 19% for mussels and 5% for other shellfish);
5 8% of the value of sales (4%, 16% and 9%);
6 15% of companies and 12% of shellfish jobs.

These shellfish farming activities are mainly concentrated in the department of Hérault (88% of jobs), where oyster farming is practiced mainly in coastal ponds. The mussel industry is more diversified geographically and is divided between lagoon and open sea production. The number of jobs in the sector is trending downwards over the period 2002-2009 (-12%). Despite this trend, sales for shellfish consumption increased, a result of lower oyster sales (-25%) and a rise in mussel sales (+ 36%).

The Provence-Alpes-Côte-d'Azur region has two active shellfish production sites: Carteau Bay in the Bouches du Rhône (mussels) and Toulon Bay (Lazaret and Balaguier) in the Var (mussels and oysters). These sites, operated by around 60 professionals, produce approximately 3,000 to 4,000 tonnes of mussels per year.

With regard to fish farming, 20 companies were surveyed in 2009 on the Mediterranean coast, for 204 full-time equivalent jobs (FTEs) representing 35% of national jobs. The share of Mediterranean coastal companies in the metropolitan turnover of marine fish farming amounts to 37%. In the Mediterranean, as in the Channel-North Sea, fish production is mainly geared towards growth, while on the Atlantic coast, hatchery activity dominates. Production, mainly of seabass, seabreams and meagre, is about 2,500 tonnes / year.

Aquaculture farms in the Mediterranean Sea are characterized by a low footprint (less than three or four hectares per site) and by methods of enhancing the quality of products (Red label, Organic Agriculture certification, etc.).

The Provence-Alpes-Côte-d'Azur region has twelve active fish production sites, mainly for sea bass and sea bream. These sites are concentrated in six geographical sectors: the island of Frioul in the Bouches du Rhône, the bay of Lazaret in the Var, the tip of the Aiguille, Cannes, Cap d'Antibes and Cagnes-sur-Mer in the Alps Maritimes.

These sites represent about 150 jobs and an annual production of 1,500 tonnes of sea bass and sea bream, which makes Provence-Alpes-Côte d'Azur the first French region for open sea fish farming.

If it does not create mass jobs, this activity uses a qualified workforce, even highly qualified, because of the technical nature of the sector but also the qualitative bias that ensures the competitive advantage of regional productions. It uses high-level partnerships to maintain and improve farming processes and the quality of production by controlling environmental impacts.

Professionals, however, report significant obstacles to the development of aquaculture. Among these, the lack of facilities on land (pontoons, buildings, parking areas) to the right of their facilities at sea complicates the operating methods of the farms, both in terms of working conditions, cage maintenance and materials, storage of inputs but also securing sites. It severely limits the creation of new activities that create jobs and added value.

A general map at the scale of the region allows visualizing existing aquaculture sites along the coast. Existing shellfish aquaculture sites are represented by a red perimeter that reproduces the regulatory influence of the farms authorized for marine crops. For legibility reasons, existing fish sites are represented by a blue dot whose size does not reflect the real influence on the ground. Indeed, the surface of certain sites not exceeding the hectare, it is not possible to make them visible while respecting the real perimeter. Apart from the land-based sites in Saint-Mandrier-sur-Mer, for rearing fish, and on Île des Embiez for a hatchery of seahorses and sea urchins, the exploitation sites are all located at sea. They are associated with onshore logistics sites, which are essential for production and marketing. For technical reasons, it was not possible to display all of these logistics sites.

Table 15: Aquaculture sites in PACA

Sites	Communal	Production
1	Saint-Chamas	Freshwater fish (but possibility of marine species production)
2	Marseille (Îles du Frioul)	Seabream, Seabass
3	Six Fours les plages	Multipurpose experimental hatchery (seahorses, sea urchins
4	La Seyne-sur-Mer	Seabream, Seabass
5	La Seyne-sur-Mer	Seabream, Seabass
6	La Seyne-sur-Mer	Seabream, Seabass
7	Saint Mandrier su mer	Seabream, Seabass
8	Saint Mandrier su mer (à terre)	Nursery (concession awarded but not yet exploited)
9	Théoule-sur-Mer	Seabream, Seabass, Meagre (concession awarded but actually not yet exploited)
10	Théoule-sur-Mer	Seabream, Seabass, Meagre
11	Cannes	Seabream, Seabass, Meagre
12	Cannes	Seabream, Seabass, Meagre
13	Antibes	Seabream, Seabass, Meagre
14	Antibes	Seabream, Seabass, Meagre
15	Cagnes-sur-Mer	Seabream, Seabass, Meagre
16	Cagnes-sur-Mer	Seabream, Seabass, Meagre
A	Port-St Louis du Rhône	Mussels and oysters
B	La Seyne-sur-Mer	Mussels and oysters
C	La Seyne-sur-Mer	Mussels and oysters
D	La Seyne-sur-Mer	Mussels and oysters

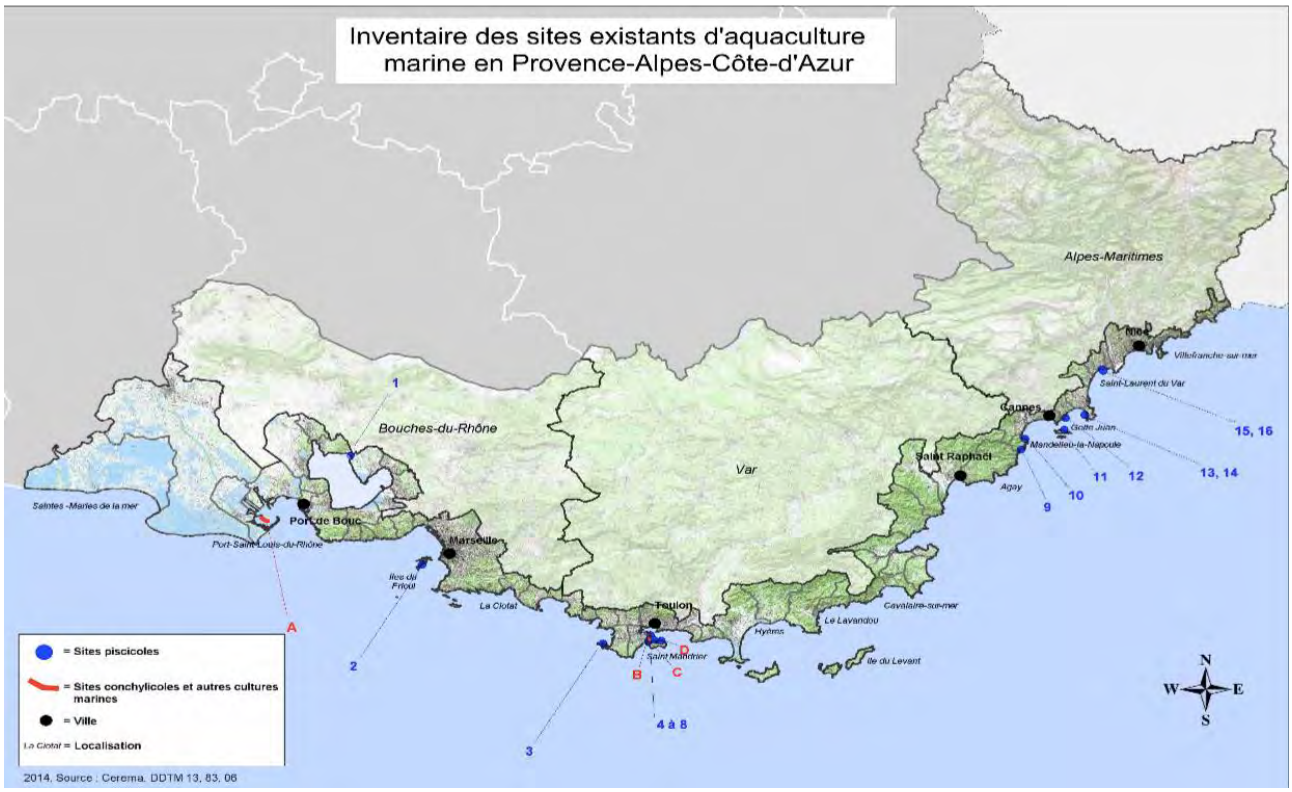


Figure 71: Existing marine aquaculture sites in PACA ***(Source: Schéma régional de développement de l'aquaculture marine Provence-Alpes-Côte d'Azur, 2015)***

<u>State of aquaculture on the French Mediterranean coast and Languedoc-Roussillon</u>

The Languedoc-Roussillon region has seven active shellfish production sites: the Leucate pond, the Gruissan salt pans, at sea off Gruissan and off Fleury d'Aude in the department of Aude; at sea off Marseillan and off the Aresquiers and the Etang de Thau in the department of Hérault. The latter site, by its area (7,500 hectares), is the first lagoon of the region in area. Since the beginning of the 20th century, it has been home to the first experiences of growing and growing oysters. Due to this anteriority and its own qualities, the Thau lagoon has become the most important shellfish growing area of the French Mediterranean. Today, about 11% of the hollow oysters produced in France are derived from it.

The total shellfish production in Languedoc-Roussillon represents around 500 companies and 1,500 jobs.

With regard to fish farming, 20 companies were surveyed in 2009 on the Mediterranean coast, for 204 full-time equivalent jobs (FTEs) representing 35% of national jobs. The share of Mediterranean coastal companies in the metropolitan turnover of marine fish farming amounts to 37%.

The Languedoc-Roussillon region has several sites on land and pond, in the departments of the Pyrénées Orientales (commune of Salses-le Château) and Hérault (municipalities of Mèze and Balaruc-les Bains). The companies concerned have specialized in hatchery and pre-growth of different marine species, with a view to selling the production to operators of farms growing at sea.

Table 16: Languedoc-Roussillon region aquaculture sites species production

Sites	Communal	Production
1	Salses le Château	Seabass
2	Salses le Château	Seabream, Seabass, Meagre
3	Port-la Nouvelle	Eels
4	Balaruc-les-Bains	Seabream, Seabass, Meagre (prefattening)
5	Balaruc-les-Bains	Seabream, Seabass, Meagre (prefattening)
6	Balaruc-les-Bains	Seabream, Seabass, Meagre (hatchery, prefattening)
A	Leucate (étang de Salses-Leucate)	Oysters
B	Leucate (Grau de Leucate)	Hatchery of oysters and shrimps
C	Gruissan (salin de l'Île St Martin)	Oysters, R&D seaweed culture, shrimp suppliers in experimentation
D	Gruissan (sea)	Mussels and oysters
E	Fleury d'Aude (sea)	Oysters
F	Vendres	seashell work products on dies at sea ?????
G	Agde/Marseillan (sea)	Mussels
H	Marseillan/Sète (sea)	Mussels
I	Sète (Sea)	Mussels
J	Marseillan	Oysters hatchery
K	Marseillan (étang de Thau)	Mussels and oysters
L	Mèze/Marseillan (étang de Thau)	Mussels and oysters
M	Mèze	Microalgae
N	Bouzigues (étang de Thau)	Mussels and oysters
O	Frontignan	hollow oysters, hatchery and shell nursery
P	Villeneuve les Maguelone (sea "Aresquiers")	Mussels
Q	Palavas les Flots (étang du Prévost)	Mussels and oysters

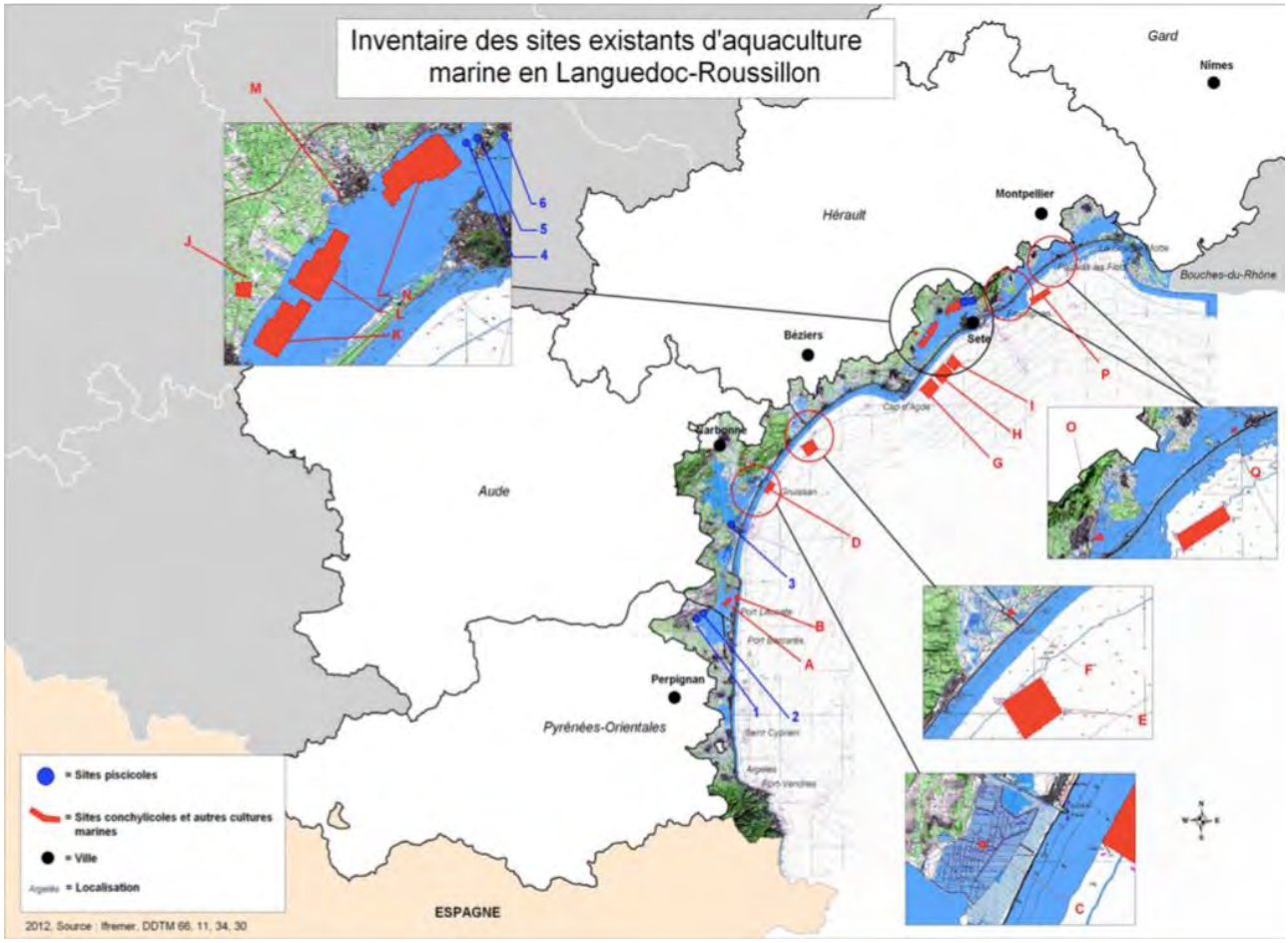


Figure 72: Existing marine aquaculture sites in Languedoc-Roussillon region ***(Source: Schéma régional de développement de l'aquaculture marine Languedoc-Roussillon, 2015)***

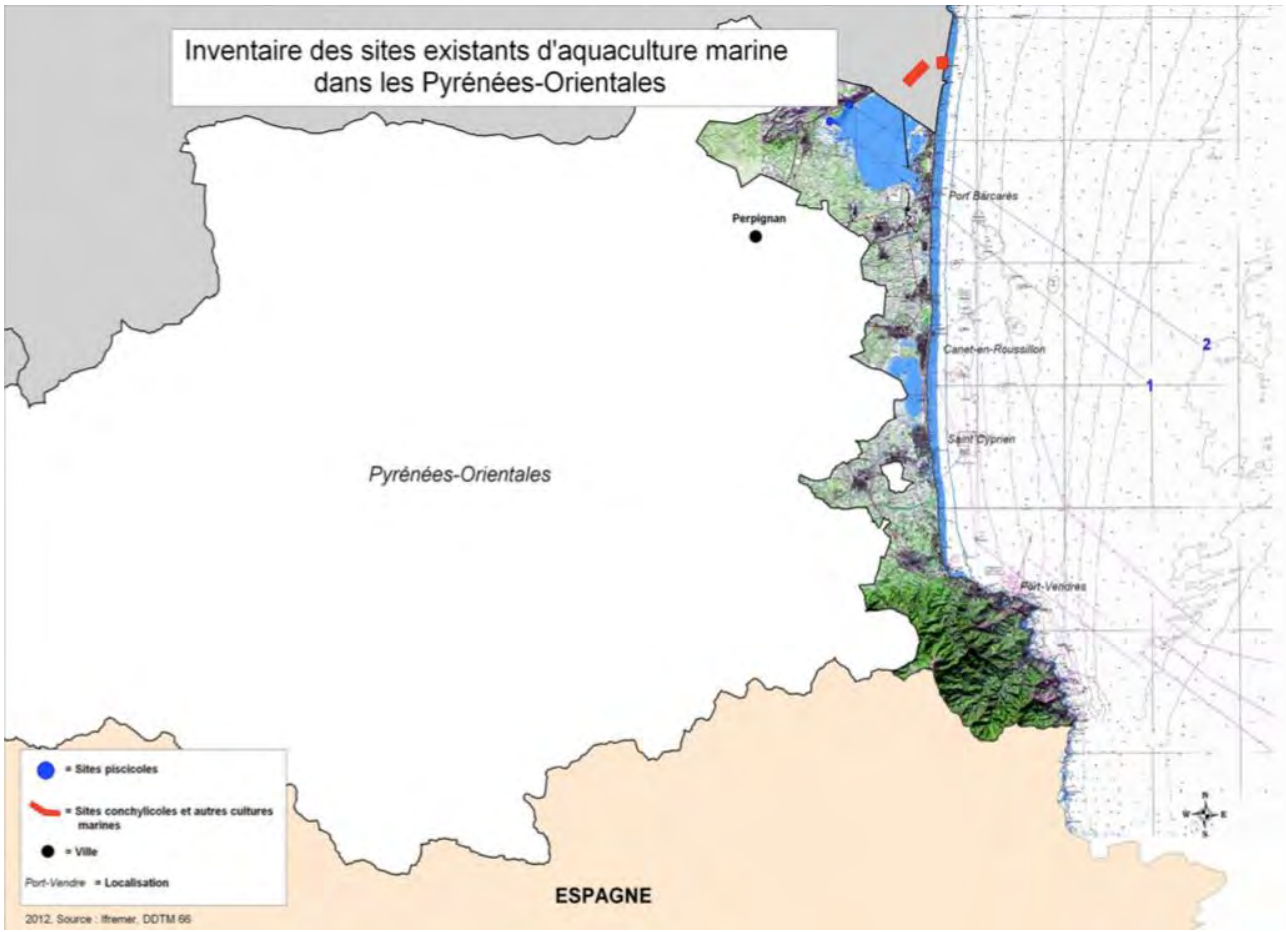


Figure 73: Existing marine aquaculture sites in the Eastern Pyrenees ***(Source: Schéma régional de développement de l'aquaculture marine Eastern Pyrenees, 2015)***

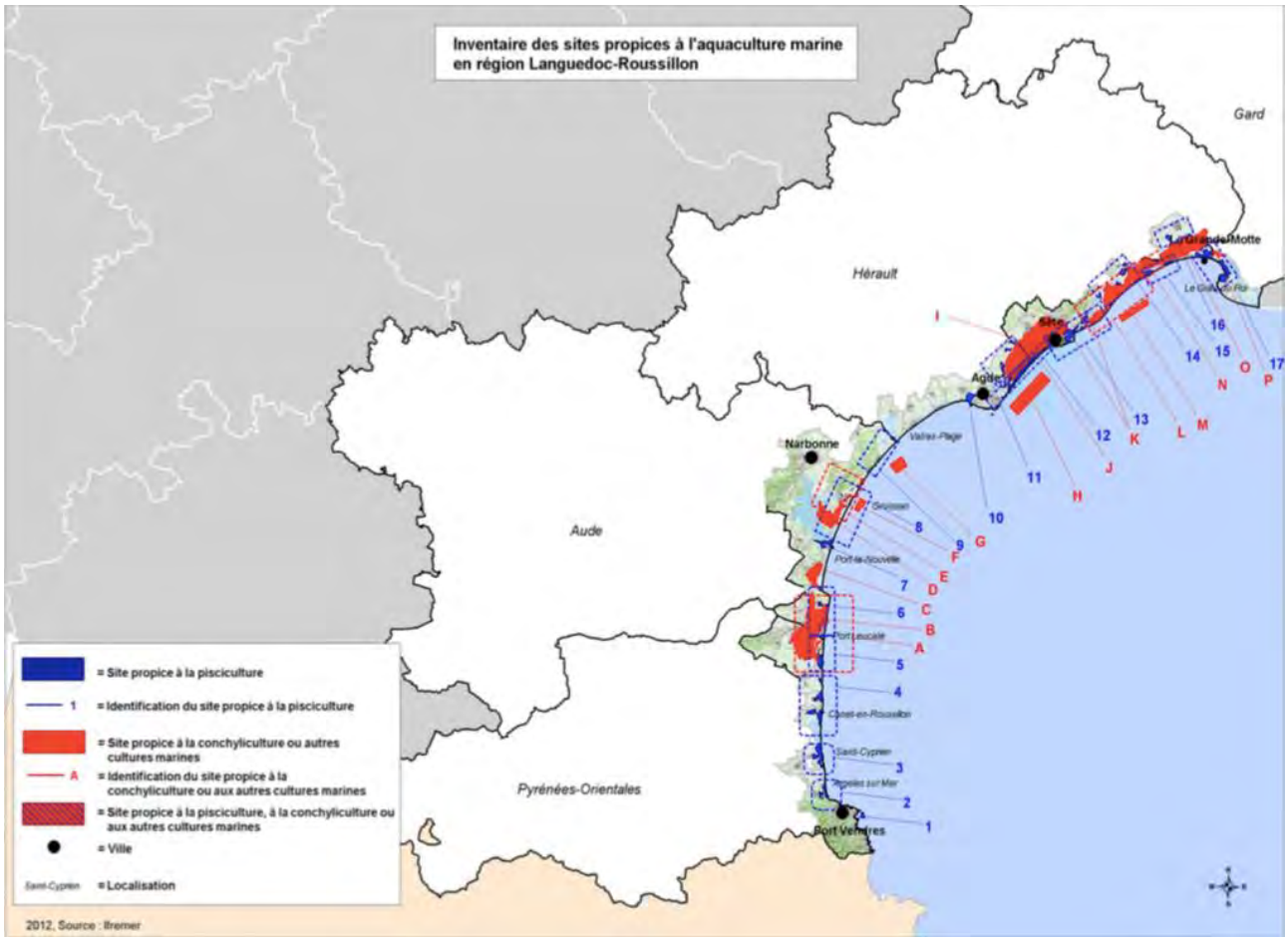


Figure 74: Propitious marine aquaculture sites in the Eastern Pyrenees ***(Source: Schéma régional de développement de l'aquaculture marine Eastern Pyrenees, 2015)***

3.3.3 Oil and Gas

The Southeast Basin is the thickest onshore French sedimentary basin where up to 10 km of Mesozoic-Cenozoic sediments can locally be found. This basin is surrounded to the east and to the south by two segments of the Alpine Thrust Belt, the Western Alps and the Pyrenees-Provence respectively, and to the west by recently uplifted elements of the Palaeozoic Basement (Massif Central). The development of the basin was related to several stages of subsidence between late Carboniferous and late Cretaceous times. Partial tectonic inversion took place during two Alpine compressive events in early Tertiary and late Tertiary times. They were separated by an intervening stretching event of Oligocene age which further south led to the opening of the western Mediterranean oceanic basin in Burdigalian times and, as a result, to the formation of the Gulf of Lion passive continental margin. In Neogene times the Palaeozoic basement of the Massif Central was uplifted to approximately 2000 m as the result of an ascending athenospheric plume.

The Provence Basin is in that portion of the western Mediterranean Sea that is deeper than 2 kilometers. The basin lies essentially beyond the outer continental shelf, between the countries of France, Italy, and Algeria, the Balearic Islands, and the islands of Sardinia and Corsica. It

encompasses nearly 300,000 square kilometers and includes the Rhone River submarine fan on the continental slope of southern France.

A single, hypothetical, total petroleum system (TPS), the Pre-Messinian TPS, was described for the Provence Basin. The designation hypothetical is used because there is no hydrocarbon production from the basin. The Provence Basin is a deep-water Tertiary rift basin in which the geothermal gradients vary regionally. The Red Sea Basin shares a similar geologic and thermal history with the rifted western Mediterranean Sea and was used as an analog to better understand the genesis of the Provence Basin and as a guide to estimating possible undiscovered amounts of hydrocarbons.

For this assessment the basin was given a potential, at the mean, for undiscovered resources of 1.4 trillion cubic meters gas, 0.42 billion barrels oil, and 2.23 million barrels natural gas liquids.

The Provence Basin is a Tertiary rift basin located entirely offshore in the western Mediterranean. Although the deep basin is a flat sea floor, it includes the Rhone River submarine fan deposited onto and beyond the continental slope off southern France. The central part of the basin is believed to contain a 3-4 km thickness of pre-Messinian age turbidite and pelagic sediments overlain by a 1-2 km thick sequence of Messinian (uppermost Miocene) evaporites. A Pliocene and Pleistocene pelagic sediment and turbidite cover is estimated to add another 1-2 km in thickness. No data exist on drilling, production, or oil chemistry that would support the existence or even the possibility of hydrocarbon generation by source rocks. However, all other essential geologic elements of reservoir, seal, and overburden rocks that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum in a petroleum system are believed to exist.

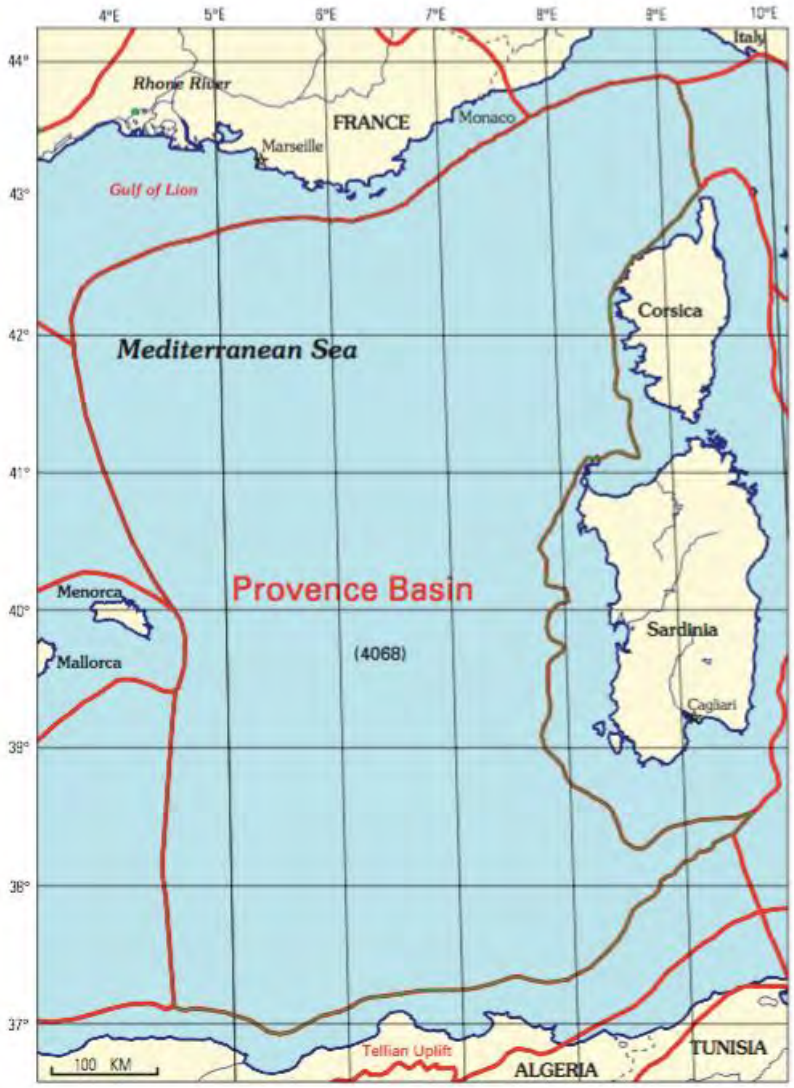


Figure 75: The Oil/Gas provinces ***(Source: Pawlewicz, 2004)***

A TPS was defined for this location using a geologic analog, and hydrocarbon resources were assigned based on that analog. That precise lithology and thickness of the subsalt sediments are unknown necessitated, in the assessment process, use of a high-risk factor for hydrocarbon charge, to limit the confidence of finding any hydrocarbons. The basin is considered to be a potential gas province with limited oil prospects. The Red Sea Basin shares a number of geologic similarities with the Provence Basin. Both are products of tectonic activity in the Oligocene to Miocene, both are rift basins with attenuated continental crusts, and both have poorly understood variable heat flow from the basement. The two basins have extensive evaporite deposits and salt domes. The differences are also significant: the Red Sea Basin is a proven oil and gas producer, whereas the Provence Basin presently has no production. Much remains to be learned about the Provence Basin.

The TPS boundary coincides with the province boundary. It is drawn on or near the base of the continental slopes of France, Algeria, Corsica, Sardinia, and the Balearic Islands. The Rhone River submarine fan, which covers the continental slope offshore southern France, is included. The

southwestern portion of the western Mediterranean between Africa and the Balearic Islands is not included.

The deep Provence Basin (>2.5 km) has not been explored for petroleum because current technology limits deep-sea exploration to about 2 km water depth. The shelf area of the Gulf of Lion has been drilled with limited success, with some production ongoing in the near offshore.

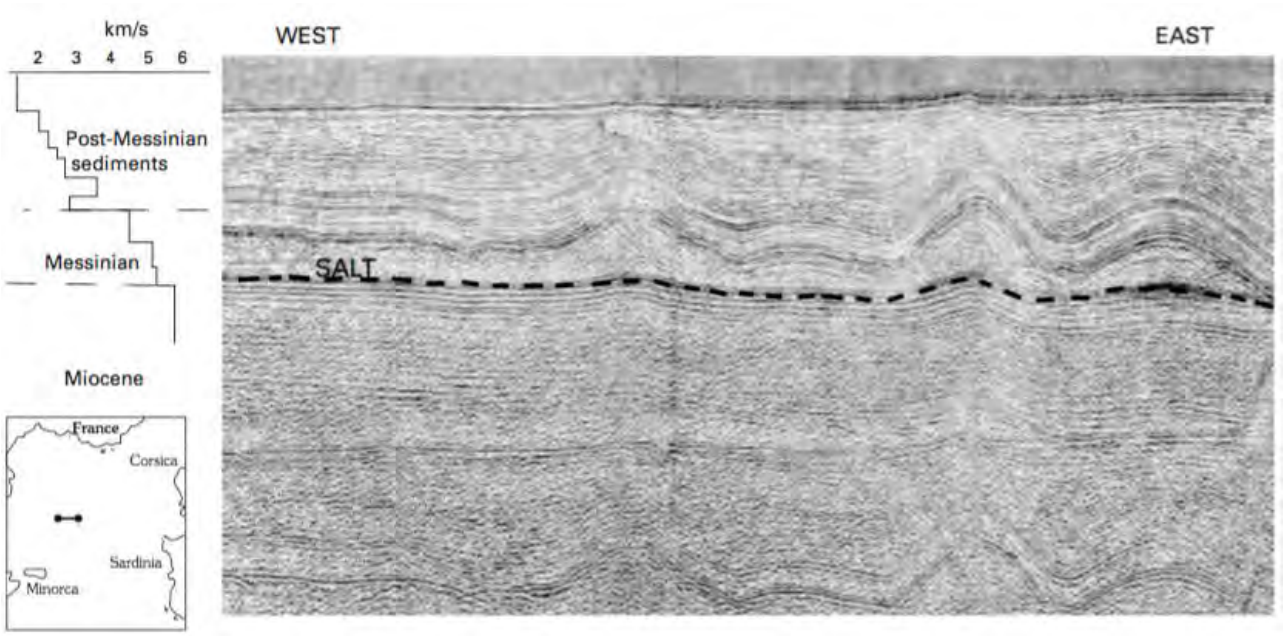


Figure 76: Stratigraphic section of the Provence Basin *(Source: Pawlewicz, 2004)*

For the World Energy 2000 Assessment, the Provence Basin was assessed as one hypothetical TPS, the Pre-Messinian (406801), with one assessment unit, the Subsalt AU (40680101). The presence of hydrocarbons is speculative. Within the TPS no hydrocarbons have been located. Seeps are not known.

The entire pre-Messinian stratigraphic section is expected to contribute to the eventual production of gas and oil. The block-faulted region above and including the basement should be the most favorable location in the basin for gas. All of the pre-Messinian subsalt section is possibly within the maturation window for gas. Because of the different geothermal gradients involved, disparities in generation on both local and subregional scales may exist, such that mature source rock may be localized as separate pods. The distribution, quantity, and quality of the organic matter in the sediments will also have a significant effect on any generation and type of hydrocarbon product. It is possible that biogenic gas will make up a portion of the anticipated hydrocarbons from this province.

Salt diapirs are present at the bottom of the Rhone River submarine fan slope and along the west side of the province boundary. Such structures are well known to be excellent hydrocarbon traps. Beneath the evaporite layer, the conditions to generate and trap hydrocarbons could exist within any part of the stratigraphic column.

Organic-rich sediments have been described from several locations in the Mediterranean. Some authors have described sapropels, or organic-rich muds, from the eastern Mediterranean. Sapropel:

"a discrete layer greater than 1 cm in thickness, set in open marine pelagic sediments and containing greater than 2.0 percent organic carbon by weight". Sapropels are thought to be deposited under euxinic bottom conditions corresponding to stagnant phases of a basin. Although sapropels have not been found in the western Provence Basin, sampling has yet to penetrate the thick Mes- sinian evaporites.

Sediment accumulation is generally facilitated by proximity to sources, and thicker, richer source rocks are often deposited closer to the continental slope. At the basin center, farther from a sediment source, the rocks would most likely be fine-grained pelagic deposits, although turbidites can reach long distances onto the abyssal plain.

Source rocks for the Provence Basin could be any or all of the following: turbidite sequences, pelagic sediments, or carbonate rocks. Of these rock/facies types, turbidites seem to offer the best source rock possibilities. Pelagic sediments are not known to be prolific oil and gas generators; their potential in the Provence Basin remains to be established. Carbonate rocks can be good source rocks, but their potential is highly variable.

A large oil seep near the city of Gabian has been exploited since the beginning of the seventeenth century. Most of the exploration undertaken from 1945 (onshore) and 1965 (offshore) to the present time has, however, been disappointing as no significant oil or gas accumulations have been discovered, despite drilling of about 150 wells.

Presently a number of closed boreholes are distributed over the entire Gulf, at relevant distance from the BGF site.

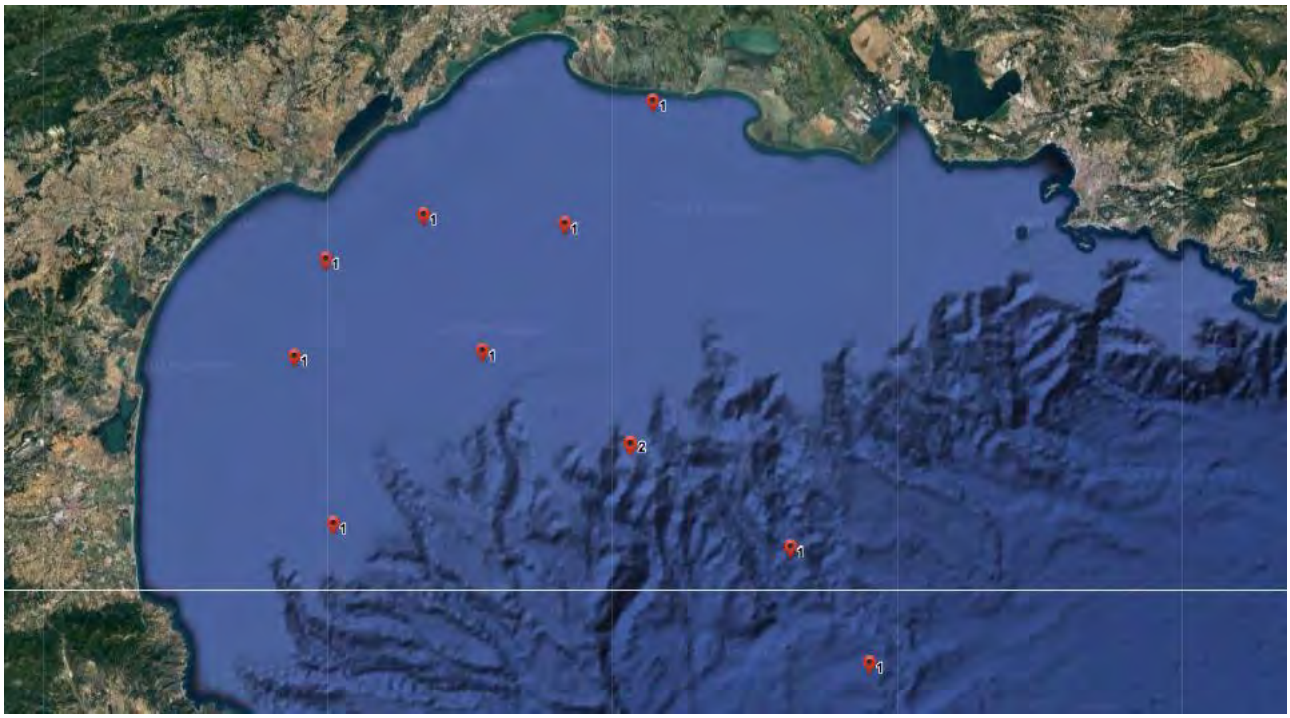


Figure 77: Closed boreholes in the Gulf of Lions area (*Source: EMODnet, www.emodnet.eu*)

A number of six offshore areas open to hydrocarbon exploration have been individuated in Gulf south-west offshore. No licence for exploitation has already been delivered.

Figure 78: Exploration blocks in french offshore (*Source: EMODnet, www.emodnet.eu*)

The French parliament has recently begun, in 2017, a legislative path to forbid the exploration and exploitation of hydrocarbon resources within its territories, included sea and overseas territories. Consequently, the currently valid permissions cannot be renewed over the 2040.

3.3.4 Wind farms

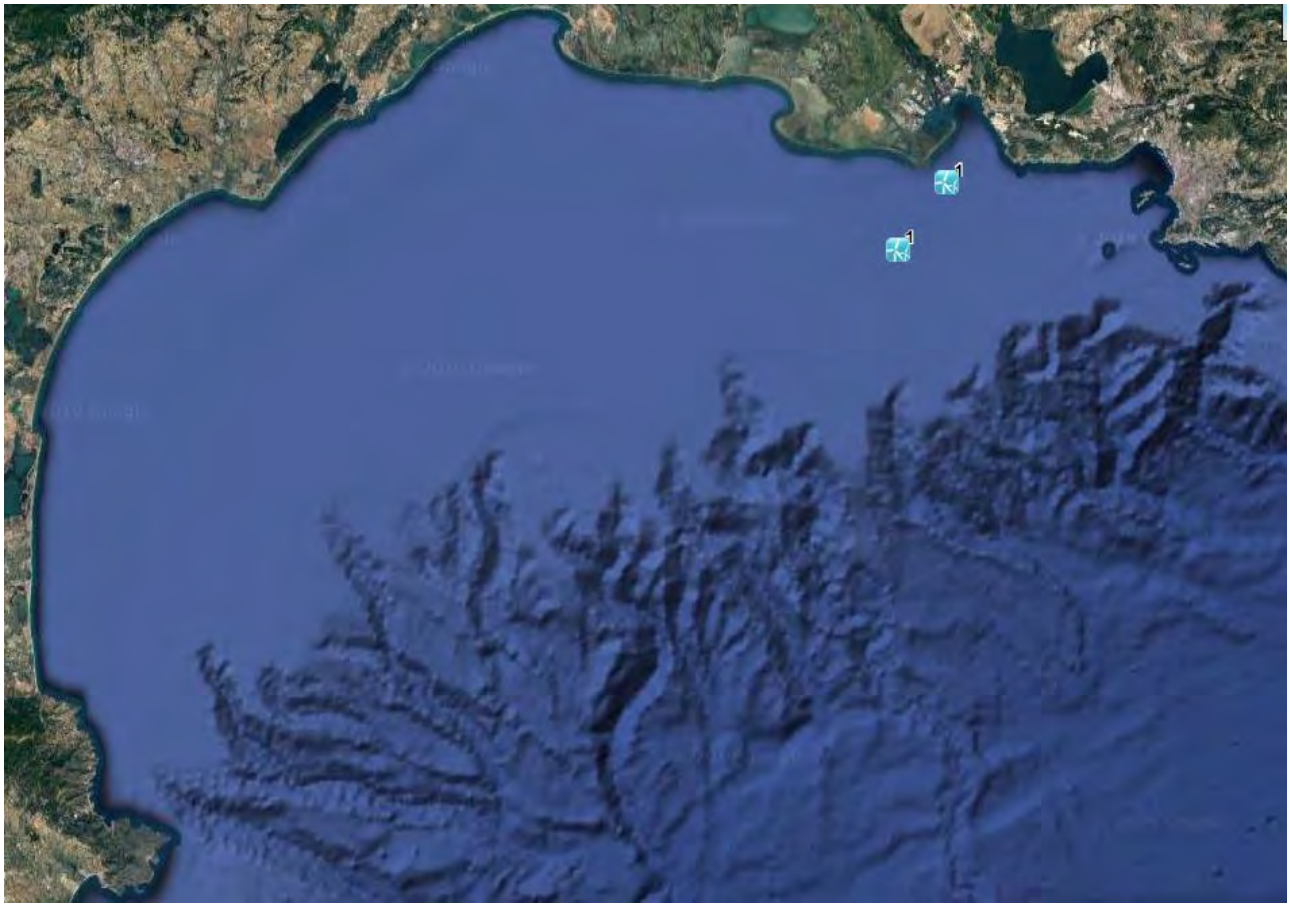


Figure 79: sites of the 2 existing authorized windfarm projects
(*Source: EMODnet, www.emodnet.eu*)

<u>The MISTRAL project</u>

This project, carried by the company Mistral SAS, is located about 5 km offshore from Port-Saint-Louis-du-Rhône. This project has been subject to an administrative authorization. It is currently being restructured with the help of the regional council and in connection with the Ecole Centrale de Marseille. This test site will be able to simultaneously accommodate 2 floating wind turbines for a maximum total installed power of 10 MW.

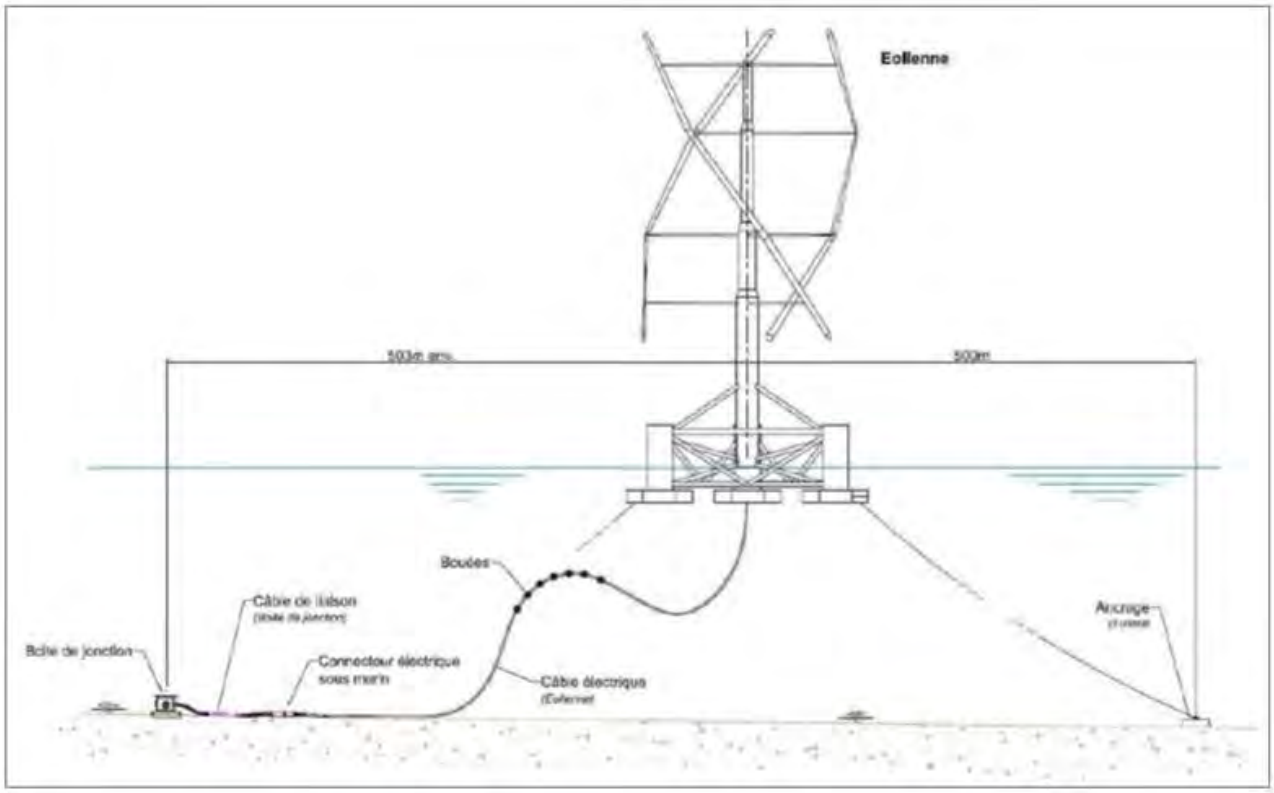


Figure 80: The mistral project, with a vertical axis wind turbine

The Mistral test site for testing two prototypes of floating wind turbines for 5 years is located about 5 km from the Napoléon beach in Port-Saint-Louis-du-Rhône, and 12 km north-east of Provence Grand Large project. Covering an area of 1.7 km^2, this test site is located between 50 m and 65 m. The Mistral project was the subject of the prefectural decree of 25 July 2014, granting authorization under the water policy and granting use of the public maritime domain. This project is carried by SAS Mistral whose main shareholder is the company Nénuphar.

The Mistral project can accommodate a maximum of 2 floating wind turbines and their anchoring systems, a junction box and connection cables between a wind turbine and a junction box. The wind turbines planned to be tested on site are vertical axis wind turbines developed by the Nénuphar Company and possibly other floating wind turbines not identified at the moment. This type of wind turbine consists of a turbine attached to a floating metal structure with 3 cylinders provided with ballasted float systems. The overall dimensions of this structure are 70 m x 70 m. The total maximum height of the whole is about 122 m, including 5 to 15 m of draft. Anchoring is carried out by a system of 3 doubled anchor lines.

<u>The Project “ Provence Grand Large”</u>

The project is located in the Provence-Alpes-Côte d'Azur (PACA) region, off the Gulf of Fos in the Bouches-du-Rhône department and benefits from both an excellent wind farm and the presence of Marseille-Fos port area, one of the few in the Western Mediterranean to have the industrial potential to implement a project of this type. It consists of 3 floating wind turbines of 8 MW each, interconnected by submarine power cables. The last section of cable is itself equipped with a

connector from which then the submarine electrical export connection, under RTE project management, for the connection to the public electricity transmission network.

The closest point to the pilot farm at sea is located about 14 km from the mouth of the Rhone in the municipality of Arles. It is also located 17 km from the Napoléon beach in Port-Saint-Louis-du-Rhône, where is also the landing point of the submarine export cable and 23 km from the nearest houses, at the blue coast, on the coast of Carro.

The wind turbines are aligned and spaced 920 m apart within the concession area, also known as the park area. The seabed is between 95.7 m LAT and 101.7 m LAT deep. This configuration around the isobath 100 has been defined in close collaboration with all local stakeholders, including the Regional Fisheries Committee (CRPMEM PACA) and the Prud'homie de Pêche of Martigues, and allows to minimize the impact of the project on fisheries activities.

The positions of the wind turbines are likely to be adapted within an area of 0.78 km^2 ("concession area") depending on the constraints that could be identified during additional reconnaissance work (geophysical and geotechnical surveys, detection of explosive devices) planned in 2017. Moreover, the wind turbines being floating, their position may vary around 15 meters around their nominal position.

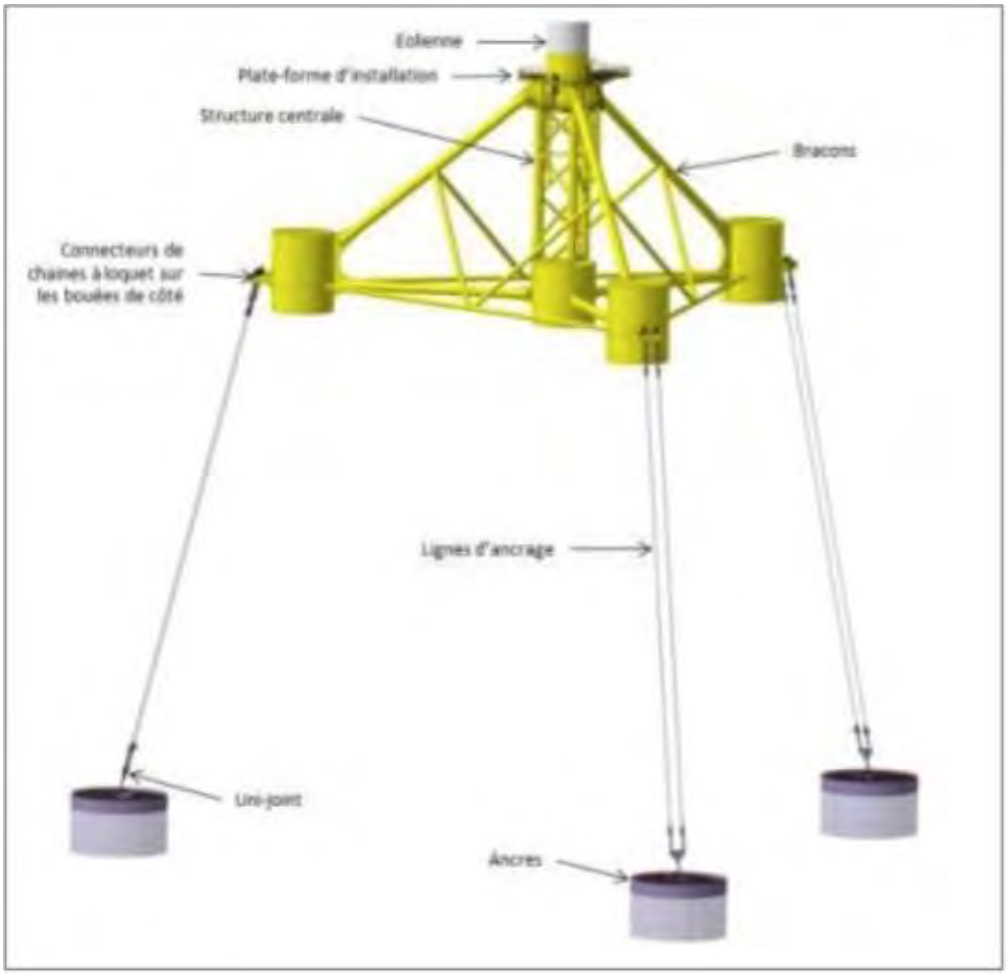


Figure 81: The wind turbine semi-sub foundation

An export cable, submarine then terrestrial, will provide the electrical connection of the offshore park. From the connector, this cable will cross the Napoléon beach in its central part, then will borrow the existing infrastructures to the existing distribution station 63 000/20 000 RTE located at the entrance to the municipality of Port-Saint-Louis-du-Nord. -Rhône. In the first six kilometers on land, the cable is buried under the pavement of the Napoléon road, giving priority to the bike path in order to reduce the impact on traffic during construction. Its route then follows the road to Carteau where it is positioned in the width of the shoulders along the way. Then it runs along the avenue of the 1st DFL to join then the Saint-Louis canal which is crossed to join an old railway and a ground belonging to "Shell". Its path then continues north and then crosses a canal and a new railway line to reach the last section. Within the latter, the route follows the sea avenue and crosses a roundabout to the location of the existing distribution station.

The total distance of the electrical connection is about 28 km including 19 km at sea.

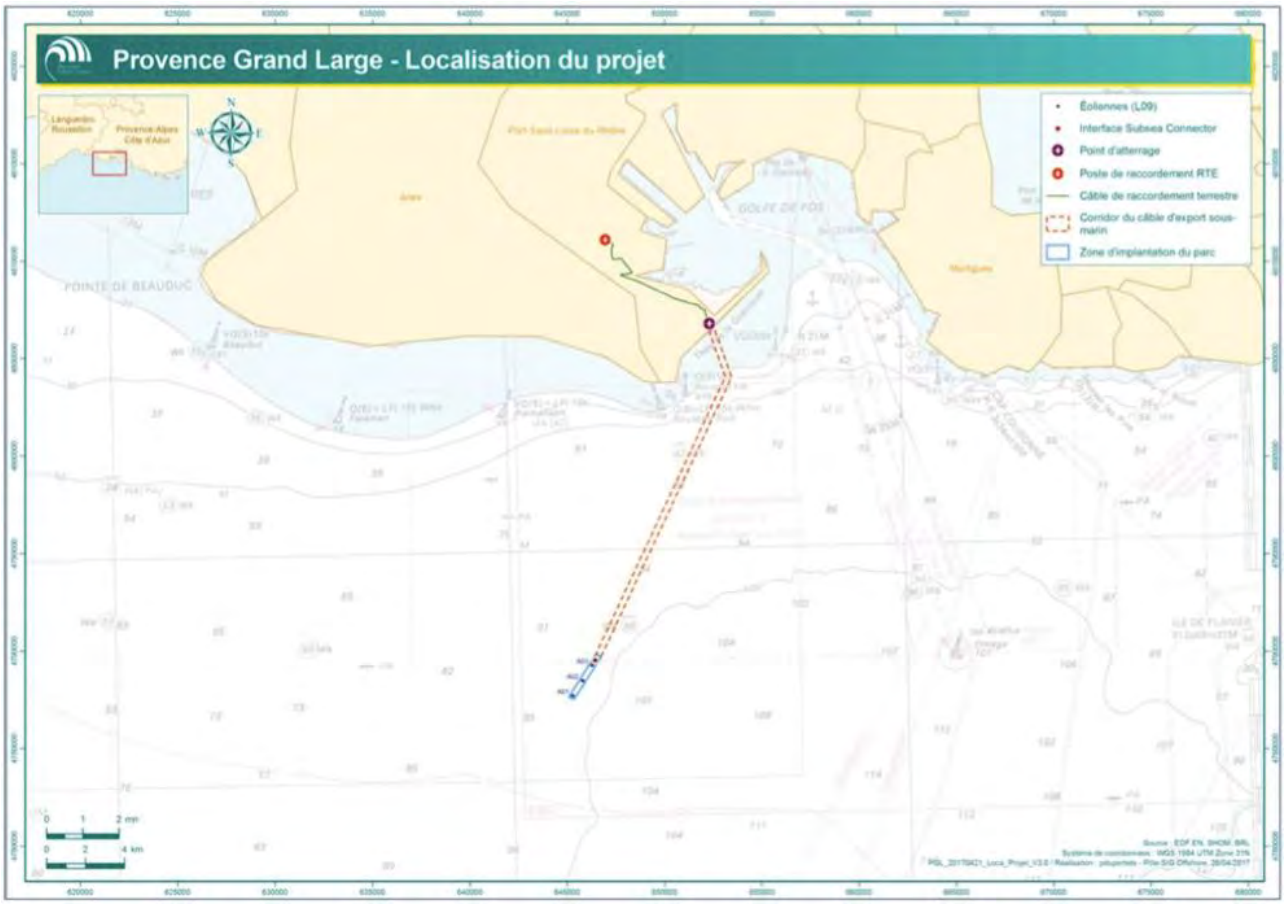


Figure 82: The Provence Grand Large Project site

The maintenance base of the wind farm will be located on the site of the EDF power plant in Martigues, taking advantage of existing infrastructures. The operating life of the wind farm is 20 years, at the end of which the developer will dismantle it. The expected electricity production is equivalent to the average household consumption of about 40,000 inhabitants. A vessel will be used to transfer personnel from the maintenance base to the wind farm, the journey time will be

approximately 45 minutes. Maintenance operations on the export electrical cable can be preventive, to check the good condition of the work, or curative when an incident occurs. In both cases, concerning the submarine link, these are ad hoc interventions that do not require a constantly chartered vessel.

The estimated operating life is 20 years. At the end of this period and unless decided otherwise by the competent administrative authority, the pilot park will be dismantled and the sites restored.

The Planned Projects

Figure 83: The planned off-shore windfarm projects (*Source: Emodnet website*)

The project "THE FLOATING WIND TURBINES OF THE GULF OF LION" was selected by the French Govenment and the ADEME (Agency of the Environment and the Mastery of the Energy) in 2016 within the framework of the call for projects "firm pilot floating wind turbines ". It deals with the installation of a pilot farm of 4 floating wind turbines off Leucate-Le Barcarès by 2021.

This park will optimize the learning of floating wind turbine technology. The Gulf of Lion, recognized as the first French offshore wind farm, is the ideal area for this decisive step.

Wind turbines with a unit capacity of about 6 MW will be assembled on floating steel structures and installed about 16 km from the coast. By capturing regular and sustained offshore winds, they

alone will cover the electricity needs of 50,000 coastal residents. The farm will be equipped with 4 6.3M152 TM turbines produced by Senvion.

The main characteristics of the turbine:

- a power of 6.33 MW
- blades 75 m long
- a mast 100 m high

The floaters will consist of 4 floats designed by Principle Power and built by Eiffage.

This innovative technology benefits from the successful 5-year experience feedback from a 2MW prototype installed in the Atlantic off Portugal in waves up to 17m in height.

The float consists of 3 cylindrical columns connected by tubes. The largest column receives the wind turbine and the other 2 columns provide ballast stability. The main features are:

- A length of about 70 m between the columns
- A total height of 24 m, including 14 m of draft at sea and 10 m at port (thanks to ballasts)

The anchoring system consists of only three anchor lines per float, with a maximum length of 600 m. At the current stage of engineering, it appears that a classic DEA anchor with a mass of 15 t is the most suitable for the project.

Figure 84: The "THE FLOATING WIND TURBINES OF THE GULF OF LION" device

The Ideol & Quadran Floating Project

Located in the Mediterranean Sea off the coast of Gruissan in the Aude region, the EolMed project consists in the installation of four wind turbines of individual capacities of 6.2 MW, installed on floating concrete foundations more than 15 km from the shore and anchored at an average depth of 55 meters.

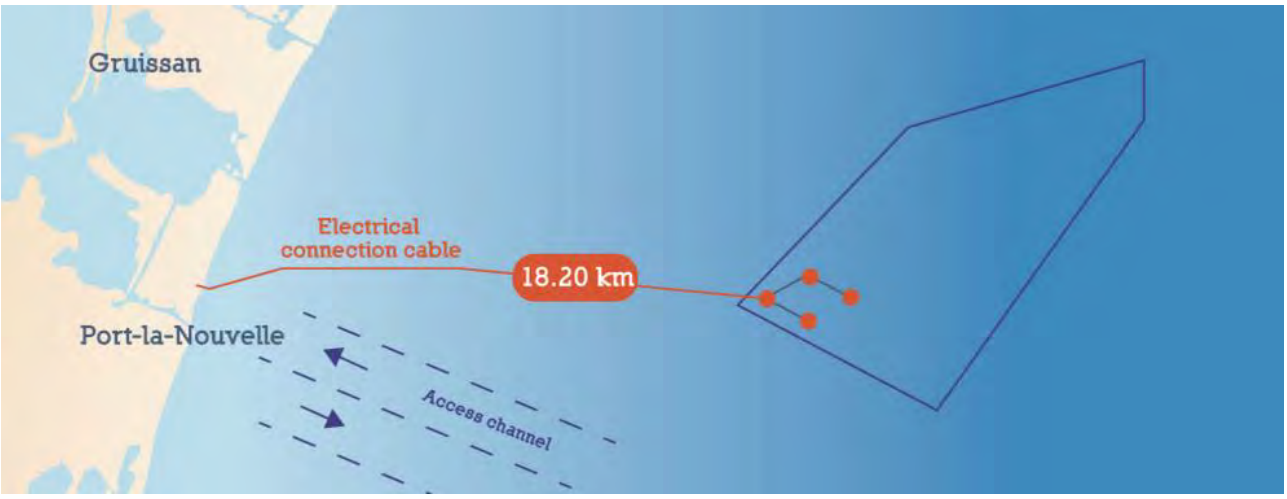


Figure 85: The Ideol and Quadran project site

This farm, with a total capacity of 24.8 MW, will be capable of producing nearly 100 million kWh/year, the annual electricity consumption of 50,000 inhabitants.

The consortium is led by the French renewable energy developer Quadran Energies Marines and includes Ideol and its Damping Pool concrete floater, the civil engineering leader Bouygues Travaux Publics and the wind turbine manufacturer Senvion.

The commissioning of the wind farm is expected by 2020, creating an estimated 300 local jobs throughout the development, construction and offshore installation phases.

The pilot farm will provide unique experience, both for the development of a high potential industry and for the confirmation of the floating foundation technology developed by the French specialist, Idéol.

As a pilot farm, it benefits from:

- The advantages of floating wind power,
- The experience of Senvion wind turbines, tested and proven for years.
- The innovative technology of the Idéol floater in the form of a square ring of concrete, the Floatgen demonstrator of which was tested off the coast of Croisic.
- A demonstration period of 20 years providing the opportunity to improve the energy performances of floating wind turbines and their interaction with the environment.
- It is adapted to the specifics of the Gruissan site: proximity to the base port in Port-la-Nouvelle, sea floor relief allowing for a distance of more than 15 km from the shore with an average depth of 55 meters, and a strong wind potential.

The floating foundation is a square shaped barge:

- The shell is a ring with a central opening (Damping Pool©), patented by Idéol, which softens the movement from swells.
- The base is extended around the entire perimeter of the floater to form a skirt that further softens the frequency of the swells.
- The wind turbine is fixed to the bridge, at the back of the floater via an intermediary transition piece.

The advantages of a floating foundation:

- The concept of a floater can be adapted to any type of wind turbine (mass, capacity) or environmental conditions.
- Once the entry data is determined, the dimensions of the floater can be optimized.
- Its relatively reduced size also means it can be integrated into the port environment without difficulty.

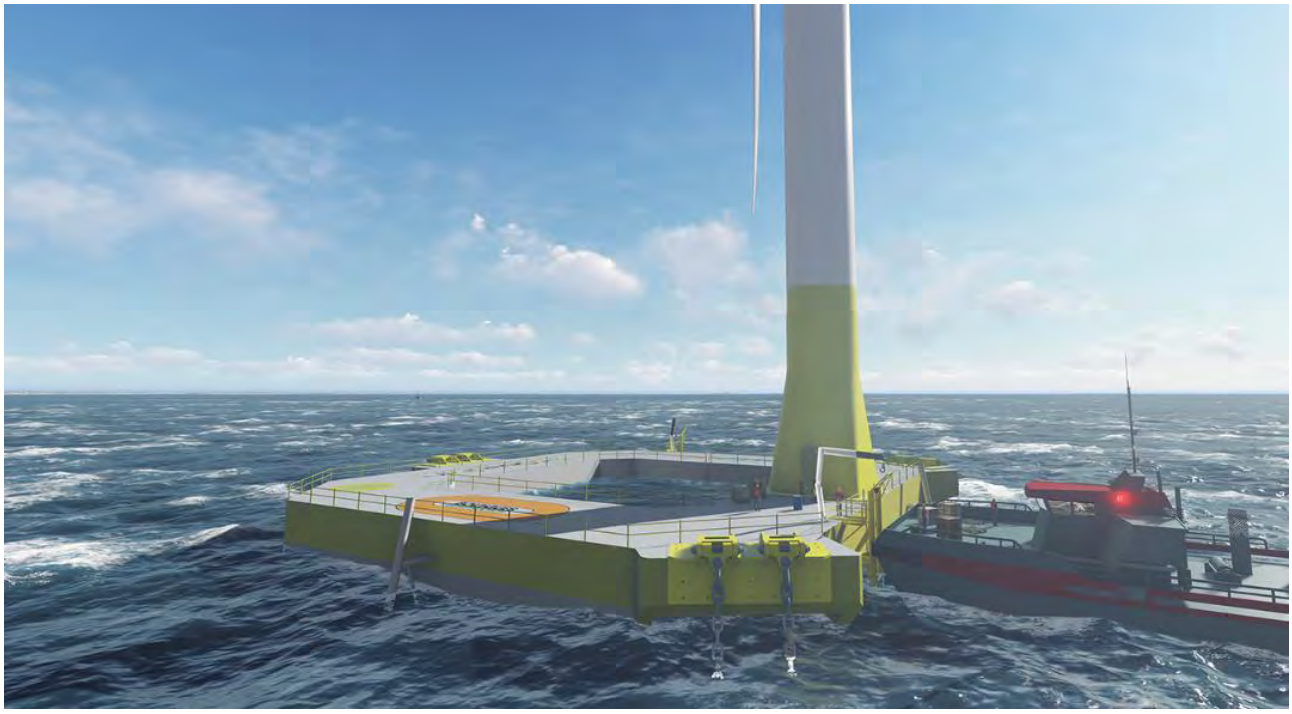


Figure 86: the EolMed floating foundation

A second Project leaded by Ideol is located in the Mediterranean Sea off Gruissan (Aude). The EolMed project consists of the installation of four wind turbines with a unit capacity of 6.2 MW, installed on concrete floating foundations of about 15000T more than 18 km sides. The turbines will be on the bathymetry of the 60m of bottom and connected to plow anchors through 8 anchor lines maximum. The technical characteristics are similar to those of the sister project, the Ideol & Quadran Floating Project.

Figure 87: The EolMed project site

The spinfloat demonstrator

A pan-European consortium led by ASAH LM, a French specialist in wind energy, a new member of the CAPENERGIES cluster, has been set up with the best players in their disciplines to develop SPINFLOAT, a new 6MW vertical axis floating wind turbine, founded on a semi-submersible float.

The project is being developed by a multi-disciplinary consortium of six private or public institutions, representing five European countries: SSP Technology Danish leader in blade manufacturing, Fraunhofer IWES the German research institute dedicated to wind energy for the system transmission and power conversion, gustomsc the Dutch designer of offshore mobile units, ECN the Dutch Institute for Energy Research and the Italian University Politecnico di Milano for wind tunnel tests. The French wind specialist ASAH LM leads the company.

This breakthrough technology results from three main observations:

- The vertical axis rotors are better adapted to the movements of a float than those of traditional wind turbines horizontal axis;
- "pitched" blades are required to control the rotational speed of the turbine in high winds and they improve the aerodynamic efficiency;
- Semi-submersible floats in one piece offer the most competitive architecture in terms of construction, inspection and maintenance costs.

Offshore wind turbines will be able to supply electricity at a lower cost than conventional offshore wind turbines on laid foundations due to higher offshore wind speeds. In addition, the costs of installation are lower (more operations being carried out on land) and there is no foundation to build under the sea. In addition, a floating wind turbine is more ecological, disturbs less the fishing, navigation and tourism. Finally, its distance from the coast makes it barely visible from the shore.

Figure 88: The Spinfloat demonstrator

3.3.5 Cultural heritage

Archaeological heritage - Marine part

Several archaeological sites are listed off the Rhone delta and the Gulf of Fos. Dozens of wrecks are present off the coast of the study area. Some of them are concentrated at the eastern end of the They de la Gracieuse. Archaeological sites are also identified near the BGF area. The location of these wrecks is shown on the following map.

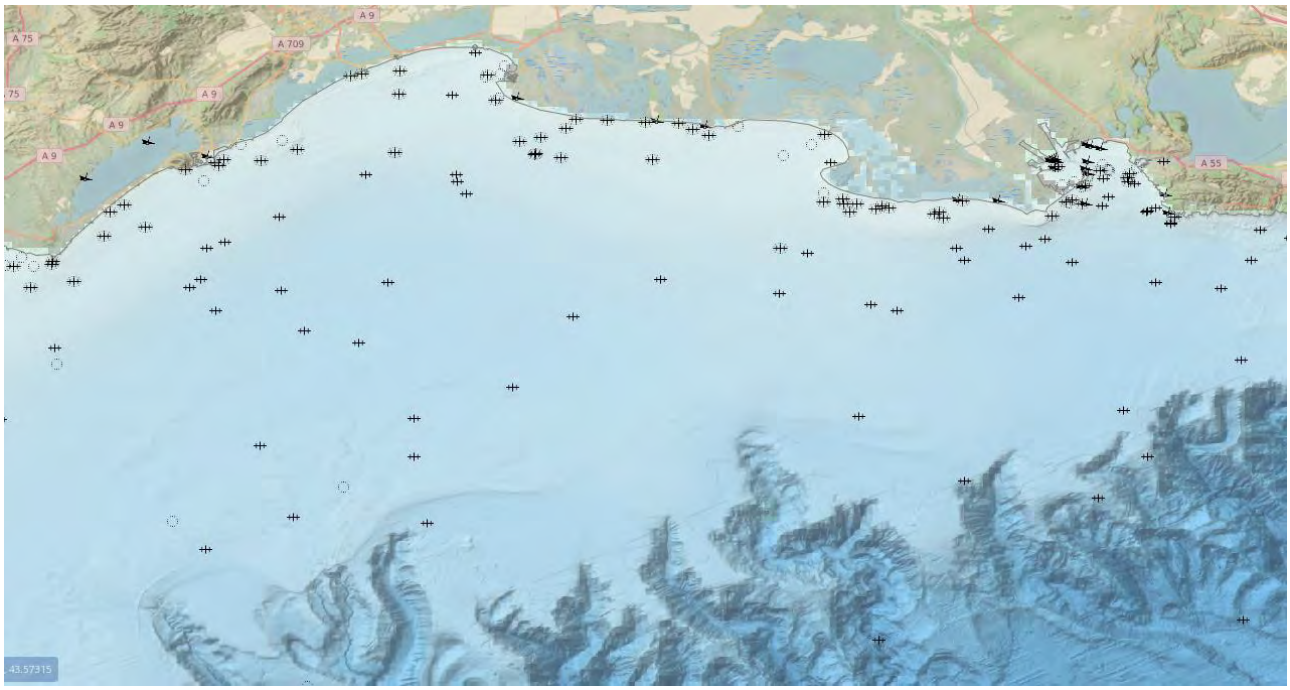


Figure 89: Map of wrecks in the Gulf of Lions (*Source: EMODnet, www.emodnet.eu*)

3.3.6 Landscape

Landscape units at the project area level

The area facing the BGF selected installation site presents contrasting landscapes characterized by two landscape units:

- The Camargue, which concerns the northern part of the study area (Crau plain);
- The Gulf of Fos, which concerns most of the study area.

Landscape unit of the Camargue

This landscape unit regards the municipalities of Port-Saint-Louis du Rhone, Arles and Saintes-Maries-de-la-Mer and covers 107,000 ha.

It is composed of 9 sub-landscape units, 1 of which related to the study area: Le Plan du Bourg. This sub-unit is intermediate between the Camargue delta and Crau neighbour.

Rice fields, field crops, manades and oak groves form a landscape mosaic. Towards the South along the Rhone, marshes and salt flats follow one another until Port-Saint-Louis-du-Rhône.

Landscape unit of the Gulf of Fos

This landscape unit concerns the municipalities of Fos-sur-Mer and Port-Saint-Louis du Rhône and covers an area of approximately 324 km^2.

It is composed of 5 sub-landscape units, 2 of which are included in the study area, which are: Port-Saint-Louis-du-Rhône, Theys and the mouth of the Rhone.

Classified sites and registered sites

Landscapes, intertwined with natural and agrarian landscapes, gives to the Camargue, which extends to the entire Rhône delta, originality and a strong identity. They are particularly vulnerable to the effects of peri-urban and diffuse urbanization, as well as to the consequences of heavy traffic associated with tourism and recreation. They are very dependent on the maintenance of ecological balances.

CHAPTER 4: PROJECT DESIGN FRAMEWORK

4.1 PROJECT DESCRIPTION

The multi-purpose platform "Blue Growth Farm" has the aim of integrating in a single structure:

- Fish farming;
- WEC;
- WT;
- Umbilical cable.

The final project proposition for the blue growth farm concept will provide a platform able of producing food and energy. The concept will be an optimized solution between environmental characteristics of the installation site, the needs of the aquaculture production, the energy harvesting system performance and construction, installation and structural constraints, to ensure the economy of the structure and its construction, operation and decommission costs. The current pre-engineering design has been tuned over the Mediterranean Sea conditions, and other locations will be studied during the project development.

The large floating offshore moored platforms are uncommon structures and need special construction processes, analyses and space. They can only be built in a limited number of harbor or bay due to their dimensions, and the construction time requires longer use of construction equipment and quay mobilization, which significantly increases the construction costs of the platform. For the above reasons, the BGF platform will be built by a modular solution.

Platform hull concept is based on building of concrete caissons, which size, shape and assembling methods have been specifically designed to be low cost, resistant to marine aggressive environment and at the lowest possible environmental cost.

The platform is designed to host inside its internal pool an aquaculture-rearing unit, destinated to the production of fishes. The overall dimension of the platform is governed by the required fish net size to provide a volume sufficient to the targeted 2000 t per year of market-size fish. The pool contains 6 fish cages of 50 m x 50 m, for a total depth of 45 m.

Figure 90: Sketch of the BGF platform, by bow side

The platform concept includes a series of harvesting devices and a wind turbine. The concept has been developed based on the 10MW DTU wind turbine, a 120 m high turbine fixed to the floating hull.

The other energy harvesting system completing the energy production objectives is a wave energy convertor patented, based on U-shaped oscillating water column technology. These WEC are installed on three sides around the hull. The hull geometry integrates then the WEC sizing requirements.

The Blue Growth platform is intrinsically a large floating structure and has to be moored to stay in place in unpredictable and harsh sea conditions. Due to the platform's large dimension and weight, the mooring lines connection and the hull itself will be designed specifically to ensure structural integrity and economy.

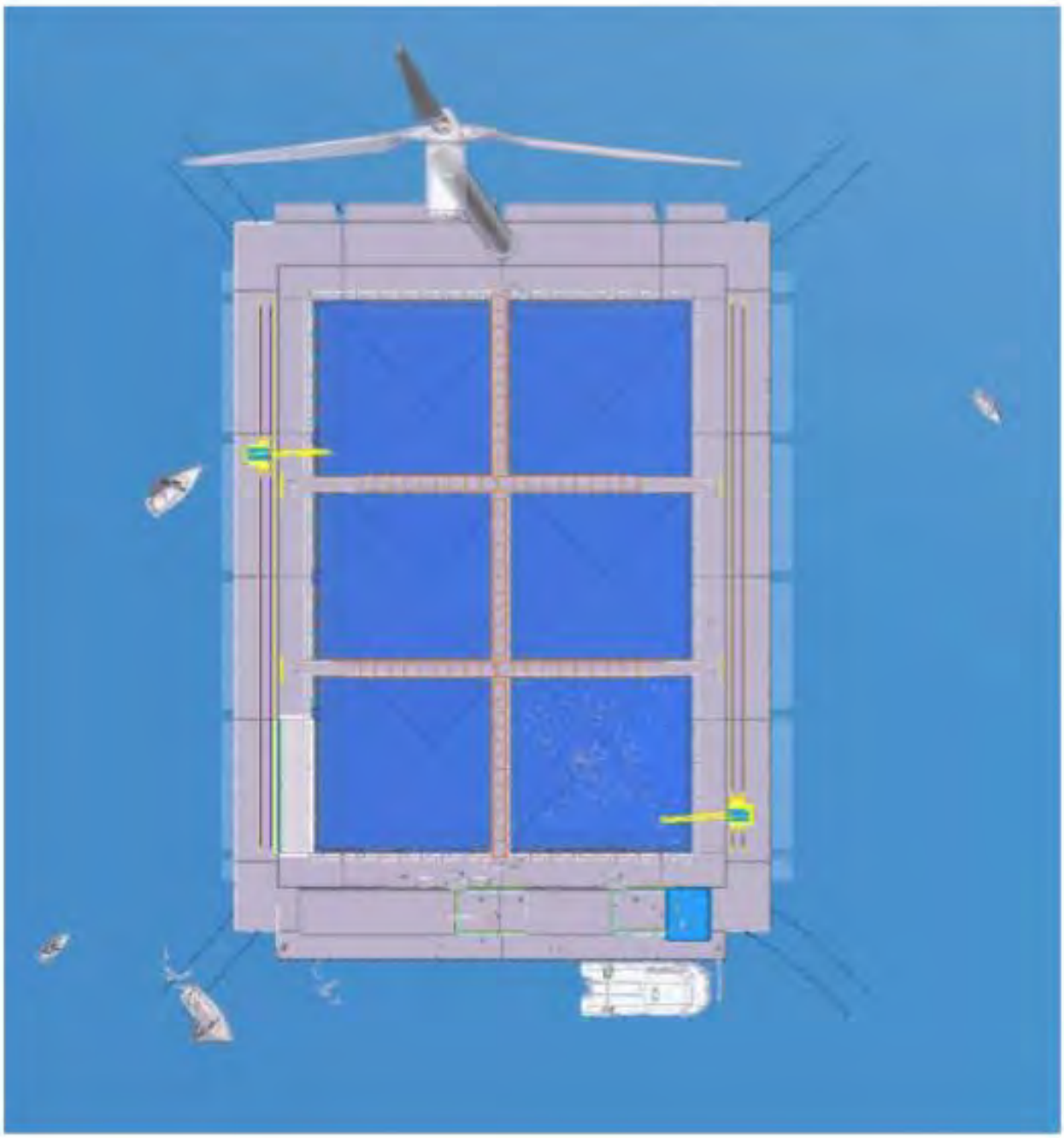


Figure 91: Sketch of the BGF platform, in plant

The BGF platform is intended to be installed in non-sheltered area where the sea state conditions induce significant loads on the hull potentially providing platform motions not in line with human activity, the on-board equipment or the platform integrity itself. The geometry should then be defined to minimize the impact of the external aero/hydrodynamic loadings. In particular, its natural motion periods should be as far as possible out of the wave spectrum to avoid excessive environment solicitation of the platform.

Specific arrangements on the hull also consider the integration of the umbilical connector.

4.1.1 Location

The Gulf of Marseille offers a large continental shelf, at a depth below the 200m threshold; some wind farms are installed and some are at still at project level; the deepest areas are assigned to O&G exploitation, and several closed boreholes are present.

The area has several large ports (Marseille, Toulon, Rone, Sete, etc.). Consequently, the marine traffic is intense.

A detailed map of benthos distribution is available (EMODnet website) for the Gulf of Marseille. Most of the gulf is characterized by soft bottom biocenosis; the deepest part is covered by Circalittoral and shelf ridge muds (EUNIS classification A5.37), the sign of a mobile seabed.

Table 17: Marseille site characteristics

Site name: Marseille	Position: λ 43,127718° φ 4,709296°
Port distance	13,7 nm
Land distance	13,2 nm
Depth	90 m
Seabottom	Mud
Protected areas distance	1,5 nm
Minimum temperature	13
Maximum temperature	24
Tide amplitude	30 cm
Annual wave power	4,5 kW/m
Annual wind power	1,2 kW/m^2
Maximum Hs 2016-2018	6,8 m

The species selected for fish farming within the Blue Growth Platform facilities located within the Mediterranean Sea is the seabass Dicentrarchus labrax (Linnaeus, 1758). This species is one of the most farmed within Mediterranean waters, showing an annual gross production of 157.698 tonnes (FEAP, 2017) in 2016.

Seabass is farmed both in coastal and offshore waters at a weight of 5 to 10 g, to attain a final weight of 350-400 g, at a length of 35 cm at the end of 18-20 months growing period.

While Seabass is spread from the North Sea to the whole Mediterranean Sea to Cape Verde (FAO, 2018; Fishbase.org, 2018), its optimal temperature range lies between 12 and 24 °C, with suboptimal temperature from 10 °C up to 28 °C.

4.1.2 Overall dimension and shape

The BGF platforma has the following dimensions:

- Overall lenght: 210m;
- Overall width: 162 m;
- Hull beam at aft: 26 m;
- Hull beam at port/starboard side: 26 m;

- Caisson height: 24 m;
- Caisson bottom beam: 26 m
- Caisson top beam: 12 m;
- WEC height: 19.6 m;
- WEC maximum beam: 7.6 m;
- Maximum hull heigth above sea level: 8.6 m;
- Deck level above sea-level: 4 m.

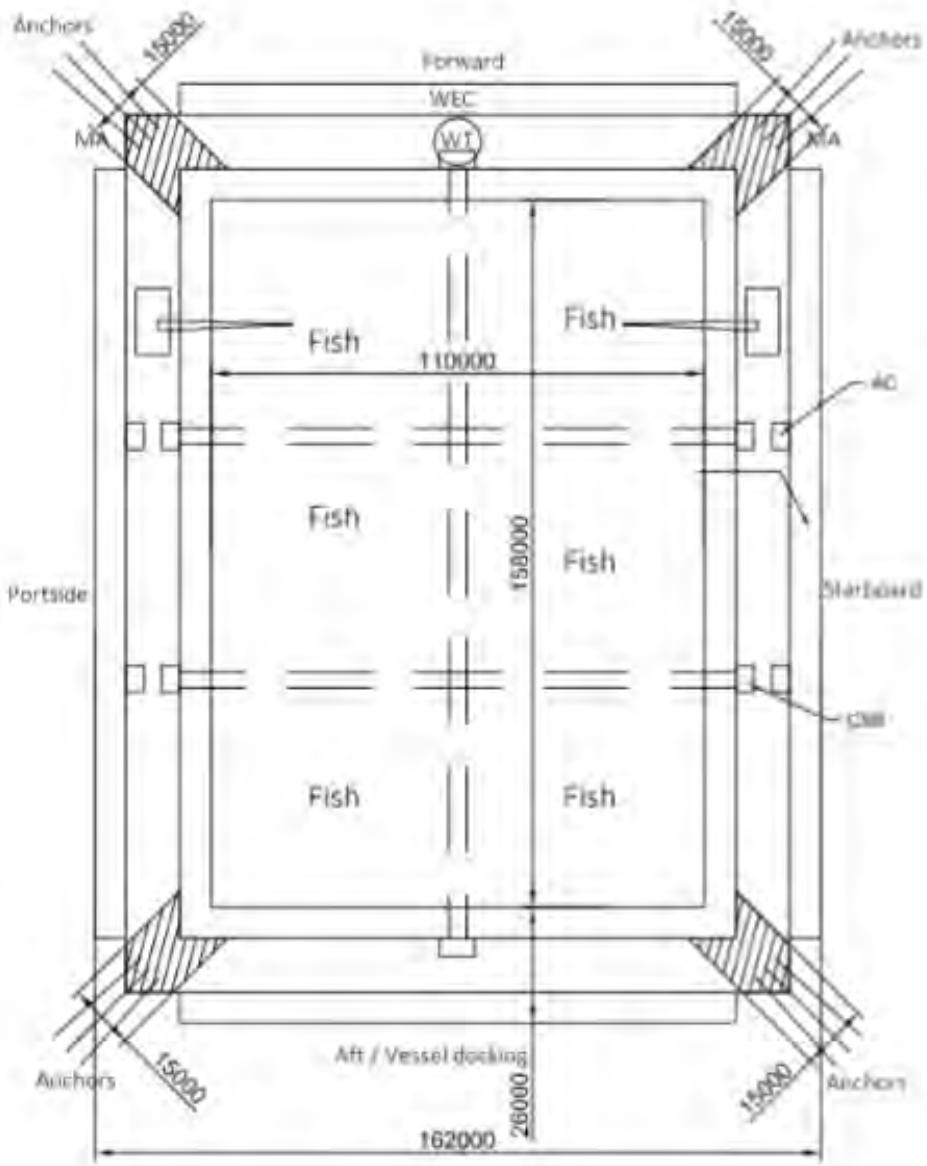


Figure 92: Overall platform dimensions

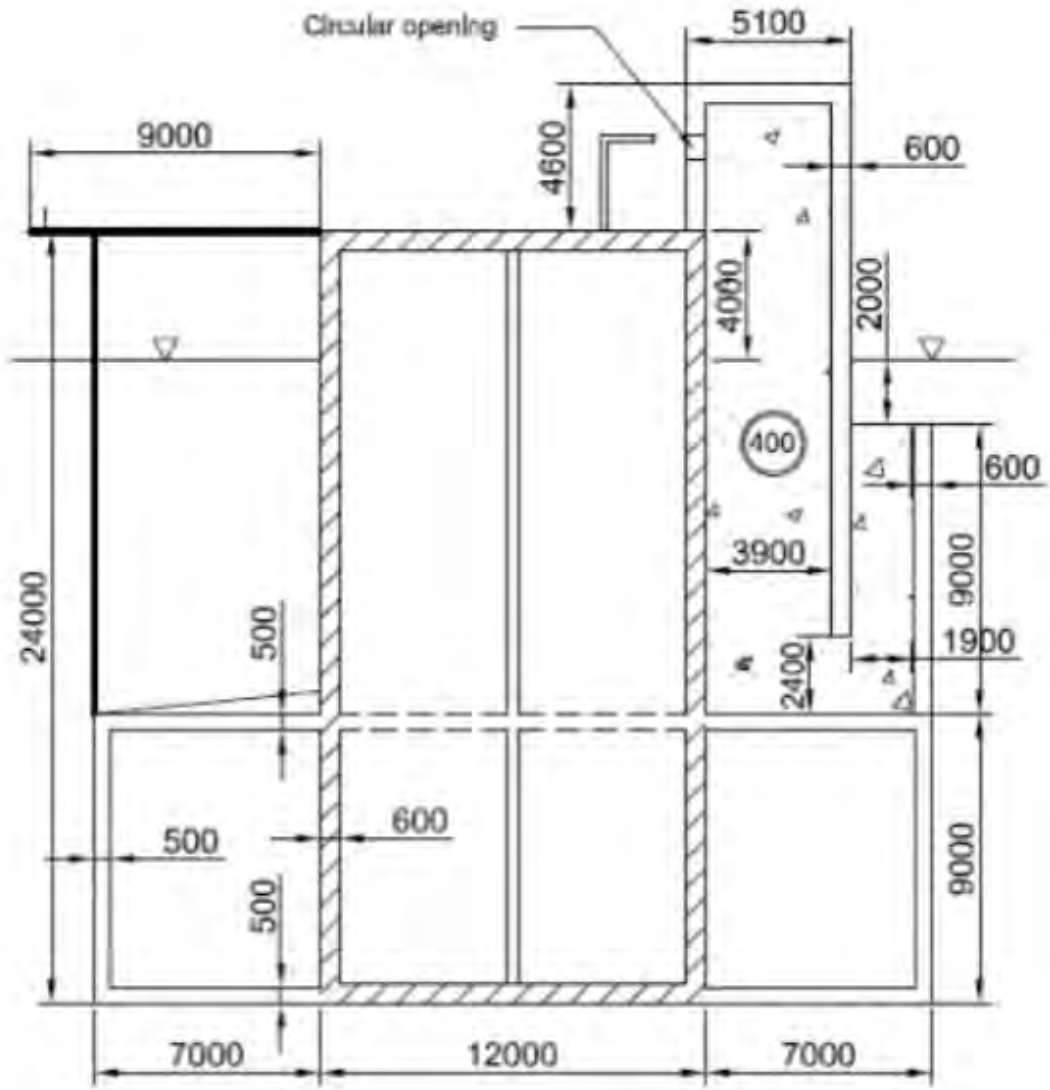


Figure 93: Platform lateral section

4.1.3 Nets

The inner pool space able to host a net system is extended for 158 m in length and 110 in width. This space can accommodate a number of six square cages, in plan, at a side length of 50 m, leaving the space for bridges or other suspension system.

The NS9415 standard has been considered in net design, with exception than for yarn resistance, where the Scottish Technical Standard for Finfish Aquaculture has been considered more appropriate to platform wave exposition.

Cage length >170 m; **Cage depth** > 40 m, therefore nets are resulting as **Grade 0**
Twine strength: Grade 0, half mesh 12.1-16.5 mm: > 79 kg MBL
Ropes strength: Grade 0 (over Grade 7): > 5000 kg MBL
Vertical ropes: at least every 5 m; **Lifting ropes**: every 10 m; **Cross-bottom Ropes** = same as

lifting ropes.

Selected yarn: Dyneema, title 100/102, half mesh 15 mm; > 100kg MBL per twine

Selected Rope: Polysteel, 20 mm minimum, > 5000 kg MBL, load factor 1.3.

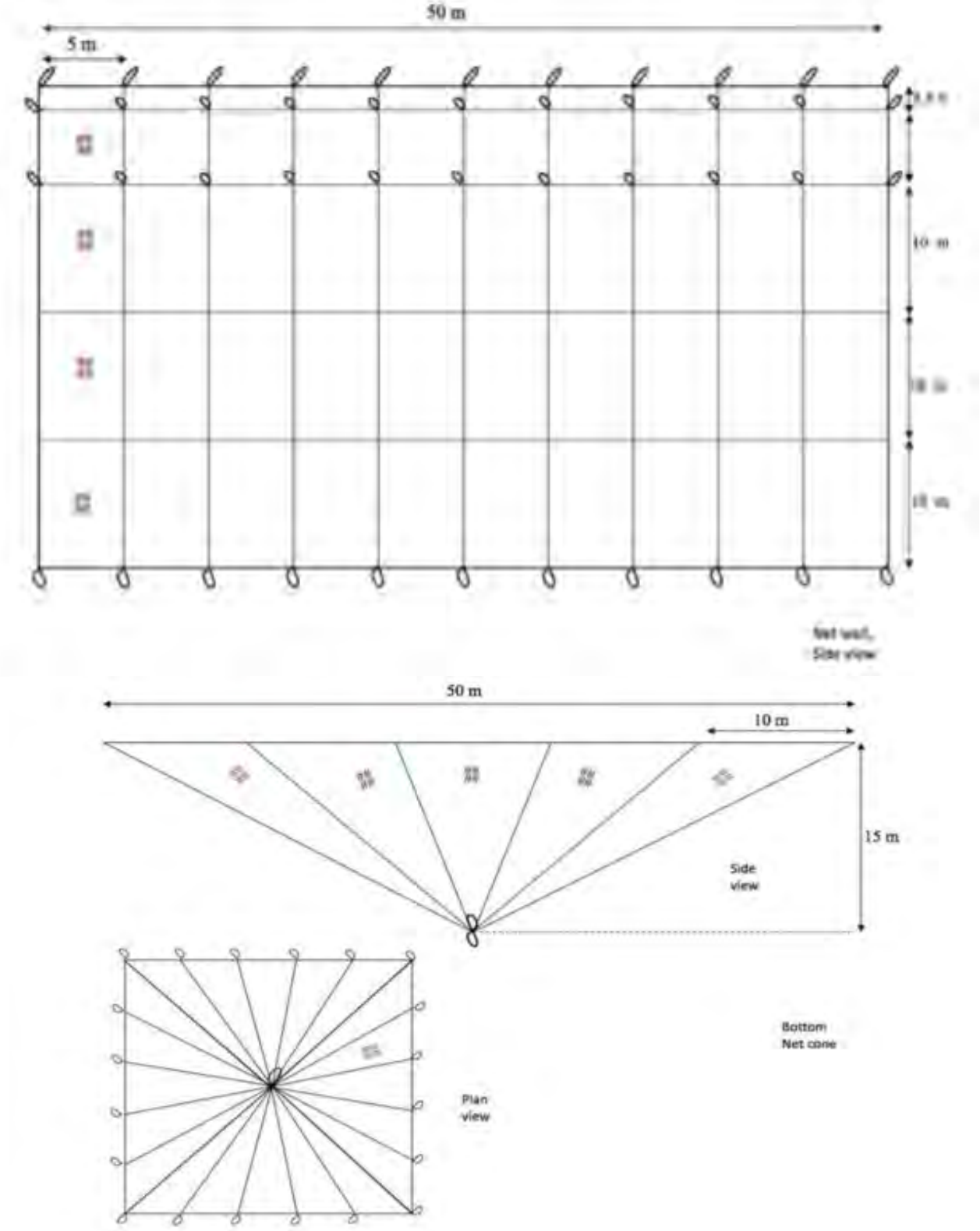


Figure 94: Net drawings

The net tensioning system is intended as composed by a frame of gravity sinkers (linears + corners), with the same cage shape in plan view, but slightly larger.

Notes

- All sinkers are connected to form a unique frame, hosting all cage tensioning lines;
- Corners are intended as rigid or semi-rigid, while flexible linears;
- Assembling by flanges, bolt and nuts;
- Linears can be demounted and floated to surface or sinked by air injection/flooding;
- Connection between cage bottom and sinker is intended by textile ropes.

A number of bridles, connected to the edge of platform bottom, will suspend to a desired depth the bottom sinker.

A suspension frame is connected to the inner edge of the platform, in order to withstand the vertical loads of the central line of the sinker frame.

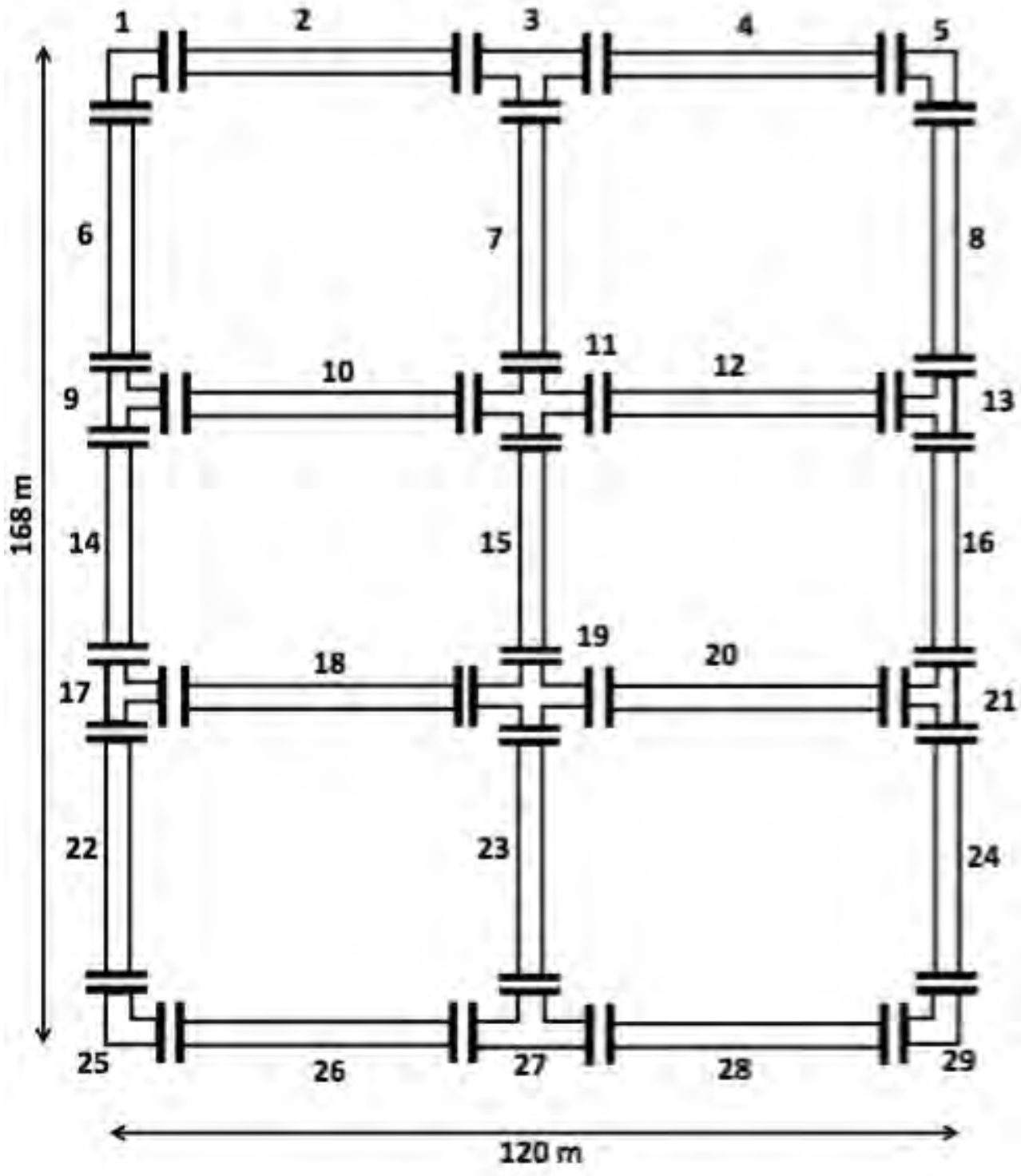


Figure 95: Sketch of the bottom sinker frame

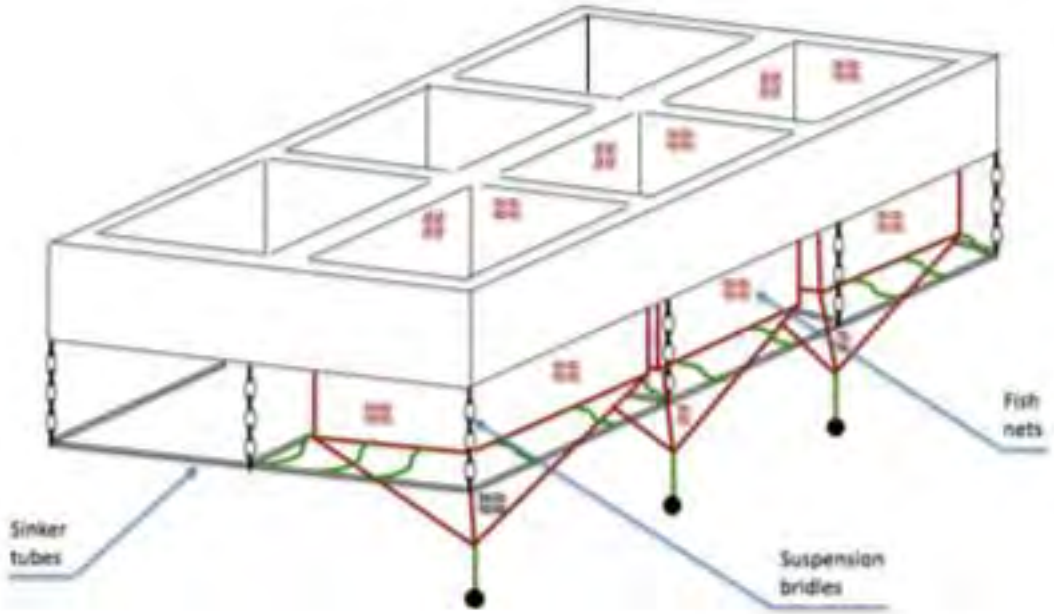


Figure 96: Nets and sinker frame relative positions

4.1.4 Fish production

The fish production program has been elaborated by SAGRO aquaculture, in the frame of Deliverable 9.3. For each site a different species has been selected (see D.2.2), at the aim of matching the local environmental conditions with the optimal growth needs characteristic of the species.

For the **Marseille** site, the *Dicentrachus labrax* species has been selected. A growth curve based on a Food Conversion Index (FCR) and a likely daily consumption has been elaborated, leading as result a monthly biomass pattern and a monthly feed consumption. Cycle calculation has been splitted over three years, the timespan necessary to attain the production target. Market size, above 400g, is reached after 16-19 months, depending of first month of stocking. Maximum biomass per cage is estimated in 1268 ton, while the maximum monthly feed distribution is 364 ton at year 2. The biomass peak, 3715 ton, is reched at year 3.

Table 18: Production cycle at year N°1

Month	Year 1							
	(Stock 1)		(Stock 2)		(Stock 3)		(Stock 4)	
	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)
Jan	70	20						
Feb	81	18						
Mar	91	21						
Apr	102	34	70	27				
May	121	61	85	49				
Jun	155	114	112	94				
Jul	218	155	164	131	70	79		
Aug	304	195	237	167	113	107		
Sep	413	208	330	213	173	143		
Oct	528	186	448	169	252	131	70	60
Nov	632	183	542	167	325	129	103	63
Dec	734	151	635	139	397	103	138	51
Jan	818	107	712	99	454	75	166	33
Feb	877	107	767	99	496	76	185	30
Mar	937	116	822	107	538	83	201	35
Apr	1001	157	882	145	584	112	221	55
May	1088	-491	962	216	646	168	251	97
Jun	816	-313	1082	334	740	264	305	173
Jul	234		1268	200	886	320	401	195
Aug			745		1064	363	509	229
Sep					1266	210	636	272
Oct					749		787	239
Nov							920	231
Dec							1049	189
Jan							1154	66
Feb							614	
Mar								
Apr								
May								
Jun								
Jul								
Aug								
Sep								
Oct								
Nov								
Dec								

Table19: Production cycle at year N°2

Month	Year 2							
	(Stock 1)		(Stock 2)		(Stock 3)		(Stock 4)	
	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)
Jan								
Feb								
Mar								
Apr								
May								
Jun								
Jul								
Aug								
Sep								
Oct								
Nov								
Dec								
Jan	70	20						
Feb	81	18						
Mar	91	21						
Apr	102	34	70	27				
May	121	61	85	49				
Jun	155	114	112	94				
Jul	218	155	164	131	70	79		
Aug	304	195	237	167	113	107		
Sep	413	208	330	213	173	143		
Oct	528	186	448	169	252	131	70	60
Nov	632	183	542	167	325	129	103	63
Dec	734	151	635	139	397	103	138	51
Jan	818	107	712	99	454	75	166	33
Feb	877	107	767	99	496	76	185	30
Mar	937	116	822	107	538	83	201	35
Apr	1001	157	882	145	584	112	221	55
May	1088	232	962	216	646	168	251	97
Jun	1217	179	1082	334	740	264	305	173
Jul	708	0	1268	200	886	320	401	195
Aug			745	0	1064	363	509	229
Sep					1266	210	636	272
Oct					749	0	787	239
Nov							920	231
Dec							1049	189

Table 20: Production cycle year N° 3

Month	Year 3							
	(Stock 1)		(Stock 2)		(Stock 3)		(Stock 4)	
	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)	Hold (tonne)	Feed (tonne)
Jan								
Feb								
Mar								
Apr								
May								
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Sep								
Oct								
Nov								
Dec								
Jan	70	20						
Feb	81	18						
Mar	91	21						
Apr	102	34	70	27				
May	121	61	85	49				
Jun	155	114	112	94				
Jul	218	155	164	131	70	79		
Aug	304	195	237	167	113	107		
Sep	413	208	330	213	173	143		
Oct	528	186	448	169	252	131	70	60
Nov	632	183	542	167	325	129	103	63
Dec	734	151	635	139	397	103	138	51

Table 21: Feed distributed and total biomass

Month	Temp	Total Monthly **FEED** (tons)	Total Annual **FEED** (tonnes)	Total Monthly Holding (tons)
Jan	13,65	20		70
Feb	12,9	18		81
Mar	13,25	21		91
Apr	14,45	61		172
May	17,15	111		206
Jun	20,4	207		267
Jul	21,35	364		452
Aug	21,95	469		654
Sep	21,95	565		915
Oct	19,3	546		1.298
Nov	17,7	542		1.602
Dec	15,45	445	**3.369**	1.903
Jan	13,65	334		2.220
Feb	12,9	330		2.405
Mar	13,25	362		2.589
Apr	14,45	530		2.860
May	17,15	101		3.154
Jun	20,4	664		3.210
Jul	21,35	1.078		3.241
Aug	21,95	1.060		2.972
Sep	21,95	1.047		2.817
Oct	19,3	785		2.835
Nov	17,7	774		2.522
Dec	15,45	634	**7.699**	2.952
Jan	13,65	400		3.373
Feb	12,9	330		3.019
Mar	13,25	362		2.589
Apr	14,45	530		2.860
May	17,15	824		3.154
Jun	20,4	1.156		3.612
Jul	21,35	1.078		3.715
Aug	21,95	1.060		2.972
Sep	21,95	1.047		2.817
Oct	19,3	785		2.775
Nov	17,7	774		2.459
Dec	15,45	634	**8.981**	2.901

4.1.5 Wind turbine

The wind turbine had a rated power of 10MW, was designed for offshore siting for an IEC class 1A wind climate and was a traditional three-bladed, upwind wind turbine. The offshore wind climate was chosen, because it was the assumptions that the very large turbines in general will be dedicated offshore sites, since transport of these constructions are a major issue.

Table 22: Wind turbine description

Rotor Orientation	Clockwise rotation – upwind
Control	Variable speed Collective pitch
Cut in wind speed [m/s]	4
Cut out wind speed [m/s]	25
Rated wind speed [m/s]	11.4
Rated power [MW]	10.0
Number of blades	3
Rotor diameter [m]	178.3
Hub diameter [m]	5.6
Hub height [m]	119.0
Drivetrain	Medium speed, multiple-stage gearbox
Minimum rotor speed [rpm]	6.0
Maximum rotor speed [rpm]	9.6
Gearbox ratio	50
Hub overhang [m]	7.1
Shaft tilt angle [deg]	5.0
Rotor precone angle [deg]	-2.5
Blade prebend [m]	3.332
Rotor mass [kg]	227,962
Nacelle mass [kg]	446,036
Tower mass [kg]	628,442

The outer diameter of the tower varies linearly from D = 8.3m at the bottom (h = 0 m) to D = 5.5 m at the top (h = 115.63 m). The tower was divided into 10 sections, where the wall thickness is constant in each section. Table 4.15 shows the wall thickness distribution.

Table 23: Wall thickness distribution of the tower

height m	outer diameter m	wall thickness mm
0.000	8.3000	38
11.500	8.0215	38
11.501	8.0215	36
23.000	7.7431	36
23.001	7.7430	34
34.500	7.4646	34
34.501	7.4646	32
46.000	7.1861	32
46.001	7.1861	30
57.500	6.9076	30
57.501	6.9076	28
69.000	6.6292	28
69.001	6.6291	26
80.500	6.3507	26
80.501	6.3507	24
92.000	6.0722	24
92.001	6.0722	22
103.500	5.7937	22
103.501	5.7937	20
115.630	5.5000	20

The hub of the DTU 10MW RWT is located 7.07 m upwind of the tower centerline at an elevation of 119 m above the ground. The yaw bearing is placed 115.63 m above ground and with a shaft tilt of 5 deg., this gives a distance directed along the shaft from the hub center to the yaw axis of 7.1 m. The vertical distance along the yaw axis from the tower top to the shaft is 2.75 m.

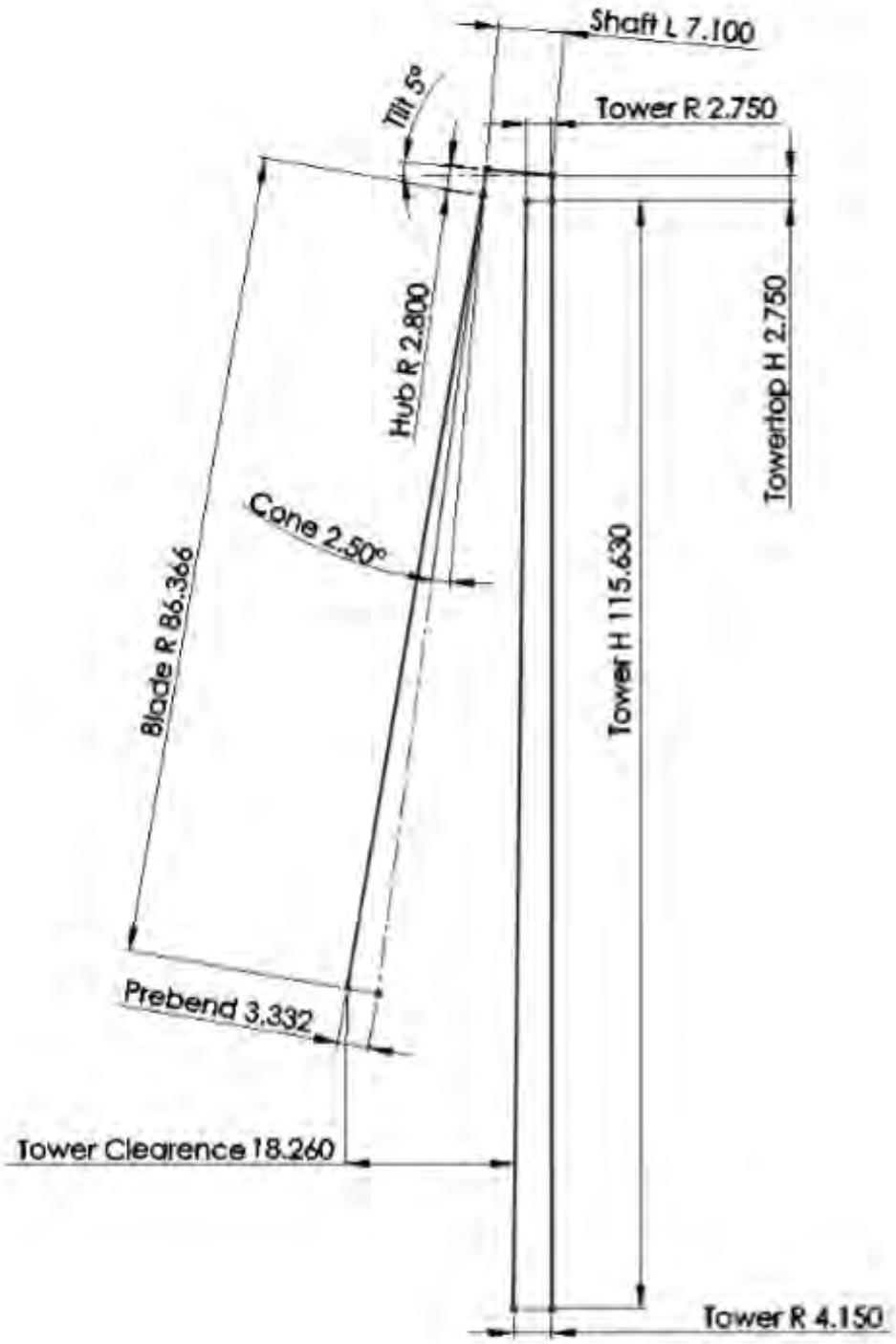


Figure 97: DTU 10MW wind turbine sizes

The DTU 10MW RWT turbine has a rated rotor speed of 9.6 rpm and a rated generator speed of 480 rpm with a gearbox ratio of 50:1.

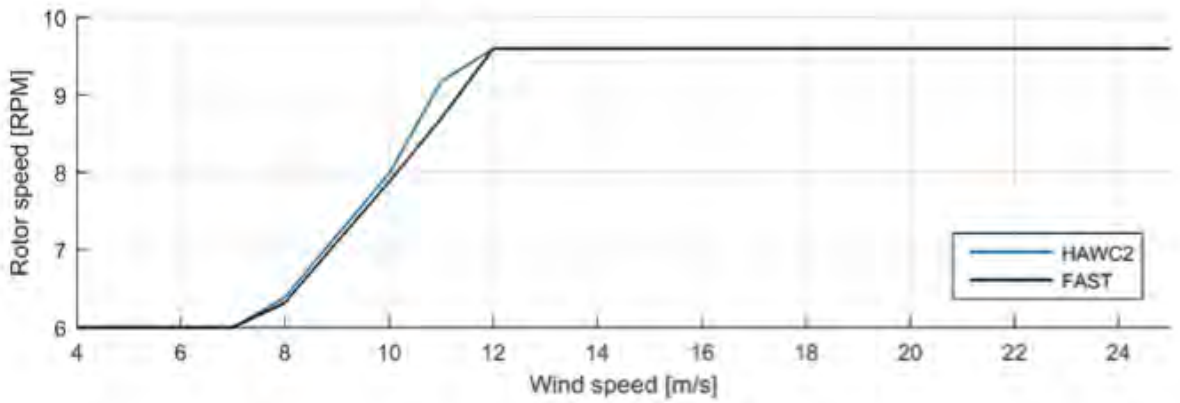


Figure 98: Rotor speed in function of wind speed

The rotor radius was 89.166 m.
The relative thickness was minimum 24.1%.
The absolute thickness of the root part up to radius of 10m was 5.38m.
The curvature of the twist should not change sign.

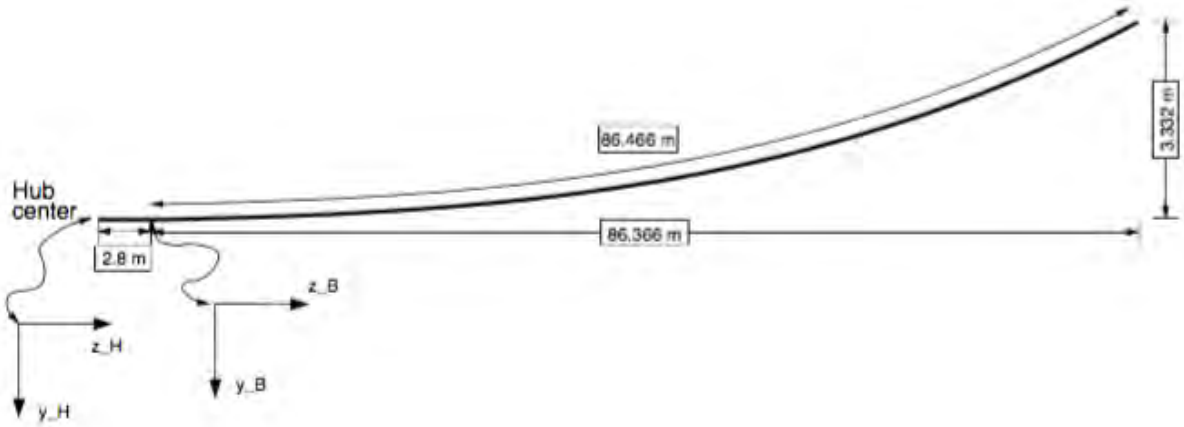


Figure 99: The prebend shape of the DTU 10 MW RWT blade

4.1.6 WEC

The REWEC3 (Resonant Wave Energy Converter) is an oscillating water column (OWC) wave energy converter (WEC) based on a U-shaped collector. The present design has been developed in WP2, Deliverable 2.3.

This device is composed by a chamber containing a water column in its lower part and an air pocket in its upper part. The air pocket is connected to the atmosphere via a small duct hosting a self-rectifying turbine. In addition to that, a REWEC3 includes a small vertical U-shaped duct for connecting the water column to the open sea. The working principle of the system is quite simple: by the action of the incident waves, the water inside the U-shaped duct is subject to a reciprocating motion. This motion induces alternately a compression and an expansion of the air pocket, which

generates an air flow in the air duct. A turbine coupled to an electrical generator, installed into the air duct, is driven in this way to produce electrical energy.

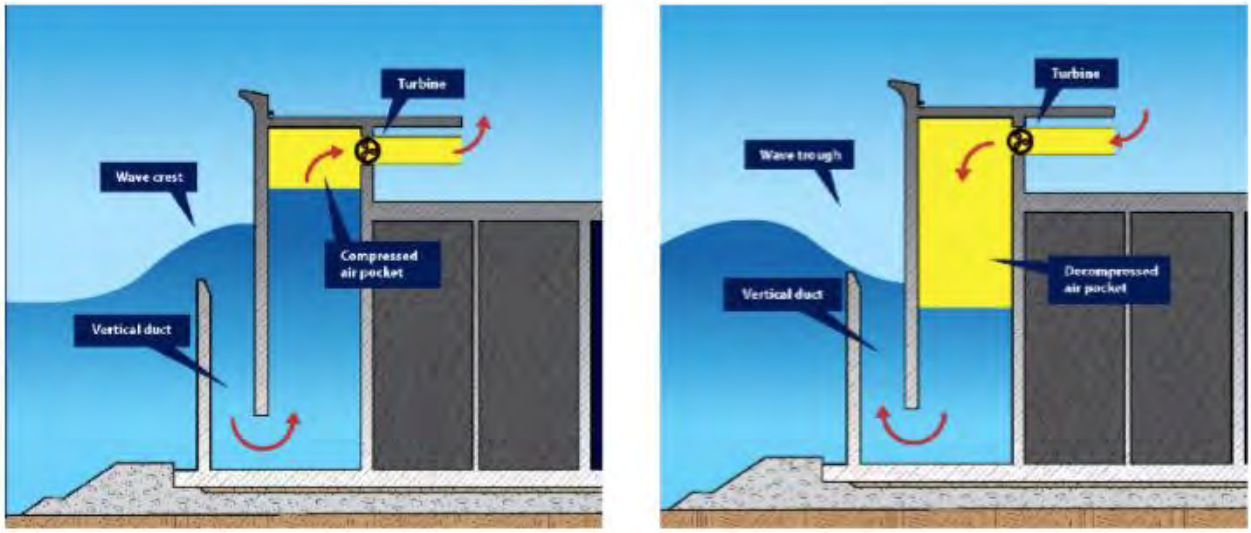


Figure 100: Principle of functioning of WEC

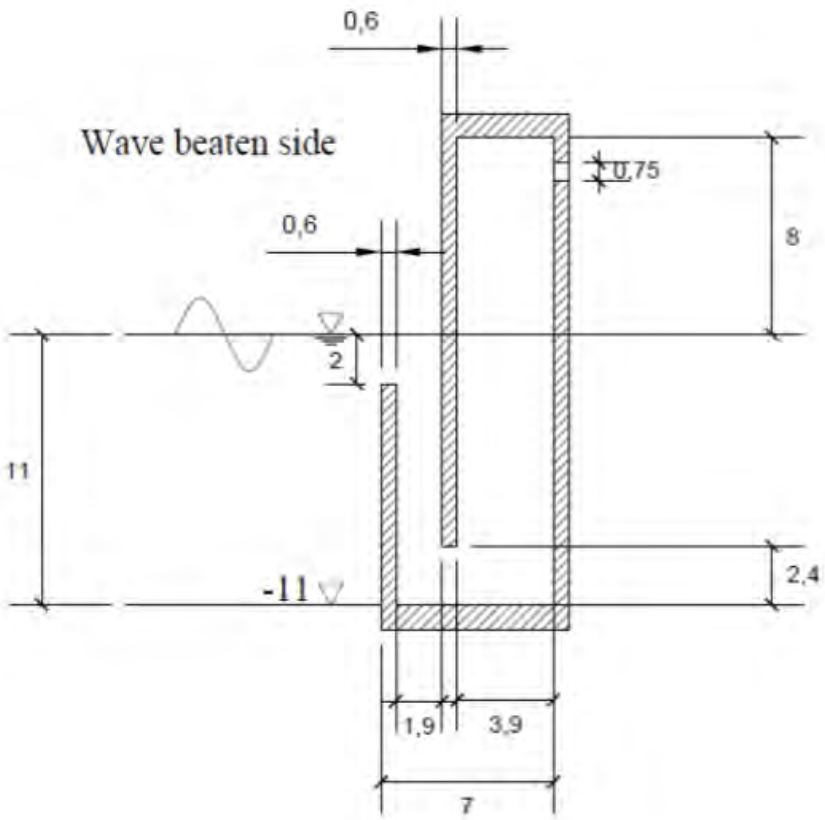


Figure 101: BGF WEC main dimensions

The device has a frontal opening of 1.9 m, spanning the total length of the caisson, and located 2 m below sea level. A further opening, of a height of 2.4 m, brings to the resonance chamber, at a total depth below sea level of 11 m, and a width of 3.9 m. The resonance chamber has a space filled by atmospheric air.

The devices are located at the external side of the BGF platform.

Natural light can diffuse into the resonance chamber by the front-side opening, and possibly through the turbine duct.

The openings are free of any obstacle or device preventing intrusions.

4.1.7 Lights

The BGF platform is intended to be equipped by a network of either nocturnal lights and to signalling lights. While the first are mandatory to ensure the safety of on-board staff, the second are requested by the maritime authority to mark plaform position.

At the present design stage, light equipments are not yet defined, but it is clear that the platform cannot be safely run without them.

4.1.8 Marine traffic

Marine traffic intensity to service the platform needs will be assessed in a later stage, since fish feeds storage capacity, their reloading interval and service boats fetures are not yet defined.

4.1.9 Moorings

The mooring pattern for the final concept was designed to withstand a storm condition. The mooring pattern is composed of 12 mooring lines of 850 m lengths each, connected to anchors at each corner of the platform. At each corner, the mooring bundle is composed of 3 mooring lines, with 3° azimuth difference. A 142mm diameter studless chain has been chosen.

The 12 mooring lines system has been chosen based on preliminary calculations and comparison with similar concepts. The mooring lines are attached symmetrically around the platform and have 3 degrees azimuth difference for the same fairlead. The lines are anchored in the seabed at a horizontal distance of 930m from the centre of floatation of the platform at a water depth of 80m

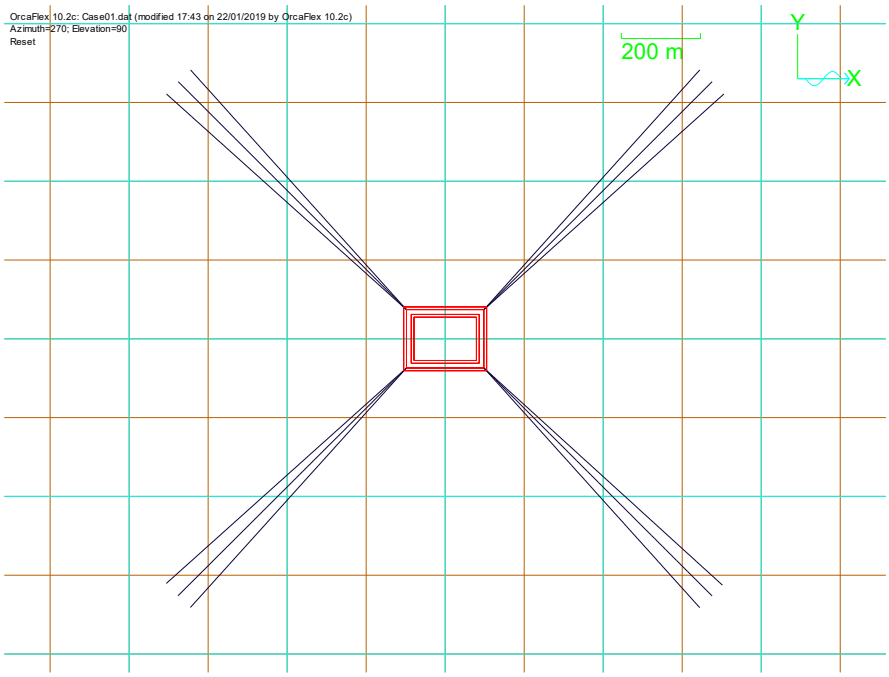


Figure 102: Mooring system arrangement, plan view

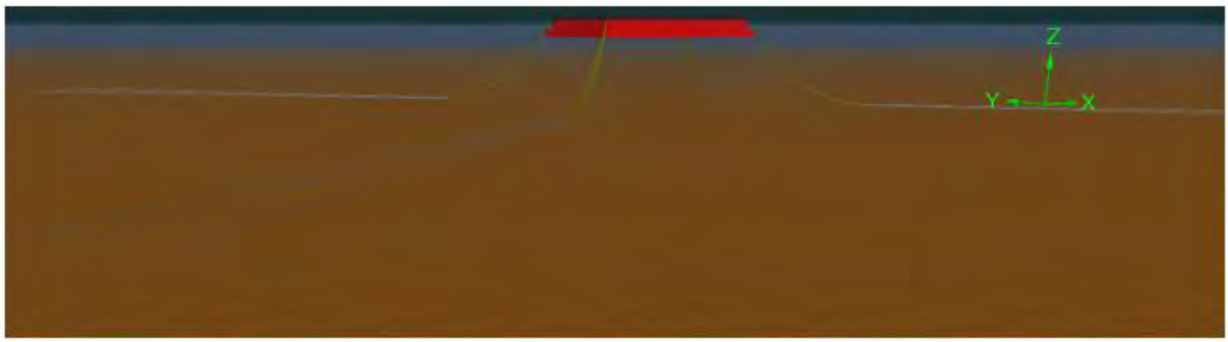


Figure 103: Mooring system arrangement, side view

In order to withstand significant tension at anchor, the Stevmanta VLA plate anchor or the Stevpris Mk6 drag anchor from the Vryhof anchor manufacturer are suited. Size of the Stevmanta fluke area, will be 30m² for a 25 tons drag anchor.

For each line, the length laying on the seabed is:

- 850 m – 113 m = 737 m (approx., considering raising chain at 45° from seabed)
- using simple trigonometric relations, as:
- total mooring length= (a) and (b) = 850 m
- angle included (γ) = 3°;
- Area A = 0.5a*b*sinγ = 18906 m^2;
- Surface of triangle of raising chain, with (a) and (b) = 100 m
- 261 m^2;
- surface on seabed 18906 – 261 = 18645;

- 18645 x 2 = 37290 (area included within 3 chains on the seabed)
- the surface interested by the seabed disturbance of the 3 adjacent mooring line is:
- for the total mooring set, 37290 x 4 = **149160 m² (0.14 km²)**

The above calculation does not take in account lateral chains shift due to platform movements, at the moment not yet estimated.

Disturbance on seabed is estimated on the basis of indication of anchor manufacturer (Vryhof), considering maximum anchor penetration to working depth of **8** times fluke length, say:

- 25 ton VLA fluke length = 6.1 m (estimated);
- 6.1 x 8 = 48.8 m;
- penetration at 45° from seabed, therefore area of seabed affected by anchor installation is
- 30 m^2 x 24.4 m = 1464 m^2;
- 1464 m^2 x 12 anchors = 17658 m^2

Total seabed area ffected by anchors and chains installation and operation:

- 149160 + 17658 = **166728 m²**

Figure 104: Stevmanta plate anchor from VryHof manufacturer

Figure 105: Stevpris mk6 drag anchor from VryHof, manufacturer.

4.2 IMPACTING AGENTS, RESIDUALS AND EMISSIONS

Matrix of expected impacts

The matrix below has been drawn on the basis of the impacts most commoly reported in literature for offshor installations as wind farms, fish farms and Oil&Gas platforms.

The BGF platform is unique installation, and no extensive literature exists on impact of such structures, especially on the additional impacts given by the concomitant activities.

Being located 24.5 km offshore, the most of impact are referred to marine environment, and terrestrial and human components can be considered as marginally affected. Thus, the most of the attention has been focus on effects on marine components.

In the following paragraphs the impacts will be discussed in detail.

Table 24: Matrix of expected impacts

Component	Resources	Aquaculture	Noise	Rotor blades	Entangling structures	Electromagnetic fields	Moorings
Sea water	Nutrients	O					
	Oxygen	O					
Marine communities	Phytoplankton	O					
	Benthos	O					O
	Odontocetes		O				
	Mysticetes		O				
	Fish	O	O		O	O	
	Seals		O		O		
	Sea Turtles		O				
	Pelagic birds	O		O	O		
	Migratory birds			O			
	Bats			O			
Landscape	Visibility	O		O			

4.2.1 Aquaculture

A range of environmental issues has been addressed to offshore fish farming in recent years, whereas it is generally accepted that environmental impacts at offshore sites is limited.

Visual impact is of primary concern in coastal farming, and is one of the main reasons for moving farms out to sea in the Mediterranean. Farming offshore will relieve this long-lasting conflict in the coastal zone.

The use of fish for feed is controversial and is considered one of the most important environmental issues in the predicted expansion of mariculture (Naylor et al. 2009, Tacon & Metian 2009), and is a major problem for expansion of offshore farming. Fish feed generates pressure on wild fish stocks, in particular due to the low efficiency in feeding carnivorous fish, which are the high volume species in marine fish farming (Duarte et al. 2009). However, modern fish feed industry had diverted its attention on raw ingredients of different origin from fish meal and oils as by-products from agricultural and zootechnical origin, now costituting the most part of fish feed formulations (Sabbagh et al, 2019).

Benthic impacts

Benthic impacts are of primary concern in coastal mariculture, in particular under eutrophic conditions where accumulation of organic matter in the sediments may result in anoxia and loss of secondary production and biodiversity (Hargrave et *al*., 2008). Studies at off-coast farms show less benthic impact compared to coastal farms due to larger dispersion of particulate waste products. However, Kutti et *al*. (2007a) examined an off-coast farm located at 230 m water depth and found increased rates of sedimentation at distances up to 900 m away from the farm, suggesting that deep-water farms can induce enrichment of sediments over large areas. Interestingly, they found an increase in the benthic fauna biomass and diversity, suggesting a stimulation of the production in the benthic community (Kutti et *al*., 2007, 2008). The enrichment may positively affect fauna density and increase fauna biomass, whereas the community structure is modified with greater incidence of pollution-tolerant species under the net cages.

Benthic impacts can thus be expected in off-coast and offshore farms, despite their location in deeper water and more exposed conditions. This is attributed to the rapid sinking rates of feed and faecal pellets, resulting in significant sedimentation in farm areas. Dispersion increases as current velocities increase, but large particles will, unless they disintegrate into smaller parts, sink and settle near the cages. Storm events during passage of low-pressure systems or tropical storms can create turbulent waters and modify the settling of particles, in particular for cage systems located at the surface. However, as most weather events are seasonal, confined to winter or hurricane seasons of shorter duration, turbulence and strong currents may play a relatively minor role in the sedimentation of waste products over an annual cycle.

Yoza et al. (2007) found increased numbers of sulfate-reducing bacteria at an impacted offshore site, suggesting a stimulated microbial response to organic enrichment. A prolonged effect of

organic enrichment on microbial activity and sulfide accumulation in deep sediments is suggested from fal- lowing studies at off-coast farms. The fallowing period was significantly longer compared to coastal farms (Macleod et *al*., 2006), and the enrichment of the sediments disappeared relatively fast, but the benthic fauna were slow to recover (Macleod et *al*., 2006). The slow recovery of the benthic fauna was attributed to low regeneration potential hampered by the absence of pollutant-tolerant species, which recolonize the impacted and possibly sulfidic sediments (Hargrave et *al*., 2008). As the benthic fauna in shelf areas are characterized by slow growth and low recolonization potential after disturbances, this could be a major concern for fallowing practices in offshore farms.

Interactions with wild fish and predators

Fish farms are artificial structures in the sea and act as fish aggregation devices (Dempster & Taquet 2004), and the loss of waste feed and nutrients increases the availability of food, attracting wild fish to the farms (Dempster et *al*., 2002, 2004, 2009, Fernandez-Jover et *al*., 2007a). Predatory fish and mammals have also been observed in farm surroundings predating on both the cultured and attracted fish (Nash et *al*., 2000, Sepulveda & Oliva 2005). Furthermore, the input of particu- late waste to the sediments attracts benthic fish and stimulates the productivity of benthic fauna and epi-fauna, providing food for benthic fish (Kutti et *al*., 2007b). Attraction of wild fish and predators is expected at off- shore farms for the same reasons as in coastal farms, but the species most likely differ from coastal farms, reflecting offshore fish populations.

Due to the lack of general knowledge on offshore fish (e.g. feeding habits, population dynamics), their interactions with farms are difficult to predict. At coastal and off-coast sites, wild fish aggregate near all types of farms, but show great spatial and temporal variability modified by a range of factors such as farm management, local environmental conditions and seasonality in migration (Battin, 2004). The aggregations can attain quite high abundance and biomass, stimulated by the high quantity and quality of the waste feed (Dempster et *al*., 2009). The presence of wild fish may reduce the benthic impact due to their feeding (Vita et *al*., 2004a,b), but the farms can also act as ecological traps, misleading fish to inappropriate habitat selection or diverting migrating fish from migration routes, making them susceptible to capture and thereby increasing their mortality rates (Battin, 2004).

A concern at offshore farms is the attraction of large predators, causing damage to nets during their hunt for prey. Damage of nets is an economic as well as ecological risk due to the release of farmed fish to the wild. Moving farms offshore could attract larger and more abundant pre- dators to the farms, including species such as sharks and killer whales. If offshore net cages are attacked, there is a risk of releasing millions of cultured fish due to the large size of the farms. Escapees, cultured fish unintentionally released into the wild, are a major and increasing problem in mariculture (Naylor et *al*., 2005). Escapees may interbreed with wild conspecifics and reduce the genetic diversity of the local populations, which is a major problem in the salmon industry (Cross et *al*., 2008). Escapees may also obstruct the natural habitats, interfering with the native species for breeding sites and food (Buschmann et *al*., 2006), and they increase the risk of transfer of disease and parasites to wild fish.

Similar to coastal farms, there is a risk of spreading diseases between farmed and wild fish and vice versa, and several scenarios can be predicted for offshore farms. Due to the increasing size of the farms, the risk of transmission of disease from cultured to wild fish is higher compared to smaller farms, but on the other hand, the move to offshore locations could minimize the incidences of diseases due to better water quality

Use of antifoulants/chemicals

Various chemicals, including antifoulants, are used in mariculture and may accumulate in the benthic organisms and sediments below the net cages (Dean et *al*., 2007). The use of medicines for treatment of cultured fish, such as antibiotics, poses an environmental threat in the form of transmission to wild organisms and development of bacterial resistance in nature (Samuelsen et *al*., 1992). As the use of these environmental hazards and medicines is expected to decrease in offshore farming due to better water quality and less growth of biofouling combined with increased dispersal, the environmental threat is most likely lower.

Carbon footprint

Mariculture has a high carbon footprint when compared to low-energy freshwater farming, but a low footprint compared to the production of livestock, as livestock emit methane, contributing to global warming (Bunting & Pretty 2007). The carbon footprint is predicted to increase as fish farms move offshore due to increased energy use for transportation of materials, feed and cultured fish Optimizing energy use at offshore farms with renewable energy sources could compensate for some of the increased energy use.

Water quality

Finally, the last environmental issue is water quality, which is considered one of the less severe impacts (Sarà 2007). The water quality around coastal fish farms is affected by the release of dissolved and particulate inorganic and organic nutrients, but, due to rapid dispersal, only limited impacts have been documented. By moving the farms further offshore to exposed conditions, the dispersal of nutrients is expected to increase, minimizing the pressure on the environment.

4.2.2 Noise

Installation, operation, and decommissioning of marine renewables devices and the associated cables are a potential source of noise emissions. During installation the key sources of noise are potentially represented by all activities involving engines and moving parts, shipping, machinery, drilling and trenching and geophysical surveys. Noise associated with operation outcomes from the action of valves, motors, gearboxes, turbines and any other mechanical device. Noise associated with decommissioning can be considered similar to that associated with construction and installation. Current knowledge on marine noise suggests that installation noise for marine renewable devices is likely to be more intense than operational noise, and the potential effect of noise emissions is generally related to sensitivity of receptors in marine environment.

Sound levels are normally expressed in terms of decibels (dB). The decibel relates the measurement of noise to a reference unit and expresses the ratio between the reference units on a logarithmic scale. This reference unit is typically 1 micro Pascal (1μPa) (Nedwell et Al., 2003).

Sound (in dB) is normally due to several frequency components and therefore it is necessary to take into account the frequency range related to a specific sound level. Frequency is the number of sound pressure fluctuations per second, measured in Hertz (Hz). Receptors are sensitive to both the sound pressure levels (expressed as dB re 1μPa for underwater noise) and the frequency of the sound (expressed as Hertz (Hz) or kilo-Hertz (kHz)).

To assess the impact of underwater noise on the receptors living in the surrounding marine environment, it is necessary to define the thresholds that are related to the different levels of severity of impact.

The onset of permanent or temporary hearing damage in marine invertebrates, fish and mammals in the marine environment is related to the intensity of the sound to which an organism is exposed, its hearing capacity, and the duration of exposure. Two levels of possible damage are considered:

- Permanent threshold shift (PTS): an irreversible physiological damage caused by any permanent damage in the inner ear, resulting in a non-recoverable partial/total loss of hearing sensitivity;
- Temporary threshold shift (TTS): a temporary loss of efficiency in the transfer functionality in the inner ear, resulting in a temporary and partial loss of hearing sensitivity.

Heathershaw et *al*. (2001) indicates the onset of PTS in fish and marine mammals at sound pressure levels (SPLs) greater than 95 dB above their specific threshold of hearing, for exposure duration above 8 hours in a period of 24 hours. Similarly, the onset of TTS is evidenced at SPLs of 75 dB above the threshold of hearing for the same exposure duration. The SPLs, at which onset of PTS and TTS might occur, are inversely correlated to the duration of exposure.

Biological receptors may exhibit avoidance reactions to underwater noise at levels much lower than the PTS and TTS thresholds. An array of devices, emitting noise at disturbing levels, may therefore appear as an impenetrable barrier to a sensitive group of animals, perhaps separating them from a target ground, even in presence of enough space between devices to move without experiencing damaging exposure levels.

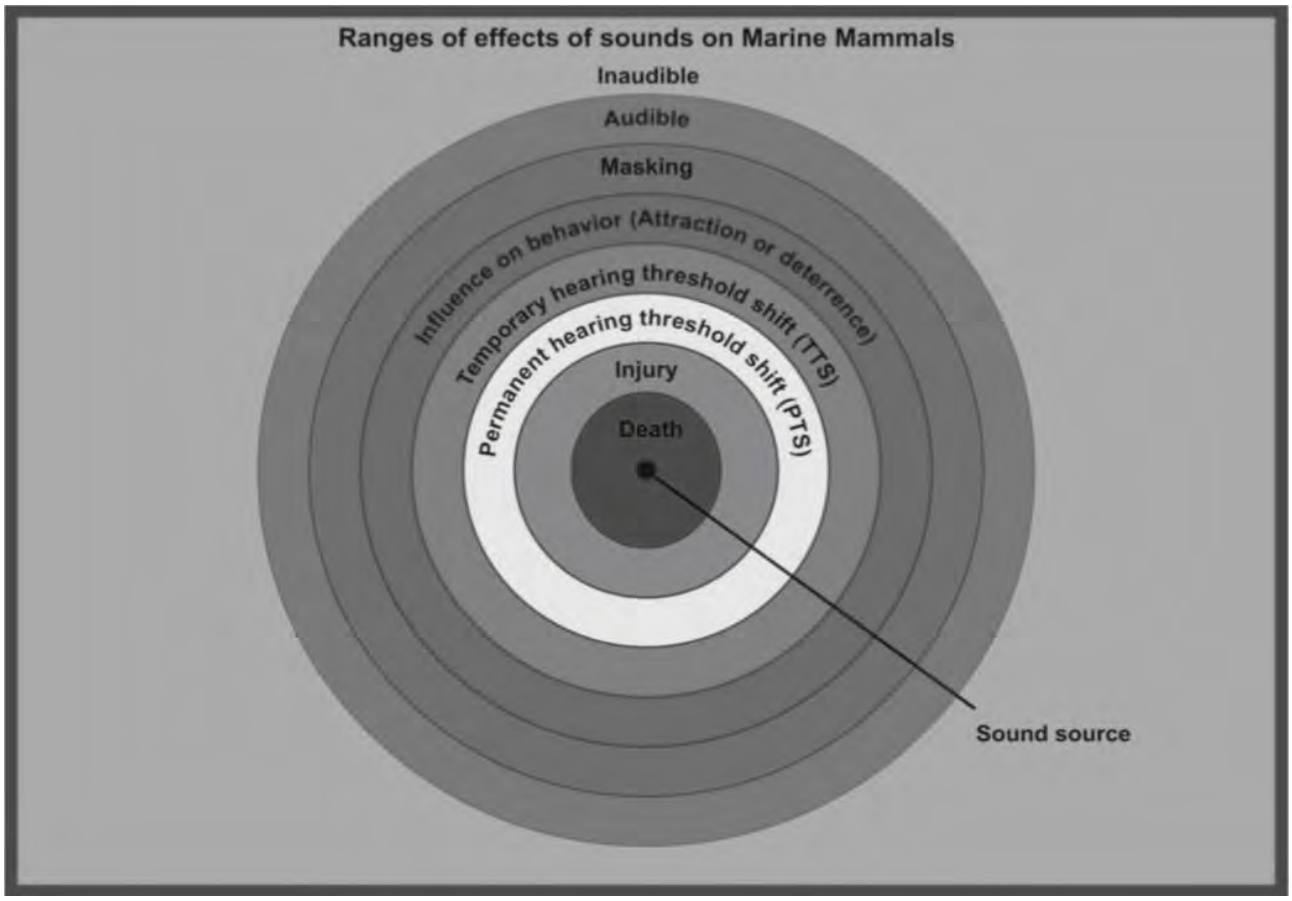


Figure 106: Behavioural/physiological effect at distance from source (*Source: Kastelein, 2013*)

The transmission of sound in water can vary in relation to salinity, temperature, and pressure and seabed type. Sound can interact strongly with the seabed, and the sediment types and seabed roughness can affect propagation loss. Hard seabeds reflect noise effectively, whereas soft silty bottoms tend to absorb noise. Similarly, waves on the surface can also affect propagation loss by scattering the sound by the interaction with the surface, or just reflecting it. Suspended sediments or bubbles can also cause an additional propagation loss. Propagation loss varies on a diurnal basis, particularly during the early summer, and on the seasonal cycle, following the water column temperature throughout the year.

The ambient noise is likely to be highly variable: a shoreline area will be dominated by shore and surf noise, while the areas offshore are more prone to shipping noise or other operational noises that add their contribution to the background noise level.

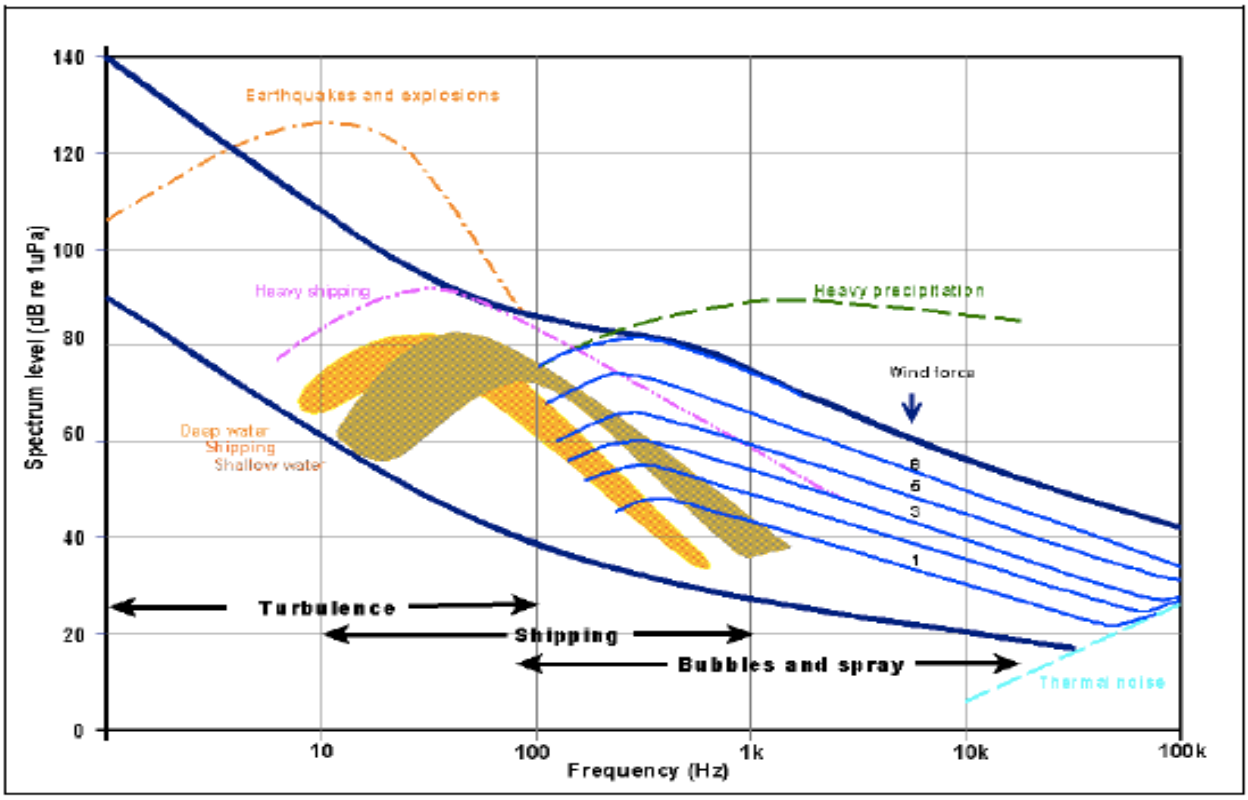


Figure 107: Marine background noise, (*Source: Wenz, 1962, modified*)

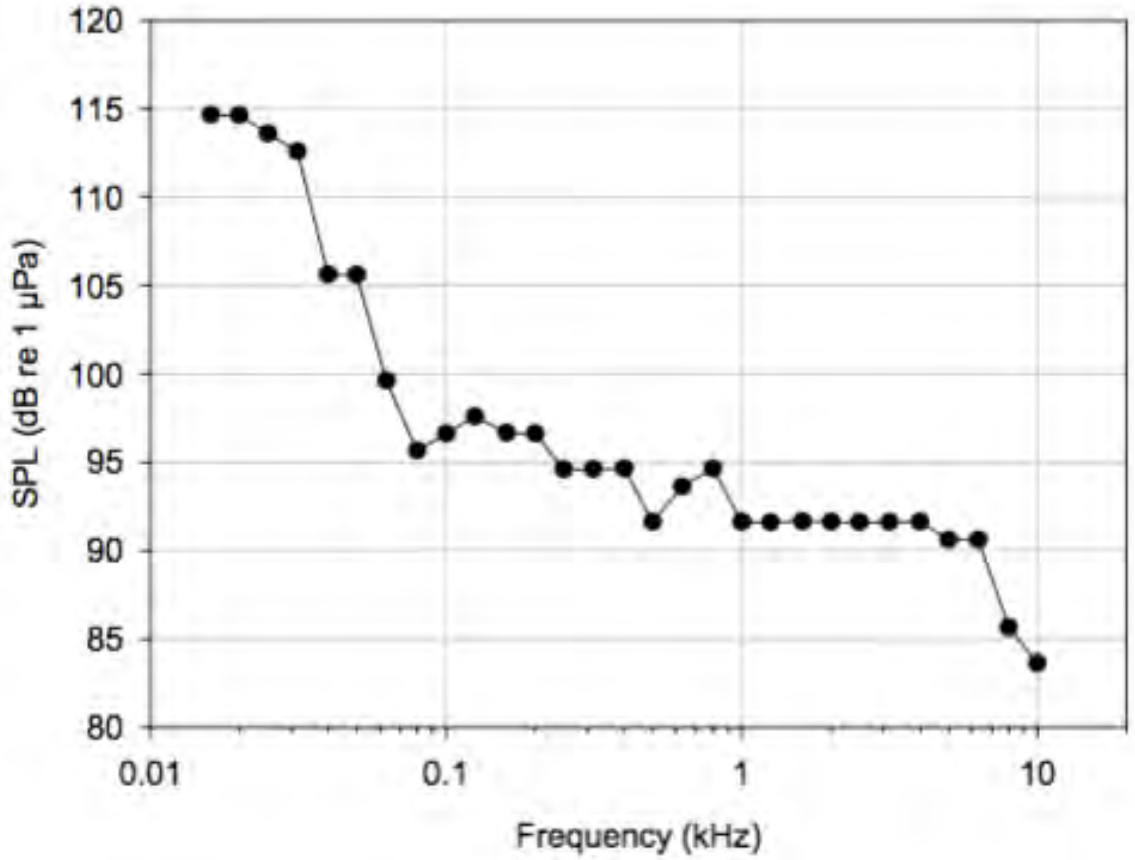


Figure 108: Ambient noise, North Sea at wind speed 3-8 m/sec (*Source: DEWI, 2004*)

The propagation of sound waves in seawater can be directly influenced by suspensions of particulate matter that can scatter, absorb, or reflect the waves. Because frequency and wavelength are inversely proportional characteristics of sound waves, low-frequency signals produce sound at long wavelengths. These long-wavelength signals encounter fewer suspended particles as they pass through the medium and thus are less subject to scattering, absorption, or reflection. As a result, low-frequency signals are able to travel over long distances without significant loss of signal strength. Naval communication systems utilize low frequency, long-wavelength signals to establish communications with submerged devices.

Within the ocean, the speed of sound varies at different depth, normally following the changes in temperature and pressure. Specific combinations of temperature, pressure, and salinity may act to create shadow zones, or reflective layers, that prevent the propagation of sound waves. A specific set of conditions, however, also act to create a channel through which sound waves propagate at minimal speed but also with minimal loss of strength. Similar to the transmission of light through the fibre-optic cables, the refraction of sound waves by layers of water with different state properties, allow for the formation of well-defined sound channels.

Although the oceans are not uniform bodies of water - there are currents of water with dramatic variations of temperature and salinity - the speed of sound in the deeper regions of the oceans is influenced mainly by the high hydrostatic pressure. Conversely, at shallower depths, temperature is

the main parameter, which governs the speed of sound. The greater the temperature of the water, the faster sound travels. Seasonal variations of surface temperature produce changes in near-surface temperatures that result in a modification of the speed of sound in water near the ocean surface. When the near-surface layer is well mixed by currents and wave action, a resulting isothermal layer allows for a uniform propagation speed. Such isothermal layers are common in mid-latitude regions, and are separated from the deeper and colder water by a thermocline, a marked temperature gradient. The thermocline shows a characteristic decrease in the speed of sound with decreasing temperature. This interface can create a sound "pipeline," or "deep sound channel," within the oceans that allows the transmission of low frequency sound over thousands of kilometers.

This channel (SOFAR) was demonstrated as capable of transmitting the low frequency, long-wavelength sound waves for very long distances. Because of refraction, sound waves moving through the SOFAR channels are deflected toward a region of lower velocity. Accordingly, waves traveling upward toward the surface, where the speed of sound increases with increasing temperature, deflect downward. Waves traveling toward deeper water, where the speed of sound increases with increasing pressure, are deflected upward. Therefore, sound waves can be trapped in a narrow channel. Some scientists hypothesize that certain species of whales utilize the SOFAR channel to spread mating calls over long distances.

Due to the interfaces and seabed reflections, sound can travel between a source and the receivers through several paths. This has the effect of diluting the arrival of signal in time. This effect is particularly important for a large frequency range of impulsive sounds such as explosions, pile driving or seismic exploration by air guns. If any of the propagation effects are frequency sensitive, then frequency dilution will also occur. A common example of this is the noise of air guns operating at great distances from a receiver, in which the low frequencies travel more slowly than the high frequencies, and the single impulse at the source is then turned into a frequency sweep at the receiver. The time dispersion effect reduces the peak energy in the received signal, and, although the integrated signal level remains unchanged, on balance the peak levels can be significantly reduced. For narrowband signals, the effects of multipath propagation can cause large fluctuations in the received signal level.

Pile-founded wind turbines are installed in relatively shallow waters up to 50 m water depth and transmission loss (TL) might be described by cylindrical spreading, with TL = 10 log (r), where TL = transmission loss and r = range in metres (Richardson et *al*., 1995). However, several field studies indicated a higher transmission loss in shallow waters, sometimes being higher than 20 log (r), depending on local conditions (Nedwell et *al*., 2003a; Nedwell and Howell 2004; Madsen et *al*., 2006).

Another factor that has to be considered is absorption of energy by the medium. Absorption of sound by seawater increases with increasing frequency with energy loss being proportional to the square of frequency (Urick 1983; Richardson et *al*., 1995). Therefore, transmission loss can be given by: $TL = SL + \alpha r$, where SL = spreading loss and α = absorption coefficient. The absorption coefficient is frequency-dependent and can be calculated by: $\alpha = 0.036\ f1.5$ (dB/km) with f = frequency in kHz (Richardson et *al*., 1995). For frequencies < 1 kHz, absorption is less than 0.1 dB/km and therefore not significant. However, at higher frequencies, absorption can cause significant loss at long ranges. Yet another factor affecting transmission loss is scattering due to reflections at boundaries (surface, bottom and shore) and other obstacles. The amount of energy lost

due to scattering varies with the roughness of the bottom and the frequency of the incident sound. Soft bottoms (e.g. mud) are associated with high bottom loss, whereas hard bottoms such as smooth rock or sand produce lower losses (Urick, 1983).

Thiele, (2002) developed a formula that is applicable for coastal North Sea and Baltic waters with water depths up to 100 m, a sandy bottom and wind-speeds < 20 knots:

TL = (16.07 + 0.185 FL) (log (r/1.000 m) + 3) + (0.174 + 0.046 FL + 0.005 FL2) r

Where FL = 10 log (f / 1 kHz; 1 m - 80 km, frequencies f in kHz from 100 Hz - > 10 kHz)

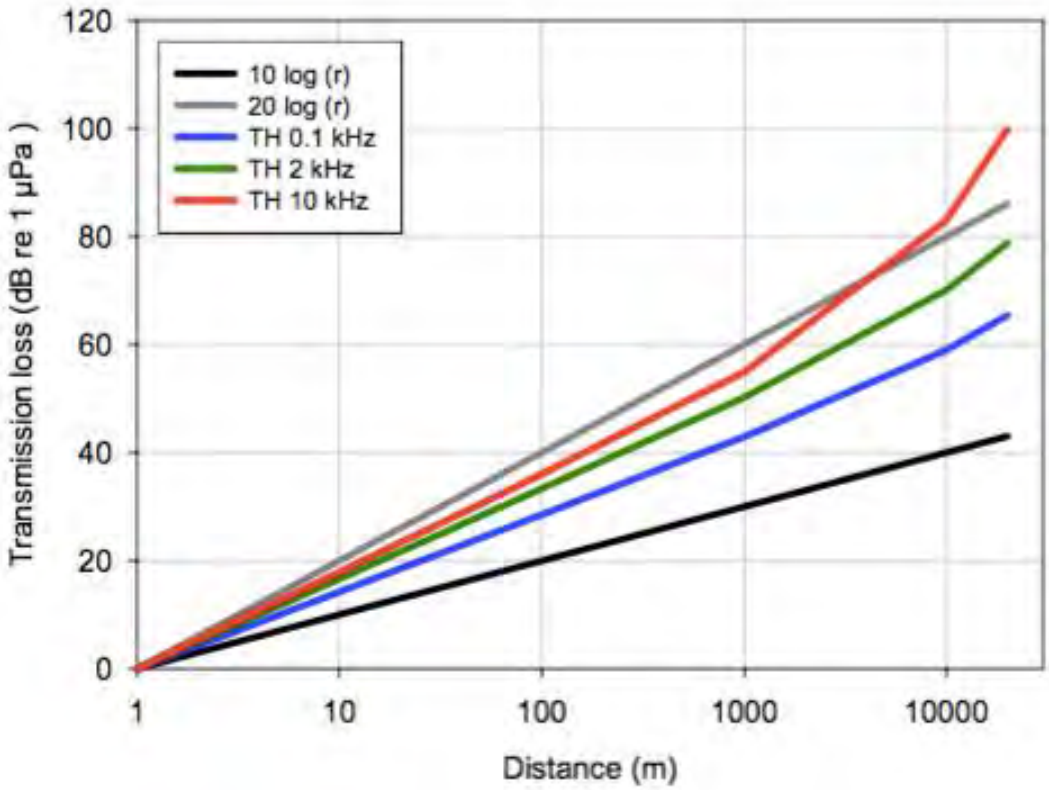


Figure 109: transmission loss at distance from 10 m to 10 km, calculated with different models (TH, Thiele 2002; 10logr cylindricla spreading; 20logr spherical spreading) (*Source: Thomsen et al., 2006*)

Noise from wind turbines comes in two forms: the first is aerodynamic noise from the blades slicing through the air leading to the characteristic noise; the second is mechanical noise associated with machinery housed in the nacelle of the turbine. Aerodynamic noise diffuses through the air to the interface between the air and water where it is almost entirely reflected. Little aerodynamic noise enters the marine environment. Conversely, the mechanical noise has a strong structural pathway between the drive train (where the vibration is created), through the nacelle support frame, the tower, into the foundation on platform and finally from the platform into the surrounding water where it is released as noise. The great majority of noise in the marine environment due to wind turbines is therefore related to mechanical vibration in the drive train.

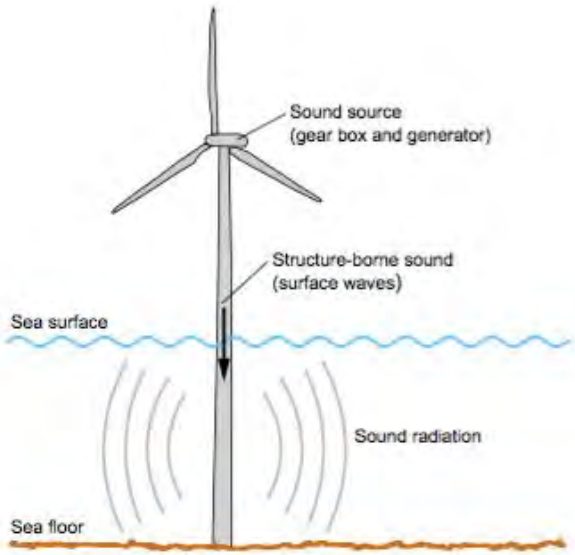


Figure 110: Founded wind turbine sound transmission (*Source: Betke, 2006*)

Vibration of the turbine's gearbox and generator is guided downwards and radiated as sound from the tower wall. Sound radiation by surface waves is difficult to compute and to predict, in particular for complicated boundary conditions.

The potential sources of noise in marine renewable energy devices are represented by:

- Structural Noise
- Rotating Machinery
- Electrical Noise
- Moving fluids
- Mooring lines
- Flexing Joints

The noise generated by these elements of the devices can be transmitted to the sea through several paths, as:

Direct coupling, with the noise generator in direct contact with the sea, e.g. the flexing joints of a wave generator. This mechanism can be the most efficient coupling mechanism.

Mechanical coupling requires a mechanical path between the noise source and the sea, as a rotational noise of a wind turbine being coupled via the nacelle support into a metallic hull directly in contact with the sea. The path can modify the characteristic of the sound.

Air coupling requires that sounds generated from the aerial part of device are then coupled through the air-water interface into the water column. This is a very inefficient coupling system due to the acoustic impedance between air and water.

Mechanical vibrations in the drive trains of wind turbines are created by imbalances of the rotating components, the teeth in the gearbox coming into contact with each other (referred to as gear meshing), and electro-magnetic (E-M) interaction between the spinning poles and stationary stators in the generator. Each of these vibration sources occurs in discrete frequency bands related

to the rotation speed of each component: the vibrations therefore tend to be tonal (as opposed to broad band). Rotational imbalances tend to occur at very low frequencies (< 50 Hz), while gear meshing and E-M interactions tend to occur at low to moderate frequencies (50 Hz to 2 kHz). Other mechanical vibration produced by wind turbines during normal operation tends to be of a temporal nature with durations of seconds to tens of seconds. These include the pumping of hydraulic fluid, cooling systems and yawing of the nacelle followed by braking.

Table 25: Frequency bands likely to contain vibration tones produced in the drive train of wind turbines (*Source: Betke, 2006*)

	Frequency
Rotational imbalance of rotor	0.05 to 0.5 Hz
Rotational imbalance of high speed shaft between gearbox and generator	10 to 50 Hz
Gear teeth meshing	8 to 1000 Hz
Electro-magnetic interactions in the generator	50 to 2000 Hz

The amplitude of the vibration of a wind turbine and related noise emitted by the foundation is controlled by the size of the excitation force, the frequency of structural resonances and the level of damping in the structure. The magnitude of the excitation of the drive train is related to the torque acting on the rotor, which is dependent on the wind speed. The amplitude of vibration of the turbine increases with the square of wind speed at the hub height. It is likely, therefore, that the noise emitted by the foundation will also rise with wind speed.

Mechanical noise can be amplified by structural resonances within the wind turbine. Structural resonances are the harmonic frequencies at which a structure vibrates when excited by a discrete event. When an excitation frequency such as gear meshing has the same frequency as a structural resonance, the amplitude of the vibration is amplified, sometime dramatically. This becomes important in the event of frequency matching between an excitation frequency in the drive train and a resonance in the foundation as the noise emitted into the marine environment will be significantly amplified. Understanding structural resonances is also important because resonances can be excited by multiples of excitation frequencies. Structural resonances can therefore produce vibration and related noise at frequencies that would not otherwise have been excited.

All structures contain some level of internal damping. Damping is the dissipation of vibration energy via processes like heat loss and has the effect of reducing the amplitude of vibration. In general, steel structures such as jackets have less damping than structures built from granular materials such as concrete foundations. The level of internal damping will therefore affect the noise emitted by different types of foundations. Damping may also be increased over time by biofouling, where the encrusted organisms begin to act as a granular aggregate with high internal friction.

Several underwater acoustic measurements of offshore wind turbines have been carried out (Betke et *al*., 2004; Thomsen, 2006; Nedwell 2011). Measurements recorded have been of turbines with different design parameters, such as foundation type, water depth, turbine size, sediment type

and wind speeds - making direct comparisons difficult. However, noise related to off-shore wind turbines have common features; specifically, the sound intensity is dominated by pure tones likely to originate from rotating machinery in the nacelle with frequencies mostly below 700 Hz.

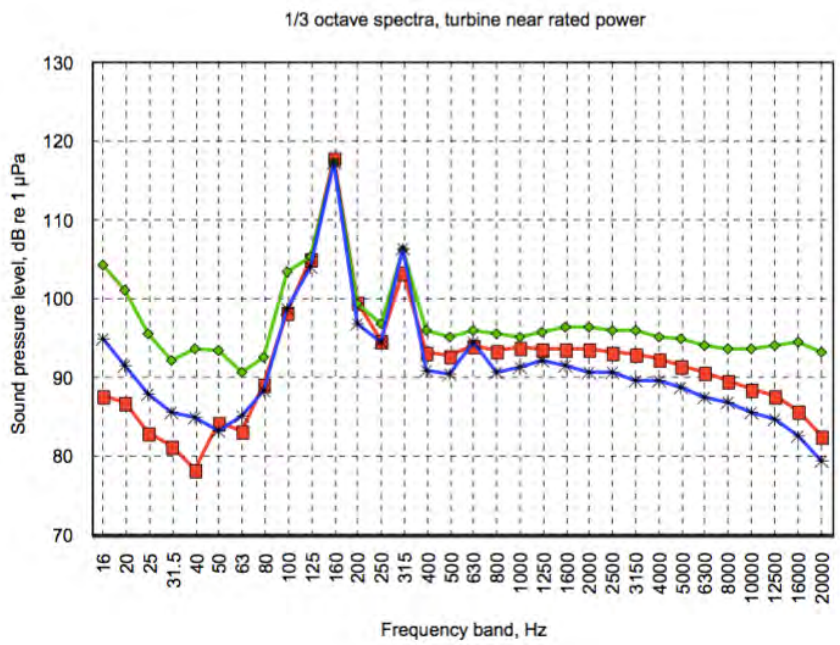


Figure 111: transmitted frequencies of a 2MW wind turbine, at wind speeds from 11,9 to 15,6 m/sec (*Source: Betke, 2006*)

The main sources of noise related to site preparation and device installation are broadly similar to those involved in an offshore renewable farm construction mainly including noise from shipping activity, machinery and dredging. Additionally, cable burial requires the use of trenching or jetting machinery in soft sediments and rock cutting machinery in hard seabeds, or rock or concrete mattress layer to protect cables in areas where they cannot be buried. Furthermore, construction of a marine energy installation involves a considerable amount of shipping activity to carry equipment and personnel between the site and the base port.

Ship noise may be an issue for maintenance activities undertaken during operation of the devices, particularly if the area has never been previously subject to shipping. The shipping noise reported in Richardson et *al*. (1995), was between 20 Hz and 10 kHz with source levels between 130 and 160 dB re 1 µPa at 1 m. Medium-sized boats (30 m and more) can exhibit source levels of 160 dB re 1 µPa at 250 Hz and 150 dB re 1 µPa at 2 kHz.

Table 26: Noise levels within the earing range at various distances (*Source: Thomsen et al., 2006*)

	Ship noise (dB_{rms} re 1μPa)	
Distance to source	**0.25 kHz**	**2 kHz**
1 m	160	150
10 m	145	133
50 m	135	122
100 m	130	117
1 km	115	100
10 km	99	80

Marine fauna exposed to anthropogenic sound may experience detrimental effects that include physical injury, behavioural disturbance and displacement, masking of biologically important signals, and other indirect effects. These are defined by the proximity of the animal to the sound source, the sound level received by the animal, the hearing sensitivity and acoustic characteristics of the vocalisations of the animal, and the acoustic characteristics of the anthropogenic noise.

The key potential impacts of operational turbine noise on marine species are:

- Disturbance as a result of underwater noise arising from operational offshore wind turbines.
- Potential longer-term avoidance of the development area by marine mammals
- Potential reduction of the feeding resource due to the effects of noise, vibration, and habitat disturbance on important prey species

The frequency band over which different species can sense noise varies greatly. In general fish sense noise in the 10s to 100s of Hz range, though some clupeiform fish including shad may hear into the 100s kHz range. Marine mammals such as seals, dolphins and whales are capable of hearing noise between 10s of Hz to 100s of kHz. Wind turbines produce vibration and related noise between 0.5 Hz to 2 kHz, which overlaps frequency bands that are detectable by several marine species.

While marine species are capable of hearing noise from wind turbines, in many cases this will be masked by the background noise of the ocean. The ocean is inherently a noisy place with background noise contributed by wind interaction with the surface, rain, industrial activity and shipping, explosions and earthquakes and biological activity. At some range from a wind turbine the noise produced will be less than the background noise at which point marine species will no longer be able to detect it. Of particular importance in relation to wind turbines is the relationship between wind speed and noise production. As has been noted above, the vibration and noise produced by wind turbines increases with wind speed. There is a similar relationship between wind speed and background noise (Urick, 1983). Thus, while wind turbine noise increases with wind speed, so too does the masking effect of background noise.

One species of marine mammals – the Harbour porpoise (*Phocaena phocaena*) has widely been used as model in studies on noise sensitivities. This species is widely distributed throughout all the

European Atlantic area and has wide-ranging hearing abilities and sensitivities to sound levels and frequencies. Harbour porpoises rely heavily on sound for orientation and foraging. They have a very wide hearing range with relatively high hearing thresholds of 92 – 115 dB re 1 µPa below 1 kHz, good hearing with thresholds of 60 – 80 dB re 1 µPa between 1 and 8 kHz, and excellent hearing abilities with thresholds of 32 – 46 dB re 1 µPa between 16 and 140 kHz (Kastelein et *al*., 2002). These hearing abilities closely match sounds emitted by conspecifics used for communication and echolocation (Verboom & Kastelein, 1995).

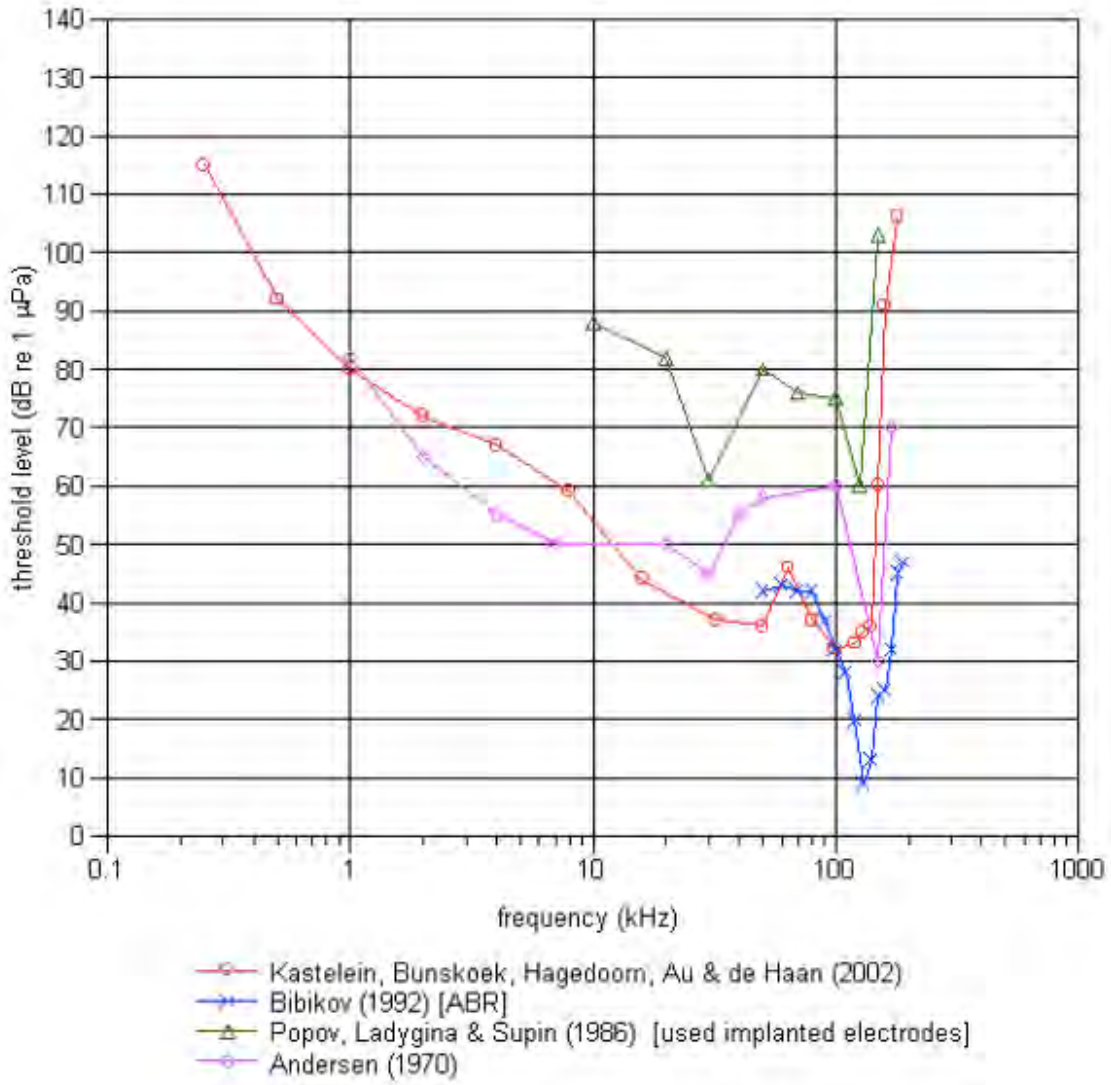


Figure 112: Audiogram for Harbour porpoise (*Phocoena phocoena*) (Source: Nedwell et *al*., 2004)

With regard to shipping noise, the zone of audibility of harbour porpoises ranges from 1 – 3 km depending on the frequency of noise emitted by the ship (Thomsen et al. 2006). The audibility can range between 3 and 20 km, and a zone of masking of other audible signals may occur at distances of up to 15 km. Shipping noise, which will occur over long periods of time (i.e. several hours to

several days, as in the case of installation operations), can therefore be a powerful pressure agent for this and for other species displaying a similar range of sensitivity.

The hearing ability of fish varies greatly in different species. Typically, fish perceive sound via particle motion in the inner ear through the sound-induced motions in the fish's body. The detection of sound pressure is restricted to those fish which have gas-filled swim bladders; however, particle motion can be somehow detected also by fish without swim bladders. Fish with swim bladders that are mechanically coupledto the inner ear have the higher sensitivity to variations in sound pressure, being able to detect sounds over 3 kHz with the best sensitivity between a 300 to 1000 Hz (Popper et al., 2003). These species are described as *sound specialists*.

Fish that do not have a mechanical way of coupling the sound-induced motions in the body with the inner ear have relatively low sensitivity, being able to detect sounds up to 500 – 1000 Hz, with best hearing capability between approximately 100 and 400 Hz. (Popper et al., 2003).

These fish can be categorised as *sound generalists*.

Table 27: Hearing sensitivity of some Atlantic fish species (*Source: Nedwell & Howell, 2004b*)

Species	Common name	Family	Swimbladder connection	Sensitivity
Anguilla anguilla	European eel	Anguillidae	None(1)	Medium
Clupea harengus	Herring	Clupeoidea	Prootic auditory bullae(2)	High
Cottus scorpius	Sculpin	Cottidae	No swimbladder(1)	Low
Gadus morhua	Cod	Gadidae	None(1)	Medium
Limanda limanda	Dab	Pleuronectidae	No swimbladder(1)	Low
Melanogrammus aeglefinus	Haddock	Gadidae	None(1)	Medium
Merluccius merluccius	European hake	Merluccidae	None(1)	Medium
Pleuronectes platessa	Plaice	Pleuronectidae	No swimbladder(3)	Low
Raja clavata	Thornback skate	Rajidae	No swimbladder(1)	Low
Scomber scomber	Atlantic mackerel	Scombridae	None(1)	Medium
Sprattus sprattus	Sprat	Clupeoidea	Prootic auditory bullae(2)	High

A BGF installation would be composed by several wave energy devices (WEC) and would also include a wind turbine and a large fish farm. In order to assess the underwater noise field originating from such multiple sources, it would be necessary to know the details of the seound emission, in terms of frequencies and sound pressure levels, of each device. Moreovere, it will be of great importance the spatial arrangement between the devices and the possible resonance effect inside the empties of the concrete caissons. It would also be necessary to know the acoustic environment (i.e. water depth, sound speed profile, seabed type and background noise level) to properly simulate the sound propagation among devices in the array, and from the array to the surrounding area.

Giving the above, an a priori simulation it's not yet possible, and such a complex structure have to be properly monitored to ensure that transmitted sounds do not impact the sourrounding natural environment.

4.2.3 Entangling structures

The BGF platform has a massive floating structure, and may represent an obstacle to the free movement of wild animals. However, platform is a static installation and the risk of trapping into moving part is null, excludingg the wind turbine, commented in another paragraph.

The WEC device presents a large opening leading to a sort of "underwater cave", which top is filled by air. Seals, diving birds and fish may temporarily occupy this space looking from shelter from predators or from open sea dynamic movements. Nevertheless, this confined environment can be exploited only in calm wave condition, when movement of inner water remains limited. In harsh wave weather, it's realistic that the enclosure would be abandoned. Ways of entering and exit from the WEC are large and below sea level, therefore any diffculty is expected to animals moving away from it.

Other flexible structure as nets can give a risk to diving birds; this point will be commented further in following paragraphs.

4.2.4 ELECTROMAGNETIC EMISSIONS

Power cables for transmitting electricity are able to produce electric and magnetic fields as a result of the current flowing in the conductor and the voltage differential. The nature and strength of these fields depends on the system voltage and current type (AC or DC) flowing through the cable. The effects on the surrounding environment also depend on the cable features and orientation in space. The materials constituting sheath and armour are permeable to magnetic fields, which will then diffuse into the surrounding environment.

The term EMF is be used to describe the direct electromagnetic field. The two constituent fields of the EMF are defined as the E (Electric) field and the B (Magnetic Field) field, and the induced electric field is regarded as the (iE) field.

Magnetic Fields (B) are produced from either AC or DC current passing through the conductor and emanate outwards from the cable perpendicularly to its longitudinal axis. The field strength decreases with the distance from the source, and the decay curve follows an inverse square law.

The magnetic field around an AC cable is constantly changing at the same frequency of the alternating current, and the modulation produced in the Earth's field will also be constantly changing.

The electric fields (E) produced by power cables are, for the most part, contained within the cable envelope by the screening effect of the sheath and armouring. Electric fields can, however, be induced in nearby electrical conductors, including seawater, fish, metallic objects, etc., within the area influenced by the cable's magnetic field. When there is a relative motion between the conductor and a magnetic field, a potential difference (electric field) will be created between the different parts of the conductor. This means that a mass of seawater or a marine organism passing through the magnetic field of an AC cable will have an electric field induced within it.

The electric field strength will vary with:

- the distance from the cables – the field decay curve follows an inverse square law;
- the strength of the magnetic field, relating to line current;

- the direction and speed of the water flow;
- the chemical properties of the external conductor.

In summary, while the field will be retained within the armour of industry-standard cables, the B field and the induced field are detectable outside the cable.

The Earth has a natural magnetic field (the geomagnetic field) forming the background against which artificial magnetic fields can be detected. This background field strength varies over time and in different Earth regions. Local variations in the geomagnetic field are a characteristic of the seabed and underlying rock strata properties.

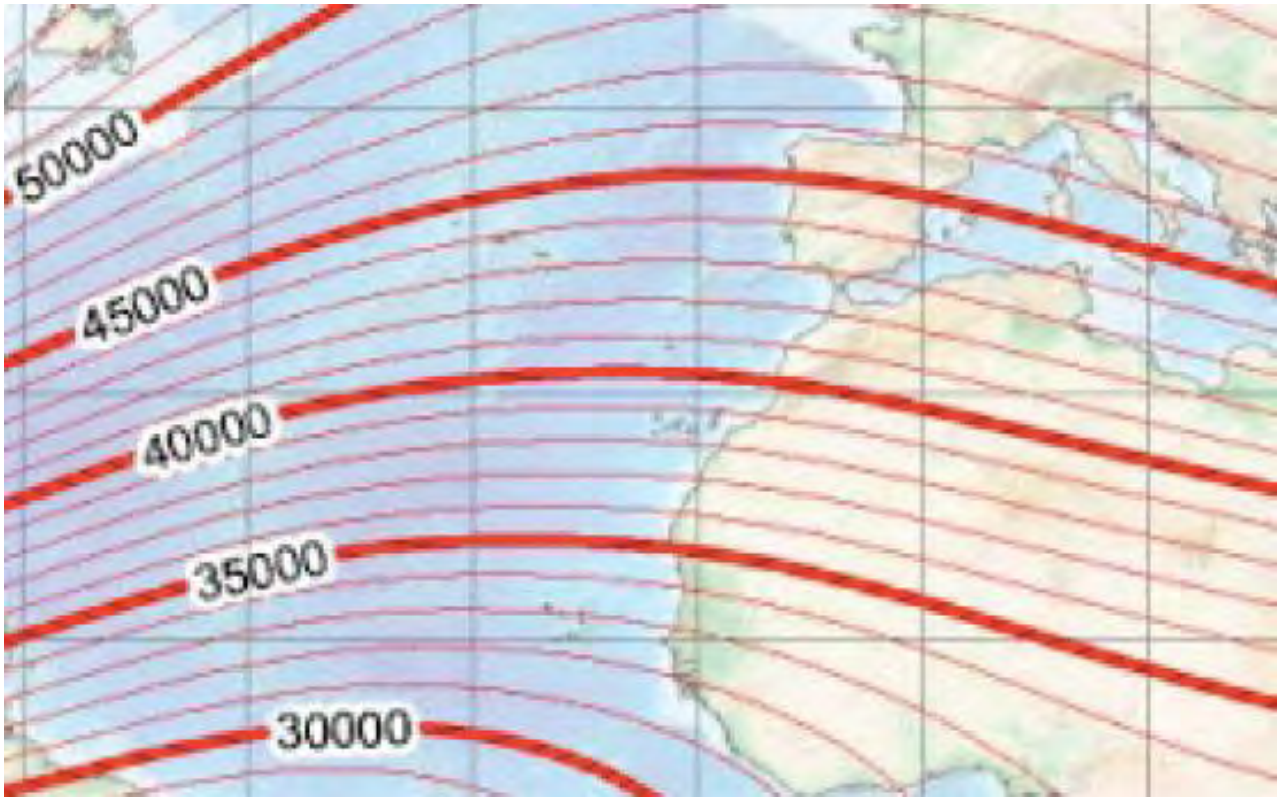


Figure 113: Intensity of geo-magnetic field (*Source: NOAA*)

In the marine environment, organisms directly emit electric fields either as a result of their own physiological processes. Induced E fields can also occur by interaction of a conductor (an organism or seawater) with geomagnetic flux lines. Electric fields are therefore induced in seawater as it moves through the earth's magnetic field. The background electric fields will be not be steady, due to the variations of water flow related to local conditions (tides and weather conditions). Increasing conductor (e.g. seawater) speeds results in an increase of the background electric field.

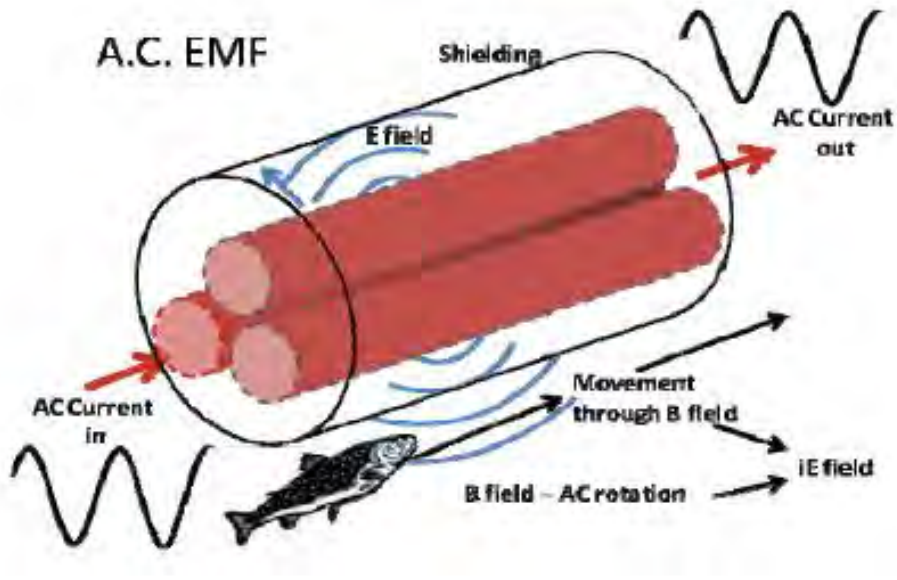


Figure 114: Electrical (E; iE) and Magnetic (B) fields associated to an AC high-voltage cable (*Source: Gill & Bartlett, 2010*)

Artificial sources of electrical and magnetic fields are present in marine environment since many years, as in offshore cables (telecommunications and power) and heated pipelines. These sources are able to produce electric and magnetic fields of a magnitude comparable to the cables of an offshore renewable energy installation.

Marine organisms are able to detect magnetic fields in two ways, by detecting the induced electric field, or by a magnetite-based detection.

The first mode refers to electro-receptive species as Elamobranchs (Sharks, Rays, Skates, and Ratfish). It is generally assumed that they use the iE field detection for navigation. Elasmobranchs utilise this mode in a passive way- when the animal estimates its drift in relation to the vertical component of the Earth's magnetic field – or in active way - when the estimation of its magnetic compass heading arises from the interaction with the Earth's magnetic field.

The electric fields generated by sea currents passing through the earth's magnetic field can be perceived by elasmobranchs and used for orienteering (CMACS, 2005). Sharks' body itself induce an electric field (range 5 to 50 µV/m) around by swimming through the background magnetic field: this allows the animal to detect its magnetic compass headings. In addition to the earth's magnetic field, the local geomagnetic anomalies form a pattern of magnetic distortions, within which sharks can track, as reading a low-resolution 'magnetic' map.

Magnetite deposits also play an important role in geomagnetic field detection in several animals, not only marine (such as birds, insects, fish and cetaceans; CMACS, 2005). For these species sensitivity to the geomagnetic field is associated with a direction-finding ability. Some salmon and eel species are considered able to use magnetic navigation during their migrations.

In a platform like the BGF, the electric and magnetic fields will be produced as a result of the power transmission through the power disptchment cables.

The design of the sub-sea cable is a key factor, as the shielding, the power transmitted and the installation design (burial depth), indetermining the electromagnetic fields induced.

The BGF cable will be rated of 33kV AC.

Table 28: EMF output parameters for industry standard cables buried 1.5 into the seabed (*Source: Gill & Bartlett, 2010*)

Cable parameter	Cable A	Cable B
Conductor size (mm^2)	500	185
Maximum voltage (kV)	33	33
Maximum current (A)	530	265
Maximum B field in seabed (μT)	1.5	0.9
Maximum B field in sea (μT)	0.03	0.02
Maximum current density in seabed (μA m^{-2})	40	25
Maximum current density in sea (μA m^{-2})	10	6
Maximum iE field in seabed (μV m^{-1})	40	25
Maximum iE field in sea(μV m^{-1})	2.5	1.5
Estimated normal iE field in seabed (μV m^{-1})	20	12.5
Estimated normal B field in sea (μT)	0.015	0.01

CHAPTER 5: ENVIRONMENTAL IMPACT ASSESSMENT

5.1 IMPACT ASSESSMENT

5.1.1 Impact on birds

<u>The collision risk model (from Band, 2012)</u>

In this paragrapgh the description of the Band model is reported; this description is derived from available literature on the topic.

The Collision Risk Model (CRM) (Band 2000; Band et al. 2007; Band 2012a) is widely used to estimate the risk to birds flying through wind farms. The model considers the number of animals likely to pass through each rotor, and the probability of collision for each such passage. The CRM refers to a 'no-avoidance collision rate', i.e. the collision rate assuming no avoidance action – this is a concept equivalent to the 'encounter rate' in other models. In the CRM the animals are assumed to be flying in a direction directly towards the rotor, i.e. in a direction perpendicular to the rotor plane. Only the component of velocity directly towards the rotor, taken as the mean flying speed, is considered when calculating the risk of collision in one transit.

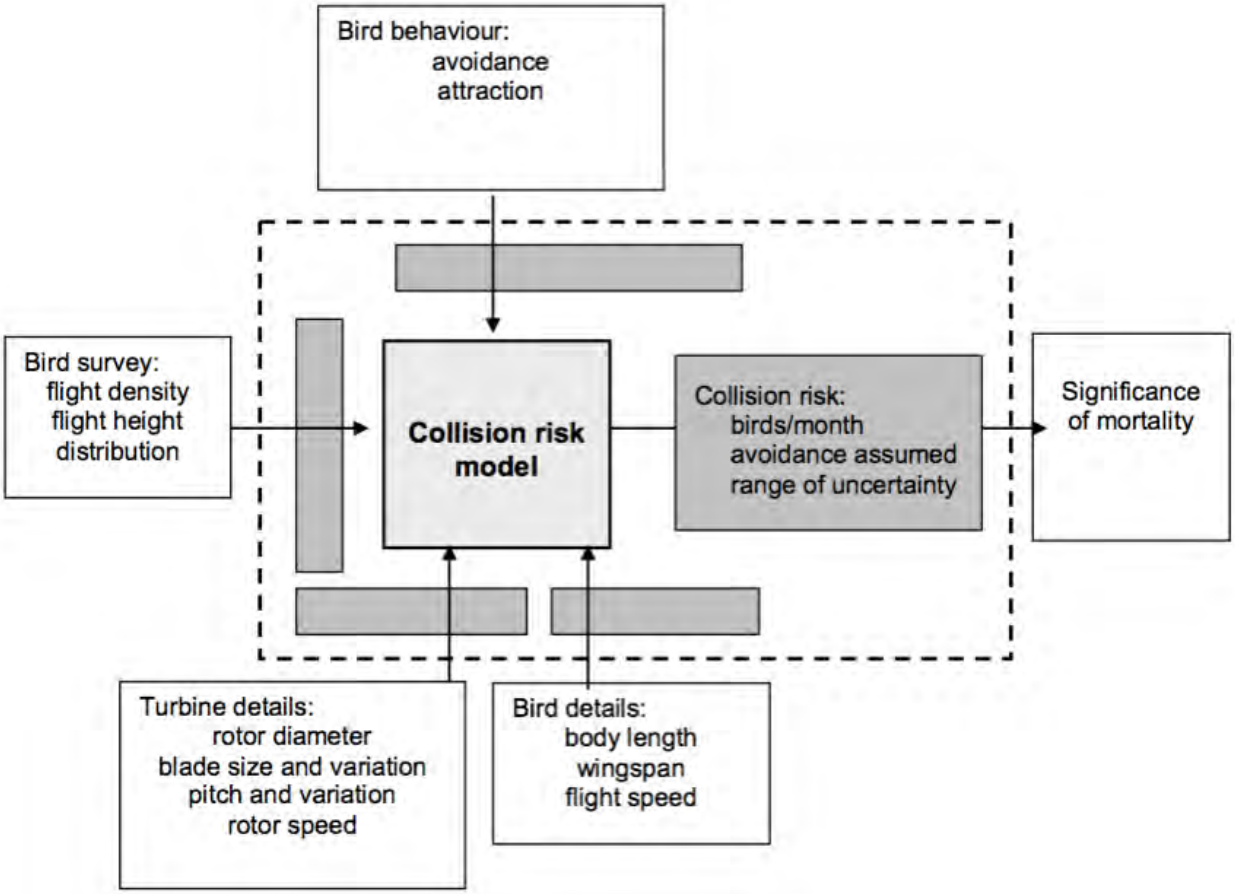


Figure 115: The collision risk model, from Band, 2012

The approach adopted follows in general terms that developed by Band (2000i) and Band et al (2007ii) and promoted in guidance published by Scottish Natural Heritage, but it has been updated to facilitate application in the offshore environment. The offshore approach differs from onshore mainly in the methods used to gather and present information on flight activity, given that direct observations of birds from key vantage points are not usually possible in the marine environment. The approach is described below in six stages:

- Assemble data on the number of flights which, in the absence of birds being displaced or taking other avoiding action, or being attracted to the windfarm, are potentially at risk from windfarm turbines; The aim of this stage is to estimate the number of flights which, in the absence of birds being displaced or taking other avoiding action, or being attracted to the windfarm, would potentially be at risk from the windfarm turbines. This requires field data to determine levels of flight activity within the proposed windfarm.
- Use that flight activity data to estimate the potential number of bird transits through rotors of the windfarm.
- Calculate the probability of collision during a single bird rotor transit. This stage uses information on the size and speed of the turbines, and physical details on the size and speed of the bird, to compute the risk of collision for a bird flying through a rotating rotor.

- Multiply these to yield the potential collision mortality rate for the bird species in question, allowing for the proportion of time that turbines are not operational, assuming current bird use of the site and that no avoiding action is taken.
- Allow for the proportion of birds likely to avoid the windfarm or its turbines, either because they have been displaced from the site or because they take evasive action; and allow for any attraction by birds to the windfarm e.g. in response to changing habitats.
- Express the uncertainty surrounding such a collision risk estimate.

The basic model has recently (March 2012) been extended to make use, where it is available, of data on the distribution of bird flight heights; in particular to enable use of the data on flight heights of birds at sea compiled for SOSS by Cook et al. This 'extended model' is described following Stage D, as within that model Stages B, C and D become merged in a single calculation. Another addition is Annex 6, which describes use of the model when assessing the collision risk to birds on migration, where there may be limited bird survey information on flight activity.

The risk in this model is calculated directly from the rotor parameters and the flight activity in the airspace surrounding each turbine. Some practitioners have used an approach which considers the risk to each bird passing through a windfarm, taking account of the layout and spacing of turbines to calculate the likelihood of encountering one or more turbines and the resulting risk. This is unnecessary if one focuses, as in this guidance, on the risk resulting from each turbine operating within its own airspace within which there is a known (or projected) level of flight activity.

There is a simplification involved in separating out Stages B and C, in assuming that the probability of collision for any bird passing through a rotor is the same regardless of the direction of flight. In fact, the collision risk depends to some extent on a bird's angle of approach, determined by the direction of its flight and the orientation of the turbine blades. A bird approaching a turbine at an oblique angle is exposed both to a reduced probability of flying through the rotor, because the rotor presents an elliptical rather than circular cross-section, and an increased risk of collision if it does so. The model adopted for use here assumes that these two factors exactly offset each other, such that all bird transits can be treated as if making perpendicular approach to the rotor. This enables Stages B and C to be undertaken sequentially. A more exact approach would require estimating the number of flights from each direction, applying the collision probability for that direction, and summing the probability over all directions. Annex 1 provides a fuller explanation of this issue and the justification for adopting the simplified approach. It should be recognised that this simplification leads to some underestimation of collision risk, which may be as much as 10% for large birds.

Seabirds mostly fly at relatively low heights over the sea surface. The height distribution varies from species to species and may depend on the site and its ecology and related bird behaviour. The basic model considers the risk only to birds flying at risk height (above the minimum and below the maximum height of the rotors) and of these, only those which pass through the rotors. However, within these limits it assumes a uniform distribution of bird flights. There are some consequences of a skewed distribution of flights with height:

1- the proportion of birds flying at risk height decreases as the height of the rotor is increased; more birds miss the rotor, where flights lie close to the bottom of the circle presented by the rotor; and
2- the collision risk, for birds passing through the lower parts of a rotor, is less than the average collision risk for the whole rotor.

The present extended model (March 2012) enables flight height distributions to be incorporated in the calculation, for use in circumstances where flight height data is available and adequately robust.

Literature on the topic does not recommend use of 'worst case' assumptions at every stage. These can lead to an overly pessimistic result, and one in which the source of the difficulty is often concealed. Rather, it is recommended that 'best estimates' are deployed, and with them an analysis of the uncertainty or variability surrounding each estimate and the range within which the collision risk can be assessed with confidence. In stating such a range, the aspiration should be to pitch that at a 95% confidence level, that is, so that there is 95% likelihood that the collision risk falls within the specified range. However, given the uncertainties and variability in source data, and the limited firm information on bird avoidance behaviour, it seems likely that for many aspects the range of uncertainty may have to be the product of expert judgement, rather than derived from statistical analysis.

The model, written around quantifying the collision risk from an entire windfarm, can equally well be applied at the level of a subgroup of turbines or even an individual turbine. If the data on flight activity is sufficiently robust to allow such discrimination, this facilitates the examination of risk on a spatial basis. Collision risk is directly proportional to flight activity which is dependent on bird density at rotor risk height. Siting windfarms, or groups of turbines, in areas of lower bird density is likely to yield a proportionately lower collision risk.

The CRM calculates the number of passages through a rotor which would be made by animals during a period such as a year, using the same formula as equation (1), applying it to complete rotors, not to each individual blade. However, given that there is a significant probability of an animal passing through a rotor without colliding, this is then multiplied by the risk of collision during a single transit:

(1) Collision rate derived using the CRM model:

C = D x B π (R + 0.5 W x v animal speed x pcoll (8) mean risk of collision during single transit

Animal density cross-sectional area of B rotors D is once again the animal density in animals m^3. The cross-sectional area of each turbine through which animal transits may occur is π (R+0.5W)^2 where the radius R is extended by half an animal breadth 0.5 W to allow for animals not clearing the blade tips.

v is the speed with which the animals approach the rotors. In one second, all animals within a cylindrical volume of cross-sectional area π (R+0.5W)^2 and length v (i.e. volume π (R+0.5W)^2v) will pass through a rotor. Thus, for B rotors, the number of transits in unit time is:

No of transits = D B π (R + 0.5W)^2 v. Where D is animal density, in animals/m^3 (9)

Not all transits through the swept area of a rotor will lead to a collision, however, since there is space for passage between the blades, at least for animals which are small relative to the turbine. In a second stage, the CRM multiplies that transit rate by the average risk of collision for a single transit, calculated using information on blade size, taper, speed of rotation, and on animal size, shape and speed:

No of collisions = No of transits x Risk of collision during a single transit (10)

The idealised animal shape used in the model is as shown below, pictured as two solid cones, stuck together base to base, travelling in a direction along its longitudinal axis. This shape is quite well matched to the shape of a marine bird, if the circular cross-section at the widest point is regarded as the body cross-section.

This adjustment from R to R+0.5W has not normally been applied when considering bird collisions with wind turbines where W<<R.

In the CRM each blade of the rotor is modelled as a twisted lamina, that is to say the blade has a width (the 'chord') which typically has a maximum some way out from the centre, then tapers off to become narrow at the tip. The blade is assumed to have no thickness (though in reality it will have an aerofoil cross-section). If c is the chord width at radius r, and C is the maximum chord width, the blade chord profile is expressed as a set of values for c/C for values of r/R from 0 to 1. The pitch of the blade – the angle between the flat of the blade and the rotor plane is usually quite small (say 5 degrees) near the tip but increases towards the centre.

Rotor current v rotor axis max chord C radius R blade pitch γ(r) increases towards centre

The risk of collision during a single transit at radius r from the centre can be calculated geometrically:

$p(r) = (b\Omega/2\pi v) [|\pm c \sin \gamma + \alpha c \cos \gamma| + \max (L, W\alpha)]$ (11)

Where:
r is the radius from the rotor centre at the point of transit
b is no of blades
Ω is rotational speed
v is speed of animal relative to rotor (taken as the mean current speed)

c is the chord width of the blade at radius r
γ is the pitch angle of the blade at radius r, relative to the rotor plane
L is the length of the animal
W is its breadth (wingspan for a bird)
$\alpha = v/r\Omega$

For the derivation of equation (11) see Band et *al*. (2007) or Band (2012). It is sufficient to note here that the collision probability p(r) depends on rotor rotation speed Ω, on both the frontal width of the blades (c cos γ) and their depth (c sin γ) and on the dimensions (L, W) of the animal. The risk of collision p(r) also depends on whether the transit is upstream or downstream: the + sign in the ±c sin γ term refers to upstream passage; the – sign to downstream. The majority of transits will be downstream, swept by the current, so the negative sign option in equation (11) is used hereafter in this guidance.

When averaged over the rotor disk area, this gives a mean risk of collision pcoll for a single transit at any random point in the rotor:

Area of rotor disc area of rotor disc
$p_{coll} = \iint p(r)\, dA / \iint dA$ (12)

Where the integrations are over the area of the rotor disc: ∬ dA is just the area of the rotor πR^2. The model assumes that the blades extend right to the rotor axis, i.e. there is no hub.

With this value calculated for pcoll, equation (8) can now be evaluated to get the collision rate C^{CRM}As with the ERM model, C^{CRM} must be multiplied by the time in the period t, and the proportion of time operational, to get the number of no-avoidance collisions

$C^{CRM} t\,(1 - nop)$ (13)

Where nop is the proportion of non-operational time expected. Finally, it must be multiplied by a non-avoidance factor – the estimated proportion of animals failing to take effective avoidance action – to arrive at an estimate of the number of collisions resulting – see section 2.4 and equation 20.

The above equations describe the basic CRM model.

As before C^{CRM} must be multiplied by the time in the period t, and the proportion of time operational nop, to get the number of no-avoidance collisions $C^{CRM}\, t\,(1 - nop)$.

<u>Density of birds in flight and at risk</u>

For the purpose of estimating collision risk, this model starts from measurements, derived from survey information, of bird density, and of the proportion of birds flying at risk height (ie between the lowest and highest points of the rotors).

The most useful way to present information on bird density is on an area basis, ie the total number of birds in flight at any height at a given point in time, per square kilometre (km^2).

The number of birds of any one species passing through a rotor is, among other factors, proportional to the density of flying birds in the vicinity of the rotor, and hence so too is the collision risk to which they are exposed. Therefore, where one of the aims of a collision risk assessment is to choose a windfarm location and design so as to minimise bird collision risks, the starting point should be to select those areas with the lowest density of the bird species vulnerable to collision. For large sites, or for consideration of collision risks at a strategic level, it may be possible to discriminate between different zones of the site or areas with different bird densities. Such information will be helpful in identifying preferred zones for development.

Flight heights

There is only a risk of collision with turbine blades at flight heights between the lowest and highest points of the rotors, a total height 2R, twice the length of a blade. Therefore, an important parameter to estimate is the proportion Q2R of birds flying within that risk height band. The data on bird density should be accompanied by an estimate of the proportion of birds flying within the risk height band for the proposed windfarm. If data is available on the distribution of bird flight density with height, that enables the calculation to be refined to allow for the fact that most flights within this risk height are at a height where the chance of passing through the rotor is low, and the actual risk of collision if they do is also lower than for an average rotor transit. Most seabirds spend a high proportion of their flight time quite close to the sea surface, and therefore any collision risk tends to be concentrated in the lower parts of the rotorvi.

Accurate data on flight heights is difficult to capture. In boat-based surveys, it relies on observers being able to estimate flight heights, and the accuracy of such estimates decreases with height. While aerial survey in the past has not normally yielded flight height information, high-definition digital photography systems are now available which provide increasingly accurate information on flight height.

For some species, survey information at a site may be insufficient to provide a reasonably precise figure for the proportion of birds flying at risk height. Where this is the case, it may be better to use a generic view of flight height behaviour, obtained by combining flight height information gathered from surveys at different sites – for which a detailed report has been compiled by Cook et al (BTO) for SOSSiii. In combining results from different surveys, care is needed to place greatest weight on those with the most robust data, which may imply discarding data with poor levels of precision. The generic information should be reviewed, assessing whether it provides more precise information than the site-based data, and whether the site-based data, if limited, is nonetheless compatible with the generic information. If so, then the generic information should be used. Care must however be taken not to mask any feature of flight behaviour at the site in question which could reflect a genuine difference of behaviour due to environmental variables or the specific use of the site made by the birds. For some species typical flight heights are dependent on the

season, and in such a case it will be best to use seasonally dependent typical flight heights in assessing collision risk for each month, rather than average flight heights across the year.

The central estimate of the proportion of birds flying at risk height should be based on a straightforward analysis of flight height survey data, without any 'margin of uncertainty' added to the risk height range. In addition, alternative +/- estimates should also be presented, reflecting the possibility of a higher or lower proportion of birds flying at risk height. Confidence intervals on flight height data should be used where these are available from the survey information. Otherwise, a realistic view should be taken of the potential for mis- estimation and error in flight height observations by field observers. Confidence intervals should be aimed at around 95% confidence that the true result lays within that range. In some circumstances, this may be no more than an expert view

For obvious reasons, most bird survey is undertaken by day, and it is generally assumed that such sampled levels of flight activity persist throughout daylight hours. Daylight hours depend both on times of year and on latitude.

There is considerable uncertainty about levels of bird flight activity by night. Garthe and Hüppop (2004) ixoffer an expert view on levels of nocturnal flight activity for a range of marine bird species, expressed in terms of a 1-5 ranking of the likely level of nocturnal activity in comparison with observed levels of daytime activity. A rating of 1 represents hardly any flight activity at night, and 5 much flight activity at night. King et *al*. (2009) provides a more comprehensive table with rankings on a similar expert basis for a wider range of seabirds.

Figures used in the collision model should take both day and night flights into account. Where there is no night-time survey data available, or other records of nocturnal activity, for the species in question, it should be assumed that the Garthe and Hüppop/ King et al. 1-5 rankings apply. These rankings should then be translated to levels of flight activity which are respectively 0%, 25%, 50%, 75% and 100% of daytime activity. These percentages are a simple way of quantifying the rankings for use in collision modelling, and they may to some extent be precautionary. For some species, there are no such expert rankings available.

Levels of activity may vary from season to season, and activity at sea may in any case differ from the levels of activity in breeding colonies for which the rankings have been formulated. Some species are particularly active during dawn and dusk or extended twilight periods, or in locations where there is ambient windfarm lighting. When expressing the output of the collision risk assessment, the uncertainty surrounding flight activity should reflect the degree of confidence (or lack of confidence) in the flight activity information.

Estimating number of bird flights through rotors

In the basic model, this stage can be addressed in the following steps:
(i) The observed bird density on an area basis, expressed per unit area, DA.

(ii) Multiply by the proportion Q2R of birds flying at risk height to get only those birds at risk in a column of air of unit area base and 2R high (i.e. from bottom to top of the rotor).

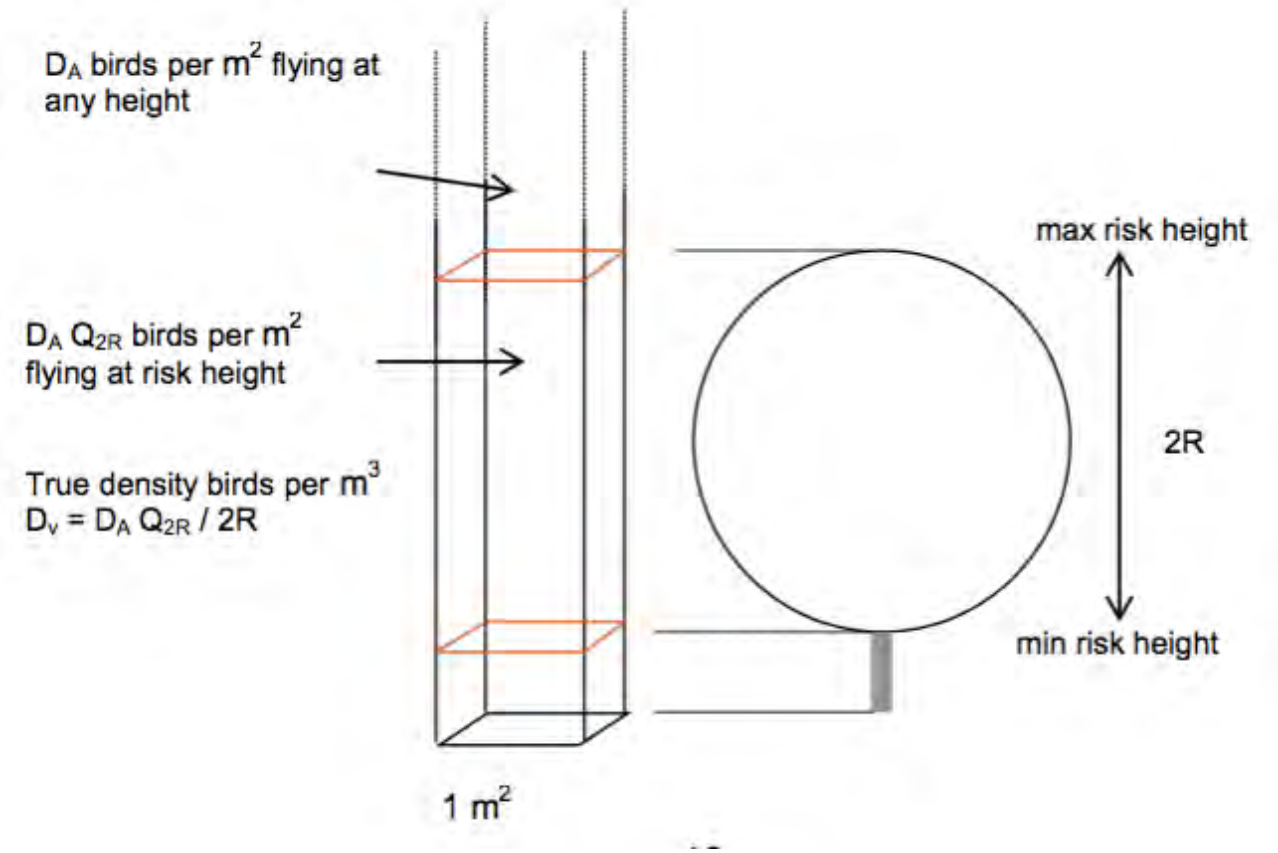
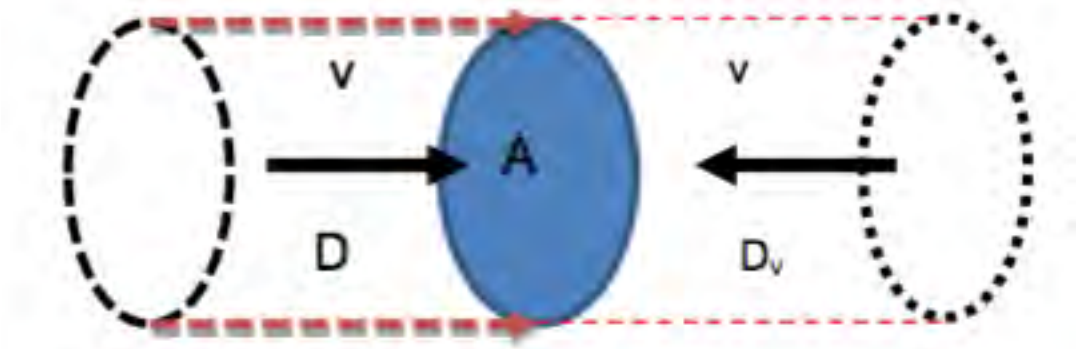


Figure 116: Assessment of bird flights through risk area

(iii) Calculate the true bird density per unit volume DV =(DAQ2R)/2R, expressed in birds per m3 (birds per cubic metre).

(iv) Calculate the flux of birds through a rotor within airspace of true bird density DV. It's assumed that all birds are flying perpendicular to the rotor, and that they are all flying with a single flight speed v., and the rotor faces the wind at all times. It is also, for simplicity, assumed that there are equal numbers of birds flying upwind as are flying downwind, which is important as the collision risk when flying upwind is greater than for downwind flight. Consider the area of the rotor A = πR2. If the birds fly at speed v m/sec, then within one second, all birds within a distance v on one side and flying towards the rotor will pass through the area A. At any one time, half the birds will be travelling upwind and half downwind. Thus, at any time there will be 1⁄2 Dv A v birds flying downwind towards the rotor and, on the other side of the rotor, 1⁄2 Dv A v birds flying upwind towards the rotor.



Thus bird flux $F = \frac{1}{2} D_v (\pi R^2) v$ upwind plus $\frac{1}{2} D_v (\pi R^2) v$ downwind

$= v D_v (\pi R^2)$ in total $= v (D_A/2R) (\pi R^2) Q_{2R}$

Figure 117: Bird flux calculation

This is expressed in birds/second passing through the rotor.

(v) Now multiply by the appropriate number of seconds during which the birds are potentially active (usually the daylight hours in the month t day plus an allowance for nocturnal activity f tnight) multiplied by 3600 to convert to seconds.

(vi) Multiply by the number T of turbines. Each turbine in a windfarm, if it is surrounded by airspace with the same bird density, and if all turbines are of the same size, will experience the same number of bird transits and will therefore contribute the same collision risk to the overall total. If the windfarm includes turbines of different sizes, or zones of differing bird densities, then the calculation should be broken down into subgroups of wind turbines where turbine size and bird density is constant within each subgroup.

The result is an estimate of the total number of bird transits through rotors of the wind farm in the specified period. In the spreadsheet provided, the entry for 'bird transits' calculates the total number of bird transits for each month, taking account of the proportions of flights deemed to be upwind and downwind. It calculates the result on the basis of the values entered for DA, Q2R, R, v, T , time for which birds are active, ie the calculation includes all of stages (i) to (vi) above.

Total number of bird transits = flux factor x proportion at risk height

Total number of bird transits =

$$\underbrace{v (D_A / 2R) (T \pi R^2) (t_{day} + f_{night} \; t_{night})}_{\text{flux factor}} \times \underbrace{Q_{2R}}_{\text{proportion at risk height}}$$

A key output should be a clear statement of the potential number of bird transits per month, and per year, through the windfarm turbines, assuming birds take no avoiding action. The collision risk is directly proportional to the potential number of bird transits.

Probability of collision for a single rotor transit

A bird is simplified in shape to a flying cross with length, wingspan, speed, and always flying perpendicularly towards the rotor. A bird may be 'gliding' (with the arms of the cross fixed, or 'flapping' with the arms of the cross flapping so as to occupy a space similar to that of a spinning top, with the length of the bird being the axis of spin). 'Gliding' flight has a marginally lower collision risk than 'flapping' flight – notably for passage at points level with the rotor hub, where the wings lie parallel with potentially colliding blades.

Rotor blades are assumed to be laminar (ie with zero blade thickness) but they have length, a chord width which varies along the length of the blade tapering towards the tip, and a pitch angle (the angle between the blade and the rotor plane) which also varies along the length of the blade.

With these simplifications, the model calculates the risk of actual collision between the bird and the rotor blades. Such a model has a number of important limitations:

Stationary infrastructure - it is assumed that birds can avoid stationary infrastructure, so no account is taken of the turbine towers, nor the blades when stationary; While this may be a valid assumption in clear daylight conditions it may not be wholly true at night or in conditions of poor visibility.

Turbulence - no account is taken of the effects on a bird's flight of turbulence in the wake of a blade. Observers have seen birds 'knocked out of the sky' by turbulence, and there is potential for this to increase mortality through disorientation or impact with the sea surface. The model only takes account of the potential for physical contact between the bird and the turbine blades. In this respect, the model may underestimate collision risk.

Slipstream - however, it is also the case that the model does not take account of any 'slipstream' effects whereby the air rushing over the surface of a blade may carry a bird clear of the blade when otherwise it was on a collision course. In this respect, the model may over-estimate collision risk.

Bird shape - real birds are larger than represented by a flying cross, though a cross should represent the main extremities. In this respect, the model may underestimate collision risk.

Flight height distribution - the basic collision model evaluates the probability of a bird colliding if it passes at random at any point through the rotor disk on a flight path perpendicular to the rotor plane. In practice, the points of passage of seabirds through the rotor are not distributed uniformly across the rotor. Survey data for seabirds has made clear that typical flight heights for many species are relatively low, such that much of the bird flux through a rotor, and the associated collision risk,

will relate to the lower parts of the rotor plane. Since it averages risk over the entire rotor including higher-risk areas close to the hub, the basic model will overestimate the collision risk for seabirds whose flight passages are more concentrated towards the lower part of the rotor plane.

The model assumes that the collision probability for oblique angles of approach is the same as for perpendicular approach. In fact, some increase in collision risk should be expected, which, taking account of both upwind and downwind flight, may be of order 10% for large birds. In this respect, the model may underestimate collision risk.

The model uses a probability p of collision for a bird flying through a rotor, at a point in the rotor plane defined by coordinates r, φ:

$$p(r,\varphi)=(b\Omega/2\pi v)[\,|\pm c\sin\gamma+\alpha c\cos\gamma| + \max(L, W\alpha F)\,]$$

Where:
r = radius of point passage of bird
φ = angle with rotor plane of bird's passage
b = number of blades
Ω = angular rotor speed
c = chord width
γ = pitch angle
R = rotor radius
L = bird's length
W = wingspan
β = aspect ratio of bird
v = bird's speed
α = v/r Ω
F = coefficient (from 1 to cos φ) for flapping/gliding

This probability is then averaged, by integrating over the entire rotor area, to yield the average collision risk for a bird making a single flight through the rotor at any point through the rotor.

There are three terms in the above equation within the square brackets:

- [c sinγ] relates to the time taken for the bird to clear the depth of the blade, which increases with pitch γ.
- [α c cosγ] relates to the probability of the bird striking the front face of the blades. Note that the appearance of α cancels any dependence of this term on rotor angular velocity Ω and bird speed v.
- [The greater of L, or WαF] relates to the time taken for the full length and wingspan of the bird to clear the sweep of the rotors, for which the geometry depends on the relative speed of bird and blade. Where the bird's aspect ratio β > α, the bird length is the limiting parameter. However, if β > α the wingspan is the limiting parameter. For a flapping bird, p(r) not dependent on φ and F is set to 1. For a gliding bird, the effective wingspan depends

on φ, reducing to zero at φ = π/2 or 3π/2 where the wings lie parallel to the rotor blade; thus F = cos φ.

Due to the geometry of the blades in relation to the flight direction, the collision risk for upwind flight is higher than for downwind, even if the bird's flight speed v relative to the ground is taken to be the same. This is expressed in the alternate sign in the first term, which is + for upwind flight, - for downwind. In practice, birds will fly more slowly in upwind flight than downwind, further widening the difference in risk between upwind and downwind flight. If both upwind and downwind flights are equally likely, it is appropriate to take an average of upwind and downwind collision probabilities.

The basic model assumes that bird flights may occur with equal probability at any point through the rotor disc. Having ascertained the collision risk p(r,φ) at different points r,φ of the rotor, the basic model then calculates an average of p(r,φ) over the entire area of the rotor disc, firstly summing over φ, then summing (integrating) over successive concentric rings, taking account of the area of each ring which increases with radius (= ring circumference 2πr times thickness of ring dr). Finally this sum is divided by the overall disk area to get the average collision probability:

$$p_{average} = \int p(r)(2\pi r)dr / \int (2\pi r)dr = \int p(r)(2\pi r)dr/\pi R = 2\int p(r)(r/R)d(r/R)$$

<u>Wind turbine speed</u>

Wind turbines are designed to operate at a range of speeds. Typically, they do not operate below a cut-in speed (usually between 3 and 4 m/sec), then increase in speed with wind speed up to an operating wind speed (which may be around 12 m/sec). Thereafter, they maintain a constant operating speed by altering the pitch of the blades until, in extreme conditions; the turbine is shut down for safety.

Collision risk should be evaluated using the turbine rotational speed for an operating turbine. Where turbines operate with a range of rotational speeds, the calculation should be done using a mean operational turbine speed. The mean used should be a mean over time, using an analysis of wind data to enable the likely frequency distribution of turbine speeds to be determined. Allowance is made elsewhere in the calculation for the proportion of time that a turbine is non-operational, either because of low wind speeds or for maintenance. The mean turbine speed should thus be a mean over operational time only, not including times when the turbine is idling or stationary. Within the typical range of operating turbine speeds, collision risk varies almost linearly with turbine speed, so that use of a mean turbine speed is adequate in order to yield a mean collision risk.

If a frequency distribution of turbine speeds is not available, then collision risk may be evaluated using the maximum operating turbine speed, but acknowledging that this will result in a collision risk which is an upper bound rather than a mean.

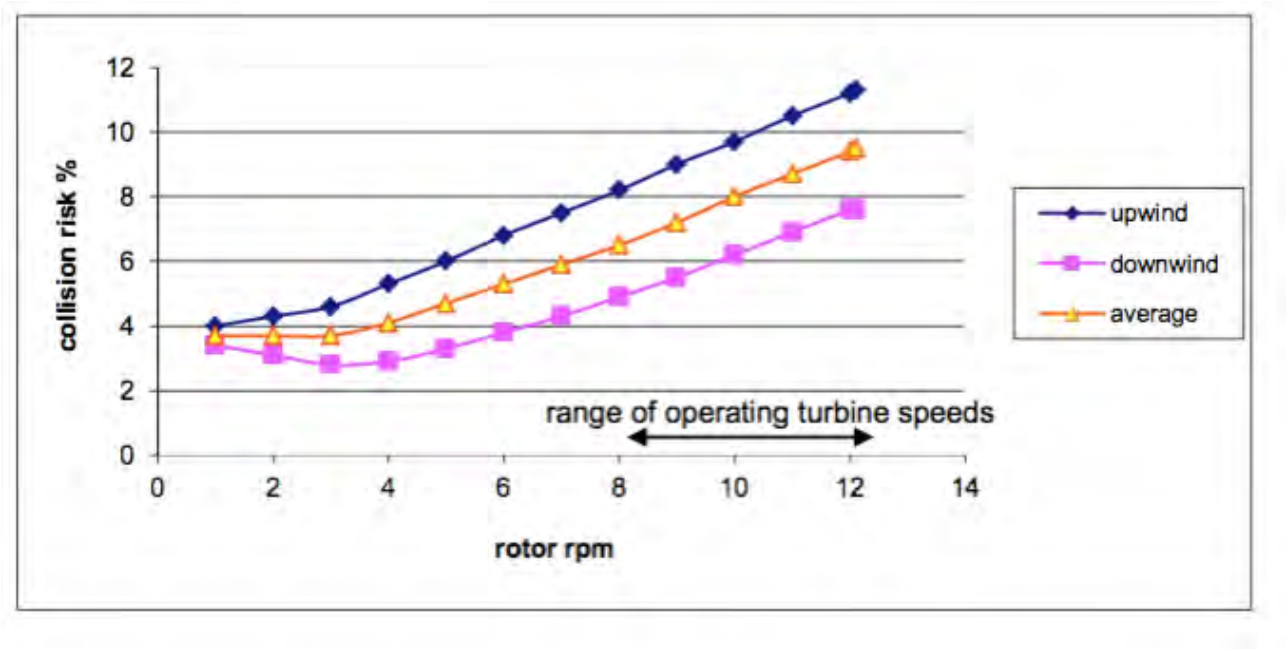


Figure 118: Collision risk for gannet at different rotor speeds

Accuracy of model

Having regard for the various simplifications in the model, and the potential sources of under- and over-estimation described above, at this stage of the model, calculation of no-avoidance collision risk for a single transit should be regarded as indicative of collision probability within around ±20%.

Obtaining expected collisions per year

Basic model – assuming uniform flight density

If the basic model is used, multiplying by the number of bird flights through the rotor is nearly trivial. Stage A has estimated the level of flight activity at potential risk; Stage B has estimated the likely number of flights through rotors across the windfarm; Stage C has calculated the risk of collision for a single bird transit through a rotor. In the present stage, Stage D, these are multiplied together to yield an estimate of total potential collision risk, including a factor to allow for the proportion of time that the wind turbines are operational (before considering avoidance behaviour, which is stage E).

Expected collisions = No of transits x Single transit collision risk x Proportion of time operating

Units

Whichever model is used, there is a need for care with units. In the spreadsheet, flight activity becomes expressed as rotor transits per month and hence the collision risk is in predicted collisions per month.

Non-operational time

Turbines do not operate all of the time. Typically a turbine may be at rest or idling for a considerable proportion of time, eg 20%, because the wind is too weak to generate power, or (exceptionally) because the turbines have been closed down to avoid damage in high wind. There is also a requirement for some downtime for maintenance. This non-operational time is accounted for in equation (5) by the factor Qop representing the proportion of time the turbine is operational. If data is available, this factor may be stated on a monthly basis to reflect the different proportions of non-operational time at different times of year – for example reflecting differing wind conditions across the year and increased access for maintenance during the summer.

Large turbine arrays

The model assumes that risks are additive, i.e. that a windfarm with 200 turbines will have 200 times the risk of a single turbine. Where a bird passes successively through two or more turbines, it is exposed to the same risk for each rotor transit. Thus, if two turbines 'overlap' in the sense that the bird passes through both turbines in a single passage, no allowance is made for that overlap, the collision risk is the sum of the risk from each rotor passage. More strictly, for large windfarms where the overall probability of a bird colliding is relatively high, it may be appropriate to take account of the fact that a declining proportion of the birds will survive passage through early rows of turbines and will thus be exposed to collision risk in later rows.

A correction may be made for a windfarm with approximately n rows of turbines. Very often the layout of a windfarm is not known at the time of collision risk assessment, so an exact value for n is not known; and in any case the collision risk has to account for birds entering the windfarm from all directions. Sometimes the layout of the windfarm is irregular, lacking in clearly defined rows; but the principle remains that a declining number of birds will be exposed to collision risk if a proportion have already been killed by collision with earlier rotors as they pass through the windfarm. A reasonable and simple approximation is to use $n = \sqrt{T}$ i.e. the square root of the total number of turbines.

If the probability of collision for a single bird passage through the windfarm is C, based on the purely additive approach, then it may be adjusted to allow for depletion of bird density in later rows of the windfarm by multiplying by a 'Large array correction factor'

CLA /C= 1 - ((n-1)/2n) C +((n-1)(n-2)/(6n2) C2 ... plus further negligible terms of powers of C

If realistic avoidance rates have been taken into account in the collision model, such 'large array corrections' are typically small and can be ignored; typically, it is only worth making corrections for values of C > 0.1.

Extended approach taking account of flight heights

Seabirds tend to fly at relatively low altitude over the sea surface. If the flight height distribution is skewed towards low heights in this way, there are three ways in which taking account of flight height is important to the calculation of collision risk:

(i) The proportion Q2R of birds flying at risk height will decrease with the height of the rotor above the sea surface. This is accounted for in the basic model if the parameter Q2R is adjusted, but the way in which Q2R changes with height can only be known if a flight height distribution for the species in question is available.

(ii) If most of the birds flying at risk height (ie above the minimum level of the rotor) do so at a level not far above the bottom edge of the rotor, the probability of passing through the rotor disc is relatively small, simply because the rotor circle occupies less width at that level than, for example, at the midpoint of its diameter. Therefore the expected number of rotor transits is reduced. For some species the reduction may be 50% or more, reducing the collision risk in proportion.

(iii) The birds flying through the rotor do so close to the extremity of the blades, the single-transit probability of collision there is rather less than for passages closer to the hub. This is a smaller effect, but may typically account for a reduction of around 10%.

When to use generic flight height distribution data

Normally, the bird survey data available for a particular site is insufficient to provide a full flight height distribution. However, it may provide some insight into typical flight heights at the site, and it should provide information on the proportion of birds flying at risk height, i.e. above minimum rotor height.

A collision risk assessment for a specific site should not be based solely on the use of generic data. Where generic data is used, it is recommended that the collision risk for three different options is stated:

- Option (i) - using the basic model, ie assuming that a uniform distribution of flight heights between lowest and highest levels of the rotors; and using the proportion of birds at risk height as derived from site survey.
- Option (ii) - again using the basic model, but using the proportion of birds at risk height as derived from the generic flight height information.
- Option (iii) - using the extended model, using the generic flight height information.

The extended model enables the distribution of flight heights to be taken into account.

The basic model calculates the number of transits through rotors, then multiplies these by the average collision probability for a single transit

No of collisions = number of transits x probability of collision.

The extended approach is underlain by this same equation. However, in this extended model, both bird flux and the probability of collision may vary over the area of the disc, such that their product must be summed over the whole area of the rotor disc.

The bird flux through an element of rotor area δA is v Dv δA, but applying it to a small area δA rather than the full rotor area A. As before there is a need to consider the proportions of flights upwind and downwind; we shall assume (for example) 50% upwind, 50% downwind.

In this extended model, Dv may vary with height Y – this is the flight height distribution Dv(Y) in birds/m3 at height Y metres.

The collision risk for a single transit through this element δA is p(X,Y), which is the same as p(r,φ) except that X-Y coordinates, with origin at the rotor hub, are used to reference the point of transit instead of r-φ coordinates; the relationship between these two coordinate sets are:

X=rsinφ, Y=rcosφ or conversely r=√(X2+Y2), φ=tan-1(X/Y)

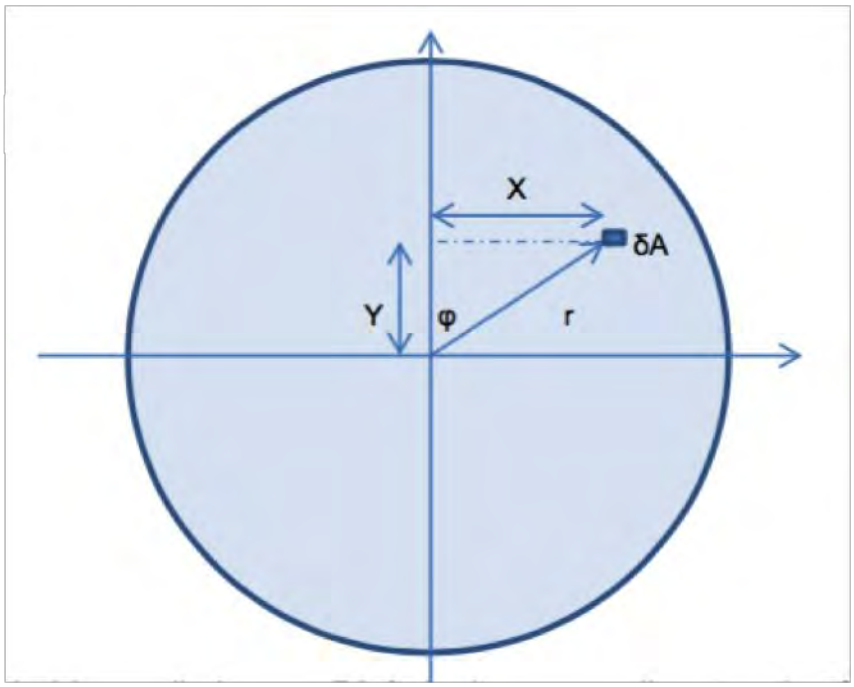


Figure 119: Relationship between rφ, and X, Y coordinates

The collision rate through this small element δA (take it as a small rectangle of width dX and height dY) is thus:

v Dv(Y) p(X,Y) dX dY

The total collision rate for flights through the whole rotor disc is then obtained by integrating this over the whole area of the disc:

$$\text{Collision rate} = v \int_{\text{Min rotor height}}^{\text{Max rotor height}} D_v(Y) \int_{-\sqrt{(R^2-Y^2)}}^{+\sqrt{(R^2-Y^2)}} p(X,Y)\, dX\, dY$$

The limits ± √(R2-Y2) to the integration over X define the outer limits of the rotor circle, and the limits to the integration over Y are the minimum and maximum rotor heights respectively.

With this approach, it is not easy to think in terms of there being a defined bird flux, and an average probability of collision, which are then multiplied. The bird flight density varies with height Y, the breadth of the circle (and therefore the number of birds flying through the circle) varies with height Y, and the collision risk too depends on height Y, as it varies with both r and φ. Hence all these factors are expressed and multiplied within the integral, and the integration yields the collision rate.

As with the basic model, to translate this into collisions per month in the windfarm, this must be multiplied by the number of seconds the birds are active, and the number of turbines, and by the factor making allowance for non-operational time.

For computational purposes, it is best to translate the factors into dimensionless units, within which the rotor has a radius of 1, by using the parameters x = X/R, y=Y/R; and using a dimensionless flight height distribution d (y) = R Dv (Y)/DA. Using these factors, and adding in the other factors (number of turbines, etc), equation above becomes:

$$\text{Collisions} = v\, D_A\, R \int_{-1}^{1} \int_{-\sqrt{(1-y^2)}}^{+\sqrt{(1-y^2)}} d(y)\; p(x,y)\, dx\, dy \;\times\; \text{No of turbines } T \;\times\; \text{Time active } t \;\times\; \text{Proportion of time operational} \;\ldots$$

$$= \underbrace{v\,(D_A/2R)\,T\pi R^2\, t}_{\text{Flux factor}} \;\times\; \underbrace{(2/\pi) \int_{-1}^{1} \int_{-\sqrt{(1-y^2)}}^{+\sqrt{(1-y^2)}} d(y)\; p(x,y)\, dx\, dy}_{\text{Collision integral}} \;\times\; \underbrace{Q_{op}}_{\text{Proportion of time operation}} \;\ldots$$

The ‘flux factor’ and Qop are the same as used in the basic model. The ‘Collision integral’ is a dimensionless quantity. If we apply this to the earlier scenario in which a proportion Q2R of birds fly at risk height, and are distributed uniformly at all heights within that zone, we then have d(y) = Q2R/2, a constant. The Collision integral is then Q2R times the average of p(x,y) over the rotor disc.

The total bird flux passing through the rotors is similar to the above equatio but with p(x,y) set to 1, ie

$$\text{Flux} = \underbrace{v\,(D_A/2R)\,T\pi R^2\,t}_{\text{Flux factor}} \times \underbrace{(2/\pi)\int_{-1}^{1}\int_{-\sqrt{(1-y^2)}}^{+\sqrt{(1-y^2)}} d(y)\;dx\,dy}_{\text{Flux integral}} \times \underbrace{Q_{op}}_{\text{Proportion of time operational}} \qquad (10)$$

The average collision probability is just the ratio Collisions /Flux.

Note that the factor Q2R does not appear explicitly in the above equations, as the proportion of birds flying at various levels is included within the distributional data d(y). However, for comparison with the basic model, a value Q’2R is readily calculated from the distribution data, as

$+1 \int d(y).\ dy = Q'2R - 1$. The symbol Q’2R is used to differentiate this calculated figure from the figure for Q2R input earlier based on bird survey data.

Avoidance

The preceding stages of the model assume that birds take no avoiding action whatsoever in response to wind turbines. In reality, birds mostly do take effective avoiding action so as to avoid collision with wind turbines. Birds may avoid the area of the windfarm altogether, or they may use more indirect flight routes to bypass the windfarm – referred to as ‘macro’ or ‘far-field’ avoidance or ‘displacement’. Alternatively, birds may continue to fly within or close to the windfarm, but exhibiting ‘micro’ or ‘near-field’ or ‘behavioural’ avoidance in which birds choose routes which pass between rotors; or fly higher or lower to avoid the rotors; or take emergency action in-flight to escape an approaching blade.

Monitoring of windfarms onshore is generating some useful information on levels of avoidance of some land-based bird species. Some of that data derives from collision monitoring, based on regular site scans for bird corpses, and some of it from observations of habitat use in the vicinity of windfarms. For many bird species, avoidance rates of 98% or higher have been observed, implying that the collision risk is less than 2% of that calculated from stages A-D alone. Avoidance is included in the collision risk model simply by multiplying the before-avoidance collision estimate by (1 - A) where A is the appropriate overall avoidance rate.

In general the information for onshore species is not sufficient to discriminate in a quantitative way between macro avoidance (ie displacement or far-field avoidance) and micro (near-field) avoidance, though some Dutch studies are yielding useful data. Offshore, a number of studies have examined macro and micro avoidance behaviour for some seabirds. As monitoring data builds up from constructed offshore windfarms, it may be possible to make more definitive predictions than at present on rates of both macro and micro avoidance. The overall avoidance rate Aoverall is simply related to macro and micro avoidance rates: (1 – Aoverall) = (1 – Amacro) x (1 – Amicro) .

To obtain an overall avoidance rate in this way, information is needed on both macro and micro avoidance rates, each of which will be less on its own than the overall avoidance rate. In particular, if information on likely displacement is used to conclude that a proportion of birds will not use the windfarm site that is in effect an application of the (1 – Amacro) factor. The avoidance rate then applied to those birds not displaced would then have to be a micro- avoidance rate Amicro, derived from monitoring observations solely of birds actually flying through windfarms. A micro-avoidance rate will be considerably lower than a rate for overall avoidance, which includes displacement effects.

Where detailed information on macro and micro avoidance is not available then overall avoidance rates are best estimated by using monitoring data from existing windfarms, comparing actual mortality to that predicted if pre-construction levels of flight activity were maintained:

Actual collision rate Aoverall = 1 - {Predicted collision rate if pre-construction levels of flight activity were maintained}

In particular, if the extended model taking account of flight height distribution is used, it is important that the calculations on which avoidance rates are based also start with a no-avoidance collision rate derived using the extended model.

Where the bird flight density is skewed towards low altitude, a greater proportion of birds above the minimum risk height will miss the rotor, simply because, at a level close to rotor minimum height, the rotor circle intercepts relatively few flights.

This propensity to miss the rotor must not be confused with avoidance, which requires a behavioural response by a bird. Put another way, if an avoidance rate is calculated by comparing collision rate observations with a calculated avoidance rate using the basic (uniform flight density) model, then that avoidance rate will already include for the fact that low-flying birds will more often miss the rotor. Using such an avoidance rate in conjunction with the extended model would double-count that factor.

All current flight activity should be included within a windfarm collision risk estimate, and the avoidance rates used for collision risk estimates should be characteristic of overall avoidance, ie they should include both macro avoidance (displacement or far- field avoidance) and micro (near-field or behavioural) avoidance. In particular the likelihood of displacement should be included as an aspect of overall avoidance. Elsewhere in the bird impact assessment the potential direct impact

of displacement on the bird population, in terms of reduction in available habitat, should also be assessed.

The lack of firm evidence surrounding avoidance rates will almost certainly dominate the uncertainty inherent in the collision risk estimate. For a few land-based bird species there is now substantial international experience on levels of avoidance from long-standing monitoring studies, such that some confidence can be placed in the assumption of high levels of avoidance. However, for marine species there is limited firm data as yet on which to base predictions. It should be noted that avoidance behaviour might vary seasonally, and between groups of birds of the same species.

The collision risk estimate should conclude with a table showing potential collision mortality using a range of assumed avoidance rates. The text relating to this table should point to any evidence from existing post-construction monitoring on the respective or similar bird species, which might indicate what levels of avoidance are best, supported by evidence. As a default in the absence of specific avoidance information for the species in question, it is recommended that collision risks be evaluated assuming avoidance rates of 95%, 98%, 99% and 99.5%.

Attraction

Offshore windfarms may create new habitat, which encourages aggregation of fish, and as a result birds may be attracted into the windfarm for foraging. Lighting on wind turbines may also have an effect in attracting birds at night. Where such attraction occurs, it follows that collision risk may be enhanced as a result of increased flight activity through the windfarm. Attraction is in effect a form of 'negative displacement' and could in principle be included in the collision risk assessment by including an appropriate negative component in macro avoidance. However, in most circumstances there is not enough definitive evidence to make quantitative predictions on attracting birds with any certainty.

Where, as part of an overall bird impact assessment, attention is drawn to the potential for a wind farm to attract birds, the potential for additional collision risk should also be considered.

Expressing Uncertainty

In a collision risk estimate following the above method, there are a large number of sources of variability or uncertainty in the output. The main sources of uncertainty are:

1. Survey data is sampled, often both in time and space, and usually exhibits a high degree of variability. Mean estimates can only be representative of flight activity;
2. Survey data is unavailable for certain conditions, including night time and storm conditions;
3. Natural variability in bird populations, over time and space, for ecological reasons;
4. Flight height information may be subject to observer bias;
5. The collision risk model uses a simplified geometry for turbine blades and bird shape, it does not include any risk of collision with turbine towers;
6. Details of blade dimension and pitch may be unavailable at the time of making the estimate;

7. Turbines deployed may differ from those used in the collision risk analysis;
8. Bird parameters (length, wingspan, flight speed) have a distribution, they are not fixed;
9. Bird speed is not a constant but is dependent on wind speed;
10. Insufficient knowledge about bird displacement and attraction effects;
11. Limited firm information on bird avoidance behaviour at sea.

Perhaps the most important issue is to keep these uncertainties in proportion. For some of these uncertainties (e.g. bird density from survey data) the range of variability may be fairly clear from the variability between different survey days. Observer bias in flight height estimates may be tested, for example, by duplicating observers on occasion and comparing results. There are uncertainties in using the collision model itself, for example in using a single bird speed, or if the calculation is made for only one turbine speed rather than deriving an average over all turbine speeds. However these uncertainties are probably less significant than the errors introduced by variability in the survey data input.

Then there is uncertainty over avoidance behaviour. At present there is only a handful of bird species for which collision mortality at onshore windfarms has been sufficiently monitored to enable an avoidance rate to be used with confidence. For marine bird species, there is as yet limited information upon which to base a judgement on an appropriate avoidance rate to use. The uncertainty here ranges over an order of magnitude. If an avoidance rate of 98% is used, for example, that may be judged subject to uncertainty covering a range from 95% to 99.5%, representing non-avoidance behaviour between 5% and 0.5%. For the foreseeable future, it seems likely that the uncertainties surrounding bird avoidance behaviour are likely to dwarf the errors and uncertainties arising from an inexact collision model or variability in survey data.

A similar position relates to the extent to which birds may respond to habitat changes caused by the windfarm. Here also there is insufficient experience yet to be able to predict with confidence likely levels of displacement or attraction in response to new habitats, or indeed whether these patterns of behaviour will persist or change over time.

For these reasons it is proposed that uncertainty due to avoidance behaviour, and uncertainty over response to habitat changes, should be handled differently from uncertainties elsewhere in the calculation.

The output should convey the uncertainty in the collision risk estimate, by indicating, in addition to a 'best estimate', a range of confidence around that estimate. Though it is unlikely (with the exception of the survey data) that these can be subject to detailed statistical analysis, the aim should be to express the range of uncertainty at around the 95% confidence level.

The range of uncertainty should reflect:

- Uncertainty or variability in flight activity data (including imprecision on flight height estimates and lack of knowledge about night-time behaviour);

- Uncertainty due to the limitations of the collision model, including the variability of bird dimensions and flight speed, the simplification in shape of a bird and turbine blades. As an expert guesstimate, the uncertainties arising from the collision model, if all required turbine parameters are fully available, may be of order ± 20%;
- Uncertainty arising from turbine options yet to be decided, in number, size and speed. These options should include a 'worst case' in terms of the option likely to present greatest bird collision risk. The range of uncertainty due to each of these three sources should be separately identified and, as the three uncertainties are of independent origin, they may be combined to give an overall uncertainty of √ (u12 + u22 + u32) where u1, u2 and u3 are respectively the percentage uncertainties from each of these sources;

Where the extended model is applied using the generic height data from Cook et alii, that paper provides confidence intervals around the median data points. The range of uncertainty relating to flight height can be estimated by replacing the median set of data by, respectively, the upper and lower 95% confidence levels, and noting the corresponding uncertainty in the collision risk.

Finally, the output should state the effect on the collision risk of a range of assumptions on avoidance. This should be covered by a statement conveying the status of current information on avoidance behaviour of the bird species in question, noting any variability in this behaviour, and drawing conclusions about the likely collision risk.

The collision risk estimate should also outline qualitatively the possible likelihood and scale of any further collision risks which might result from the wind farm attracting birds.

Seabirds

At the aim of gather information on the presence and permanence of the seabird potentially affected by the BGF installation, the Standard Data Form for all the NATURA 2000 sites (both under Bird and Habitat Directives) surrounding the BGF installation site has been investigated.
Due to the high vagrantive nature of some species (*Calonectris, Puffinus*, *Morus)*, the sites considered has been extented to spanish, italian, corsican and sardinian coasts.
The following Natura 2000 Sites has been particularly investigated:

1. **FR9112005 - Complexe lagunaire de Salses-Leucate**
2. **FR9112007 - Étangs du Narbonnais**
3. **FR9112013 - Petite Camargue laguno-marine**
4. **FR9112017 - Étang de Mauguio**
5. **FR9112018 - Étang de Thau et lido de Sète à Agde**
6. **FR9112034 - Cap Bear- cap Cerbère**
7. **FR9112035 - Côte languedocienne**
8. **FR9310019 - Camargue**
9. **FR9310020 - Iles d'Hyères**
10. **FR9312007 - Iles Marseillaises - Cassidaigne**
11. **ES0000019 - Aiguamolls de l'Alt Empordà**

12. **ES0000512 - Espacio marino del Delta de l' Ebre**
13. **ES0000513 - Espacio marino del Baix Llobregat-Garraf**
14. **ES0000514 - Espacio marino de l'Empordà**
15. **ES5120007 - Cap de Creus**
16. **ES5120015 - Litoral del Baix Empordà**
17. **ES5120016 - El Montgrí- Les Medes - El Baix Ter**
18. **ES0000521 - Espacio marino del norte y oeste de Menorca**
19. **ES0000236 - lla de l'Aire**
20. **ES0000522 - Espacio marino del sureste de Menorca**
21. **ES0000520 - Espacio marino del norte de Mallorca**
22. **ES0000073 - Costa brava de Mallorca**
23. **ES0000519 - Espacio marino del poniente de Mallorca**
24. **FR9412011 - Oiseaux marins de l' Agriate**
25. **FR9412010 - Capu Rossu, Scandola, Revellata, Calvi**
26. **FR9410096 - Iles Sanguinaires, Golfe d' Ajaccio**
27. **ITB010001 - Isola Asinara**
28. **ITB013044 - Capo Caccia**

The species presented in the checklists, with the following characteristics has been considered:

1. Marine/coastal/estuarine habitat
2. Reproductive in the Natura 2000 sites
3. Common in the Natura 2000 sites

Amongst these species, and on the basis of an extensive literature survey, a number of them have been individuated as potentially interacting with BGF installation on the basis of **their largest feeding range**, calculated as starting from the breeding site. ***The distance of BGF from coastline is estimated in 22 km.***

The table below reports the species selected from checklists for subsequent impact assessments (marked in red in Max Range column), and their status in the Regional, national, european and global IUNC Red List.

Table 29: Selected bird species and their status IUNC Red List

COMMON NAME	SCIENTIFIC NAME	CAT	MAX RANGE	RL-PACA	RLF	RLE	RLG
Razorbill	*Alca torda*	CW	95		NT	NT	NT
White-fronted Goose	*Anser albifrons*	*CW*	NO		LC	LC	LC
Greylag Goose	*Anser anser*	*CW*	NO	EN	LC	LC	LC
Barnacle Goose	*Branta leucopsis*	*CW*	NO		LC	LC	LC
Cori's shearwater	*Calonectris diomedea*	*CR*	330	VU	LC	LC	LC
Whooper Swan	*Cygnus cygnus*	CW	NO		LC	LC	LC
Black-throated diver	*Gavia arctica*	CW	poss/scarce		LC	LC	LC
Great Northern diver	*Gavia immer*	CW	poss/scarce		LC	VU	LC
Red-throated diver	*Gavia stellata*	*CW*	9		LC	LC	LC
Gull billed tern	*Gelochelidon nilotica*	*CR*	NO	EN	LC	LC	LC
Common Shag	*Gulosus aristotelis*	*CWPR*	17	EN	LC	LC	LC
Storm petrel	*Hydrobates pelagicus*	*CR*	65	EN	LC	LC	LC
Little gull	*Hydrocoloeus minutus*	*CR*	NO		LC	NT	LC
Audouin's gull	*Larus audouinii*	*CWR*	40 (200)		LC	LC	LC
Common gull	*Larus canus*	*C*	50		LC	LC	LC
Lesser black-backed gull	*Larus fuscus*	*C*	181		LC	LC	LC
Slender-billed gull	*Larus genei*	*CR*	poss/scarce	EN	LC	LC	LC
Great black-backed gull	*Larus marinus*	*C*	40		LC	LC	LC
Mediterranean gull	*Larus melanocephalus*	*CWPR*	20	VU	LC	LC	LC
Michahellis' gull	*Larus michahellis*	*CWPR*	51	LC	LC	LC	LC
Black-headed gull	*Larus ridibundus*	*CWR*	NO	VU	LC	LC	LC
Velvet scoter	*Melanitta fusca*	CW	5		VU	VU	VU
Common scoter	*Melanitta nigra*	CW	2		LC	LC	LC
Northern gannet	*Morus bassanus*	*CWP*	590		LC	LC	LC
Leach's storm petrel	*Oceanodroma leucorhoa*	*C*	poss/scarce		VU	VU	VU
Great Cormorant	*Phalacrocorax carbo*	*CW*	35	VU	LC	LC	LC
Slavonian grebe	*Podiceps auritus*	C	poss/scarce		VU	NT	VU
Great Crested Grebe	*Podiceps cristatus*	CRW	poss/scarce	LC	LC	LC	LC
Black-necked grebe	*Podiceps nigricollis*	*CWR*	poss/scarce	CR	LC	LC	LC
Manx shearwater	*Puffinus p. mauretanicus*	*CW*	330		CR	CR	CR
Levantine shearwater	*Puffinus yelkouan*	*CWR*	100	VU	VU	LC	VU
Black-legged Kittiwake	*Rissa tridactyla*	*CW*	120		VU	VU	VU
Common eider	*Somateria mollissima*	CW	80		NT	VU	NT
Long-tailed skua	*Stercorarius longicaudus*	*P*	poss/scarce		LC	LC	LC
Caspian tern	*Sterna caspia*	*C*	60		LC	LC	LC
Roseate tern	*Sterna dougallii*	CR	poss/scarce		LC	LC	LC
Common tern	*Sterna hirundo*	*CR*	30	VU	LC	LC	LC
Little tern	*Sternula albifrons*	*CR*	poss/scarce	EN	LC	LC	LC
Sandwich tern	*Thalasseus sandvicensis*	*CWR*	54	EN	LC	LC	LC

For the selected species, the number of individuals (breeding pairs + present for feeding reasons) has been derived from Natura 2000 Standard Data Form, or from literature whenever possible

Pettex et *al*. (2017), was used as a reference basis for desitity of individuals per square Km, a basic parameter for the Band model input.

Where density data were unavailable, a different method has been used, based on Thaxter et *al*. (2016). For each species, the area obtained as a circle originating from the breeding site and extending it to the maximum feeding range, exluding terrestrial areas, has been calculated. The number of individuals per site, divided the area derived as above from feeding range, has given an estimate of bird density (in ind/km2), that has been used as input in the Band model, where bird density data in literature where unavailable.

Figure 120: *Ryssa tridactyla* feeding range (not including BGF site)

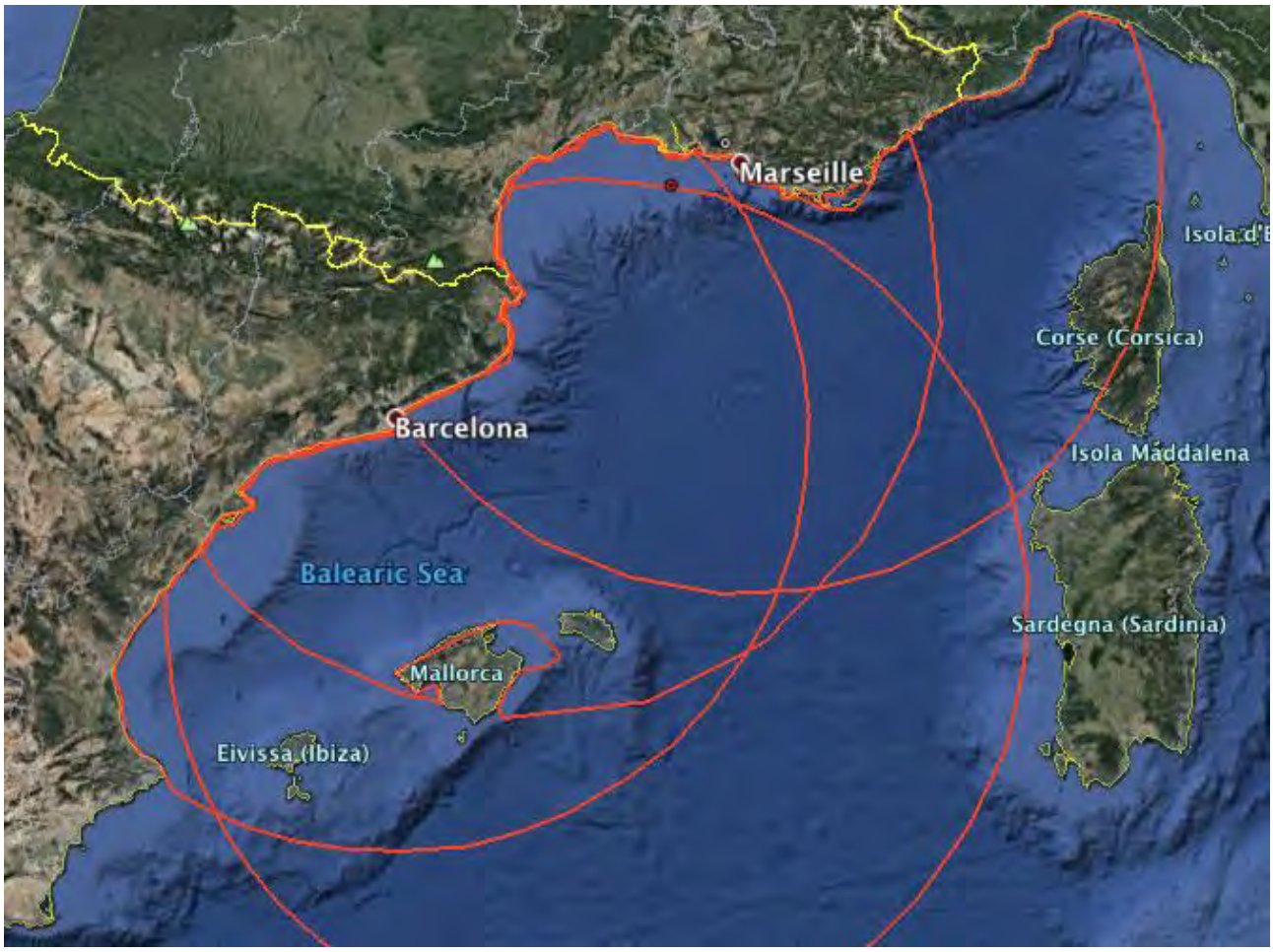


Figure 121: *Calonectris diomedea* feeding areals, as generated from the main breeding colonies

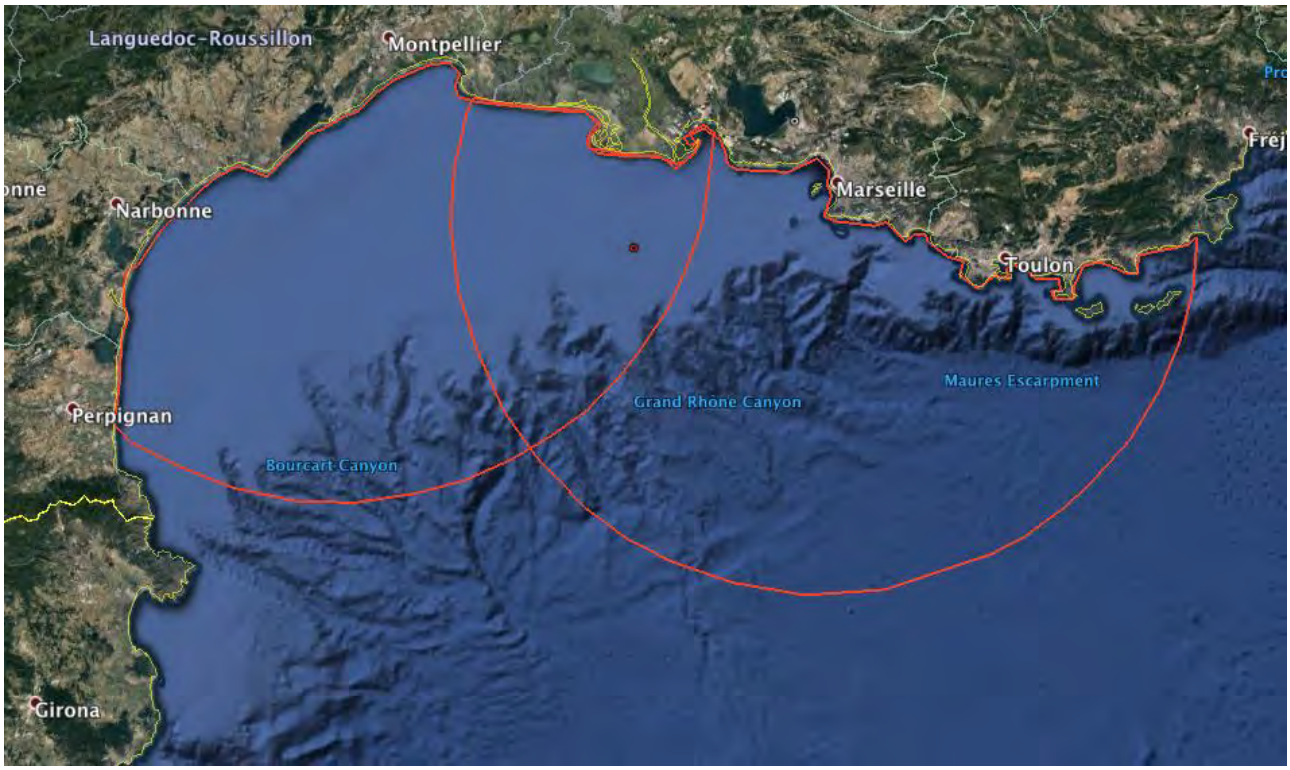


Figure 122: *Puffinus yelkouan* feeding areals, as generated from the main breeding sites

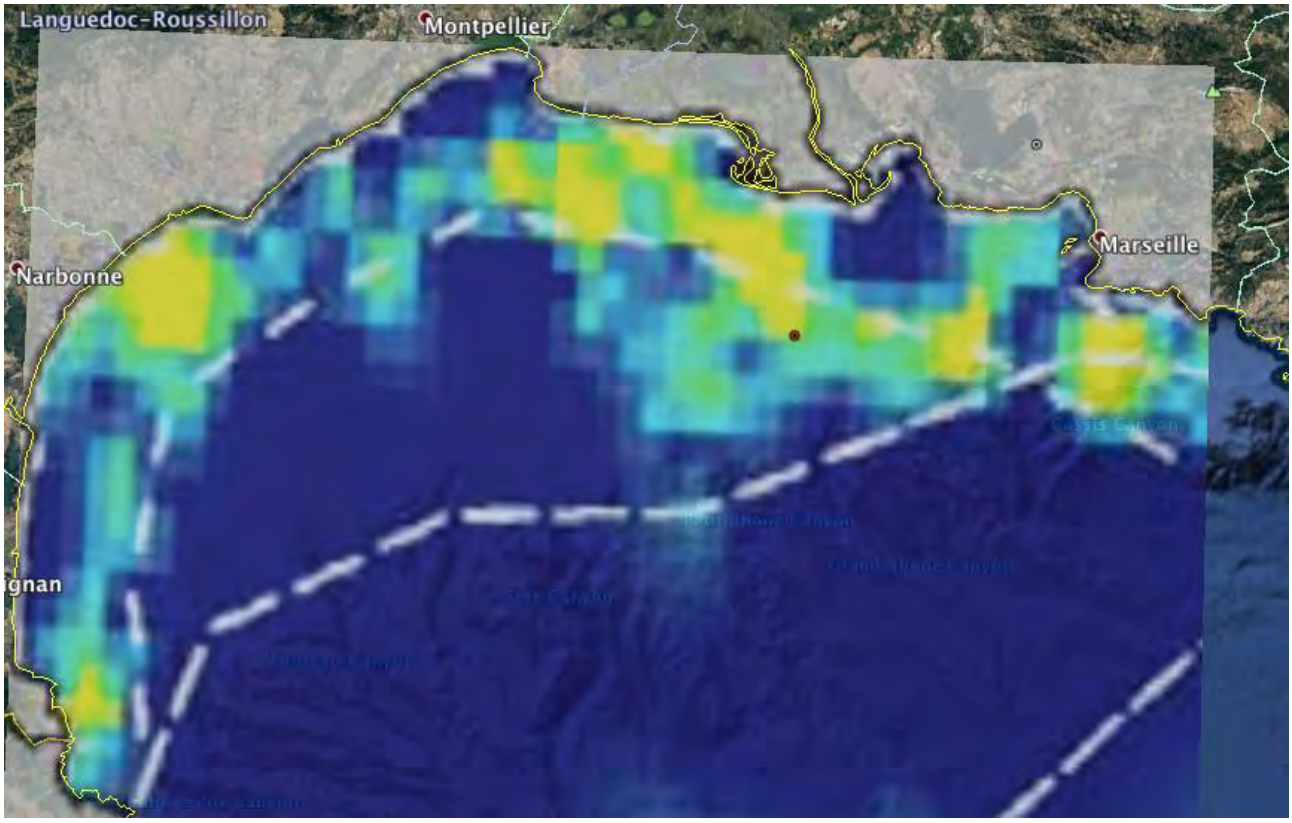


Figure 123: *Puffinus spp*. winter density (*Source: Modified from Pettex at al., 2017*)

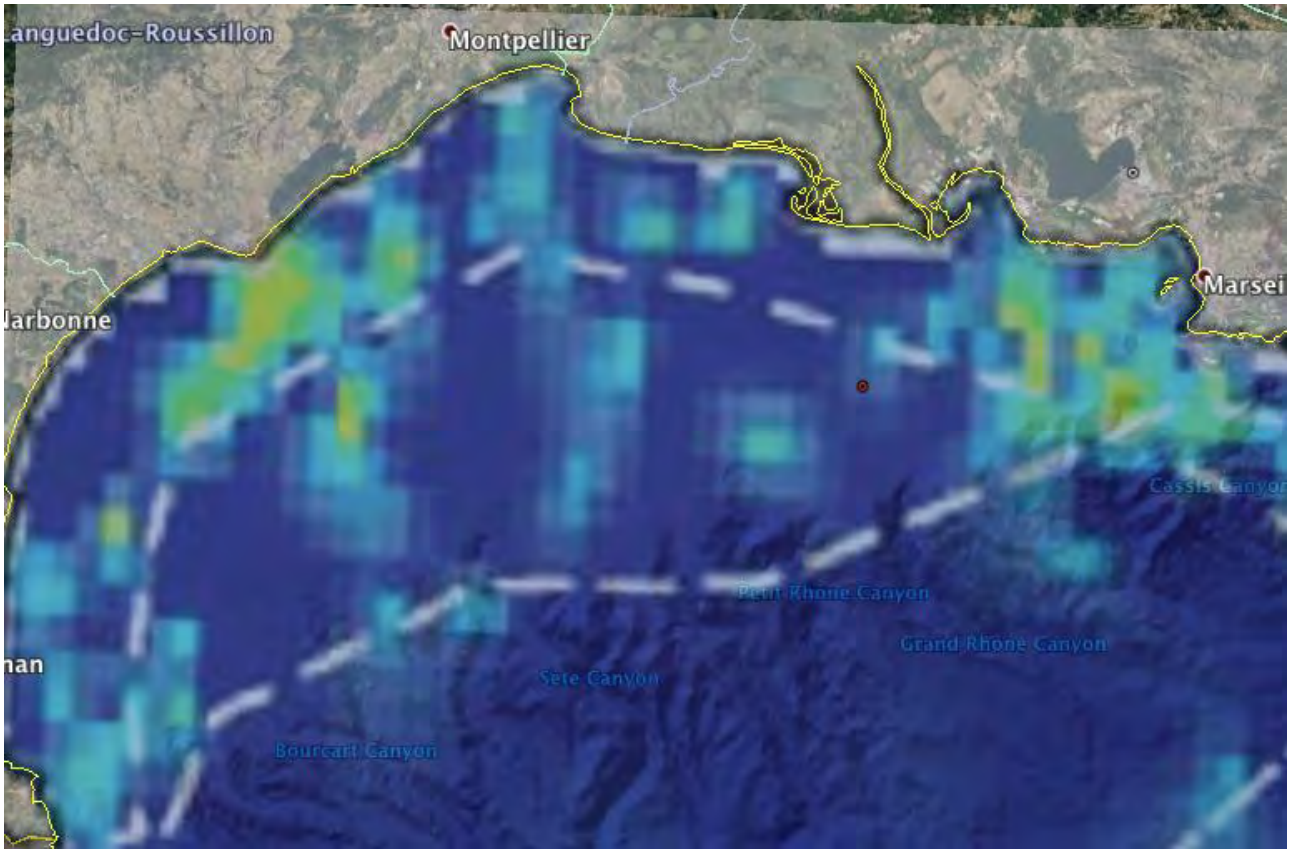


Figure 124: ***Puffinus spp.*** **summer density (*Source: Pettex at al., 2017, modified*)**

Figure 125: *Morus bassanus* feeding areals, as generated from the main presence sites

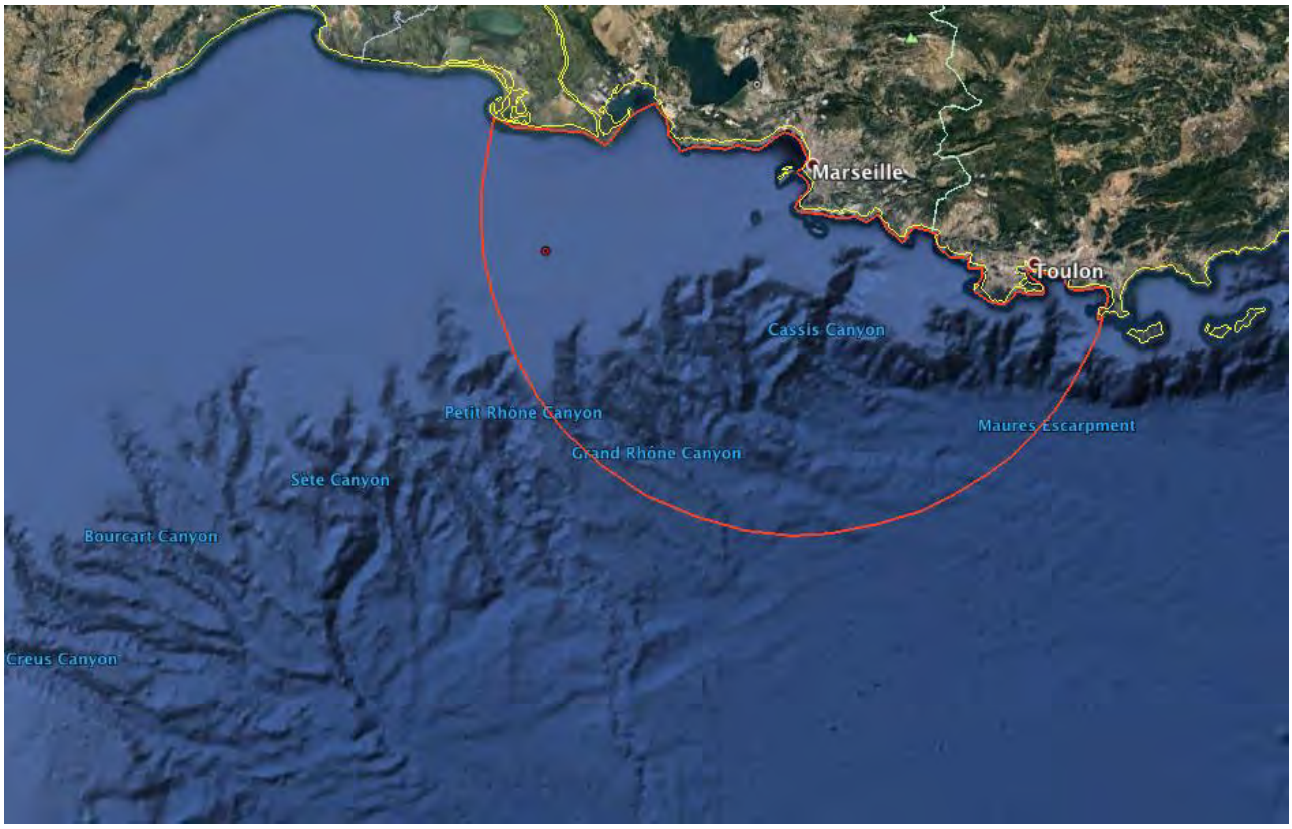


Figure 126: *Hydrobates pelagicus* feeding areals, as generated from the main breeding sites

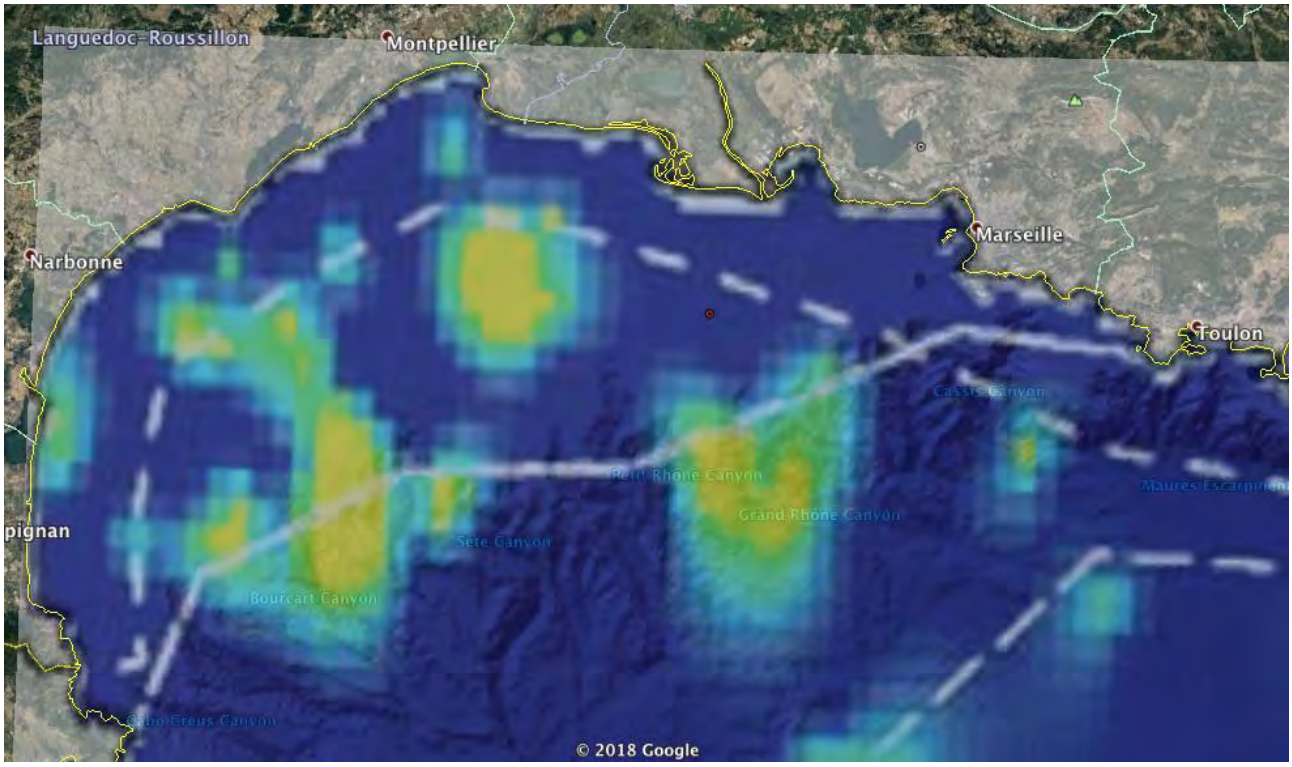


Figure 127: *Hydrobates pelagicus* summer density (*Source: Pettex at al., 2017, mod.)*

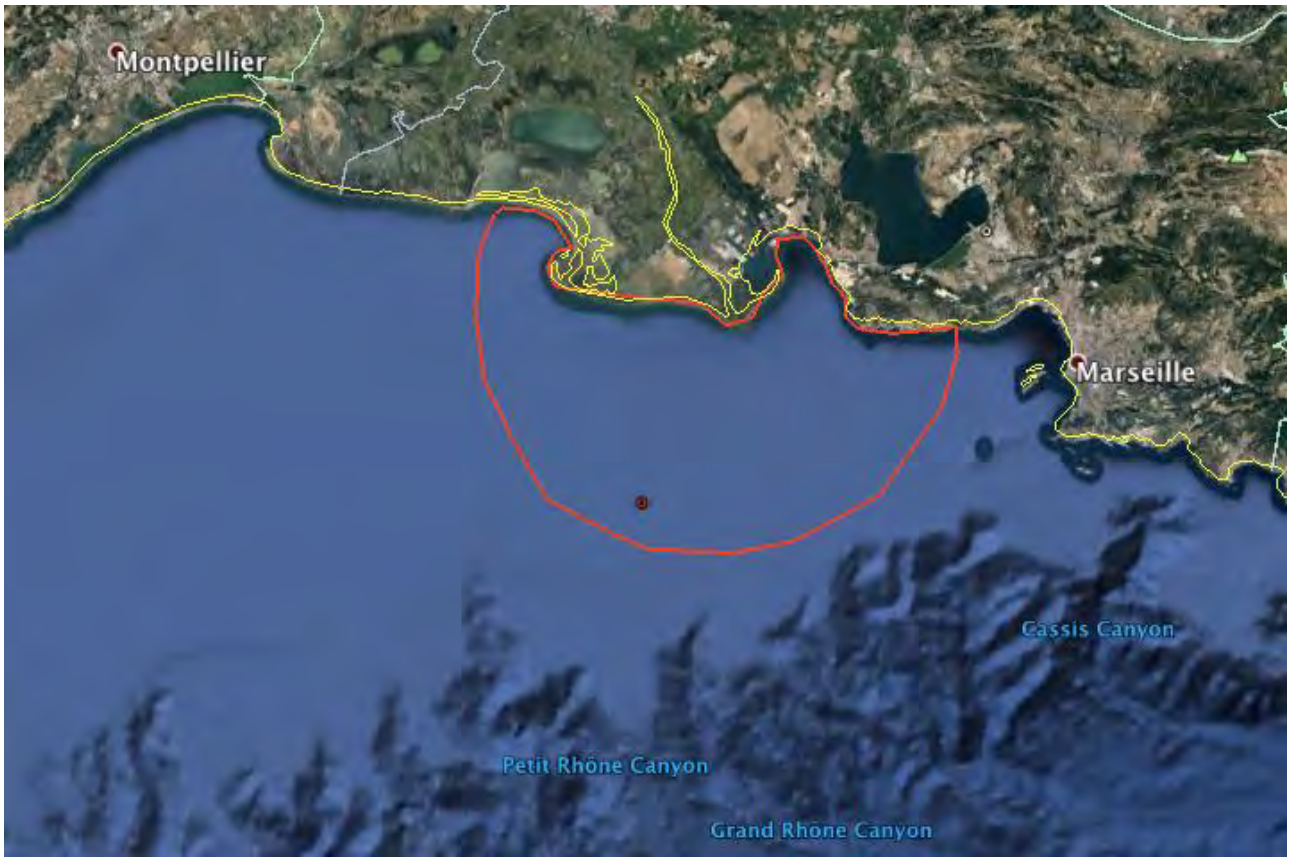


Figure 128: *Sterna hirundo* feeding areals, as generated from the main breeding sites

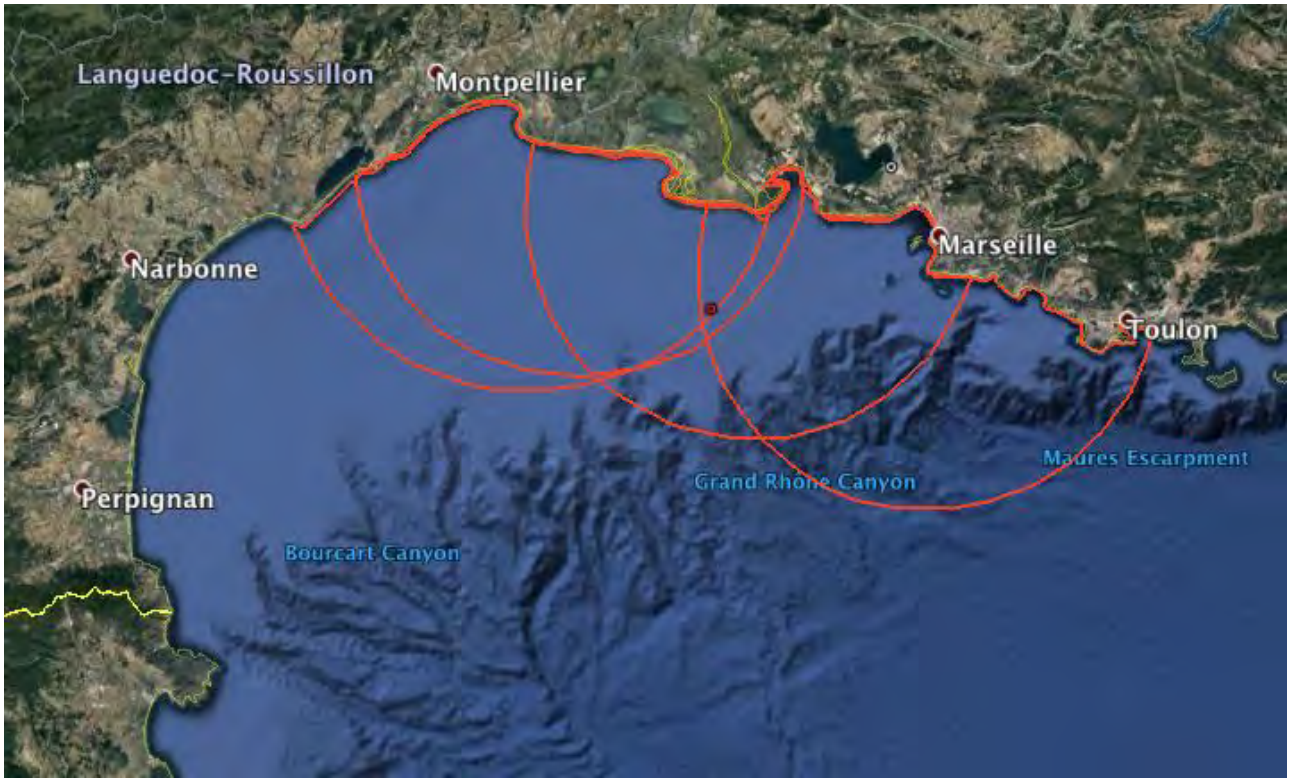


Figure 129: *Sterna sandwichensis* feeding areals, as generated from the main breeding sites

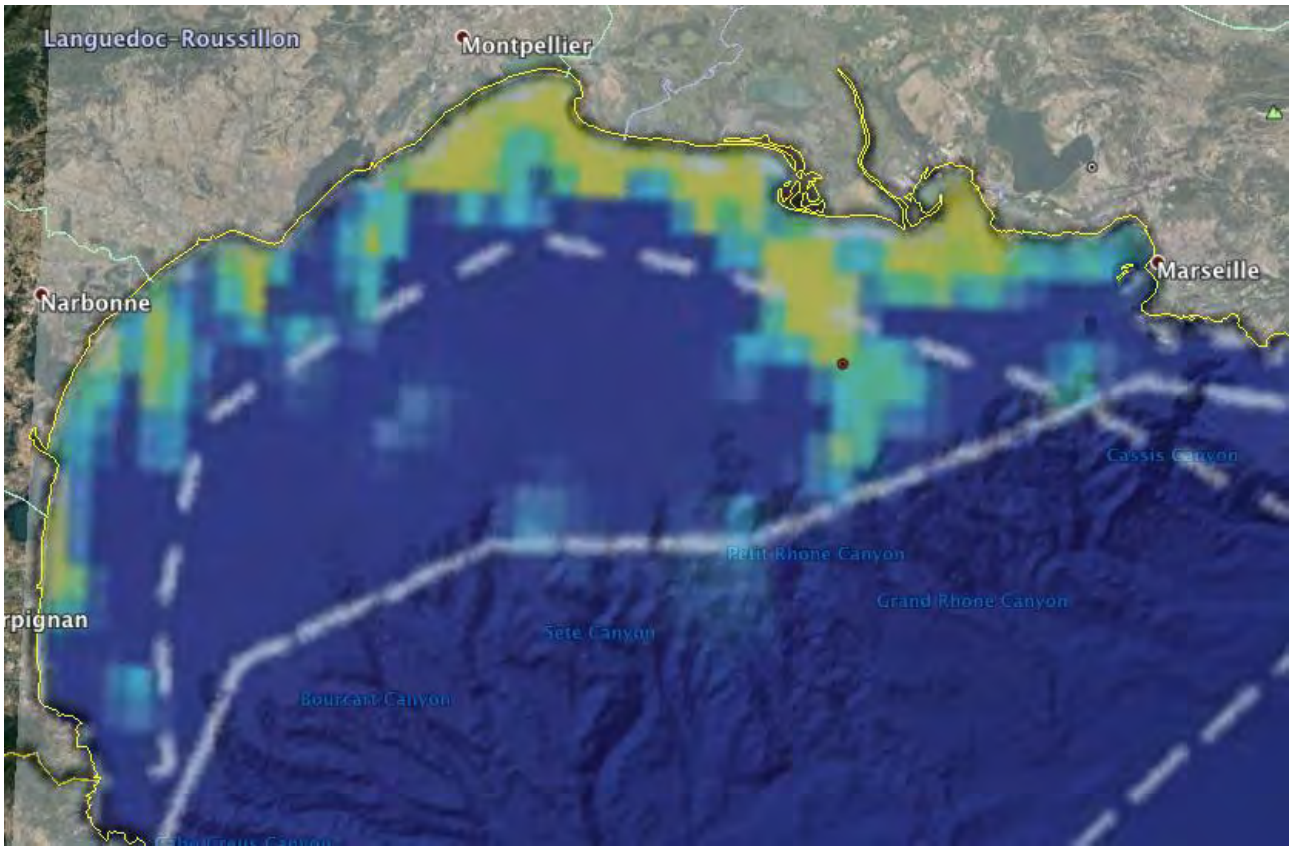


Figure 130: Terns winter distribution (*Source: Pettex at al., 2017, mod.*)

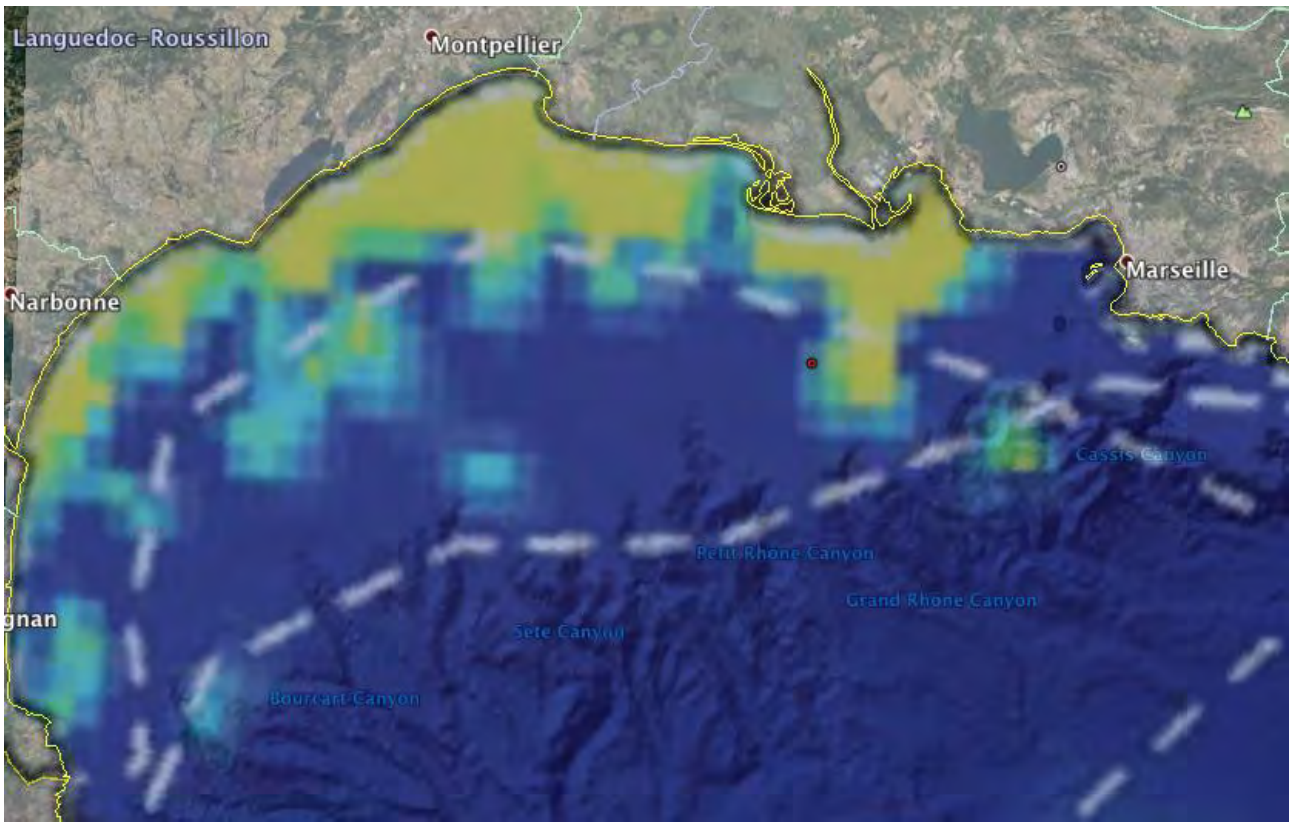


Figure 131: Terns summer distribution (*Source: Pettex at al., 2017, mod.*)

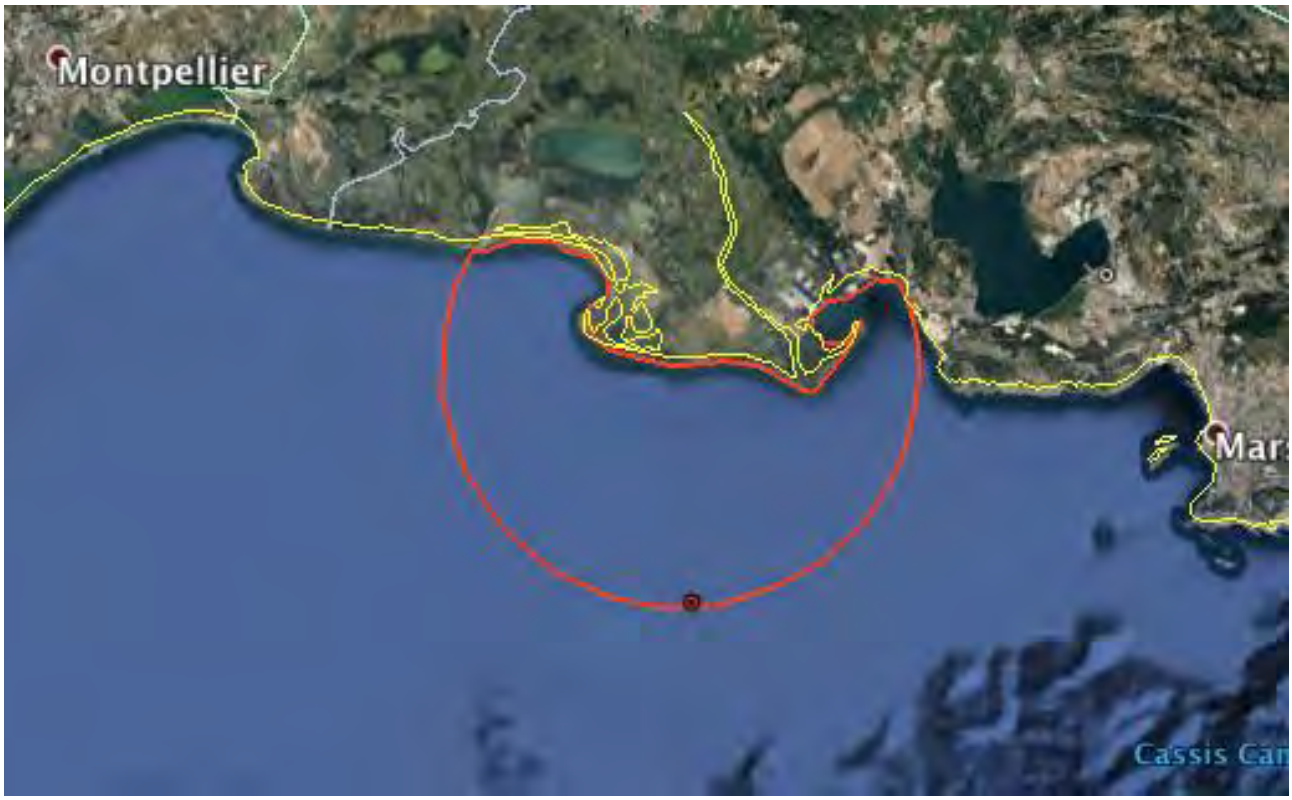


Figure 132: *Larus melanocephalus* feeding areals, as generated from the main breeding sites

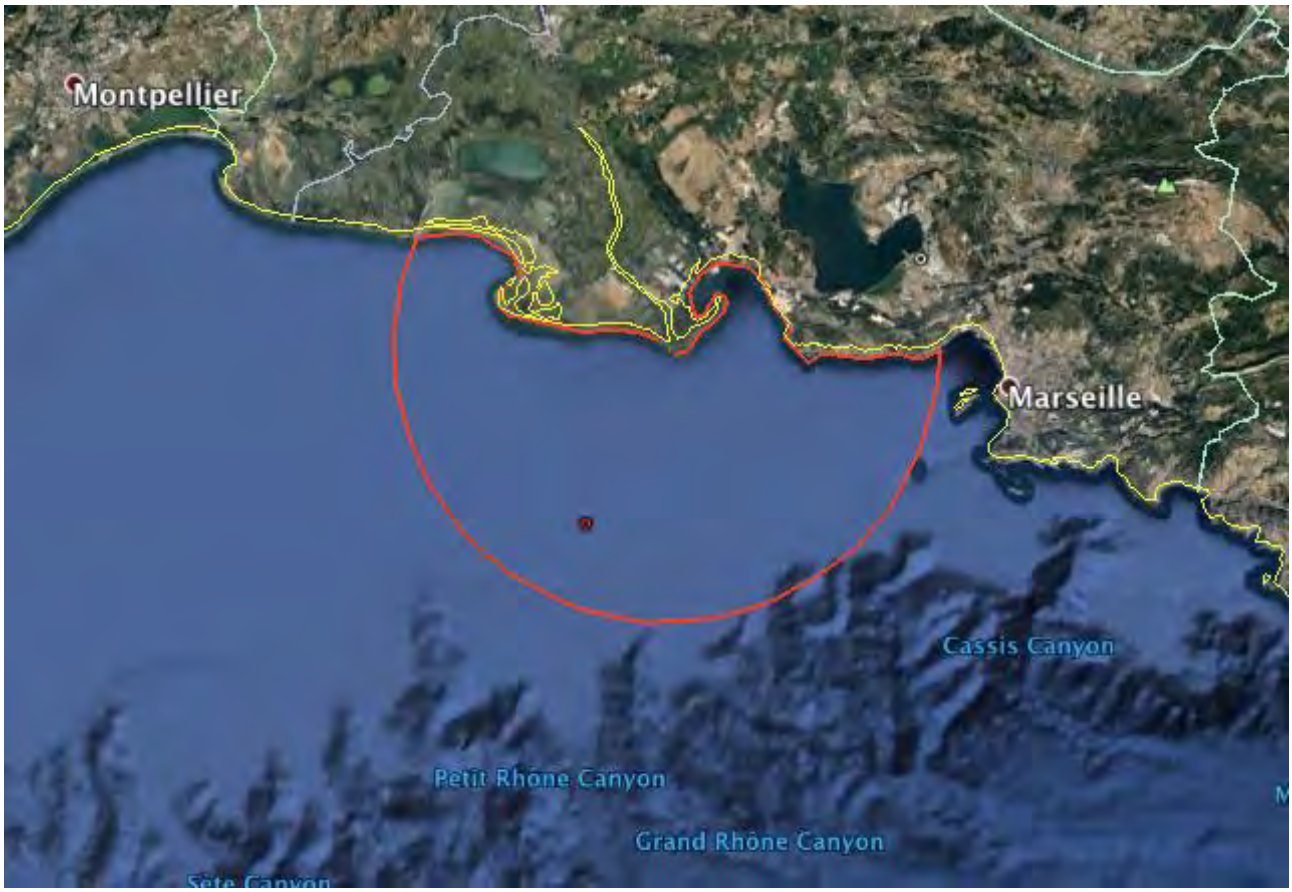


Figure 133: *Phalacrocorax carbo* feeding areals, as generated from the main breeding sites

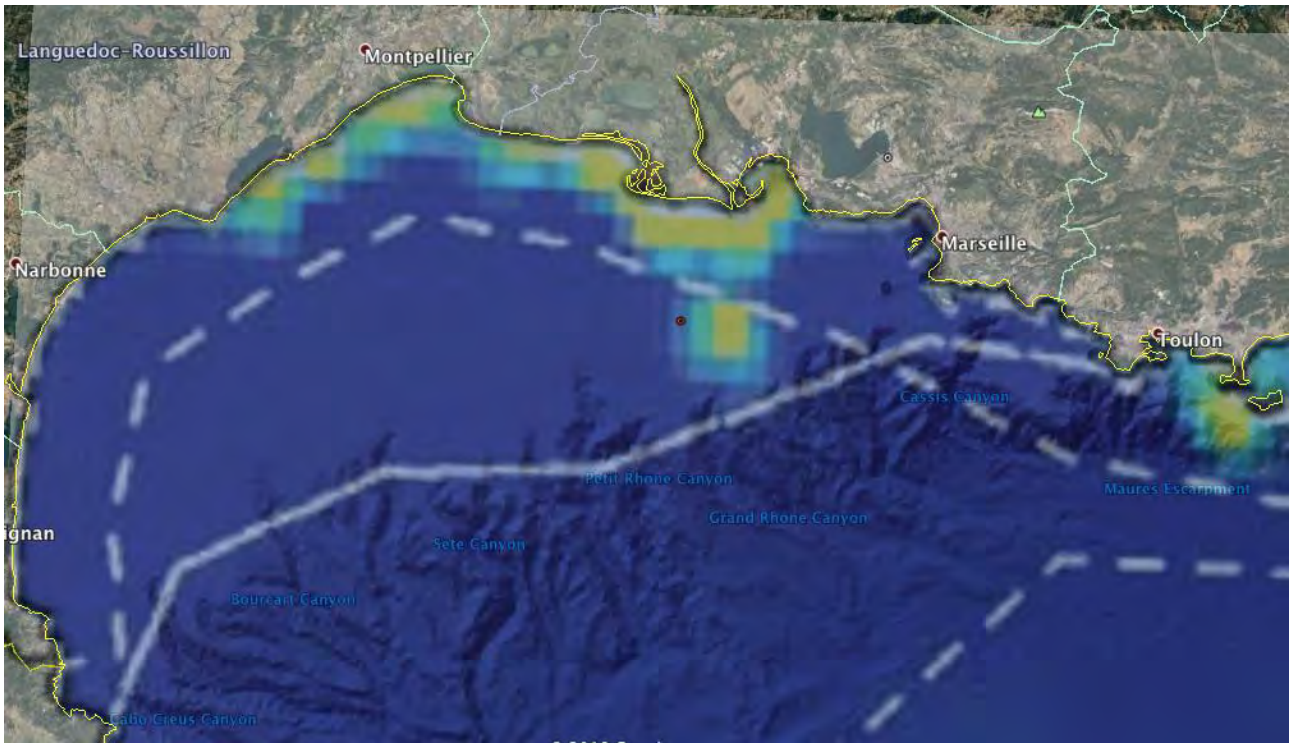


Figure 134: Cormorants winter distribution (*Source: Pettex at al., 2017, mod.*)

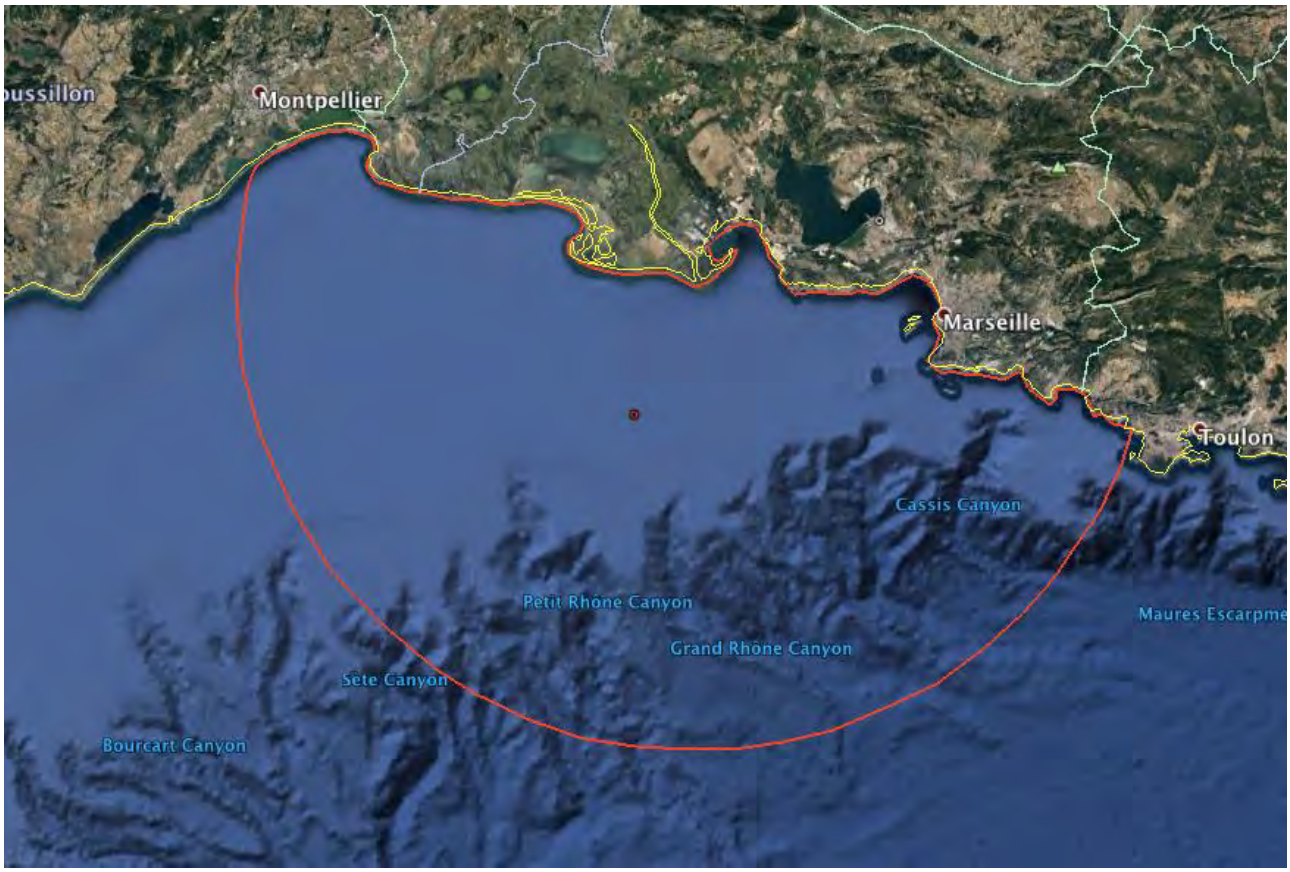


Figure 135: *Somateria mollissima* feeding areals, as generated from the main breeding sites

Larus michaellis, the great yellow-legged gull, has been inserted in the list of the species potentially affected by the BGF due ti its ecological features. In fact, although is considered a coastal species, its distribution at sea is strongly linked to the presence of the fishing fleet, being its scavenging habitus become predominant over wild resource exploitation. Distribution at sea can be roughly overlapped to fishing fleet tracks.

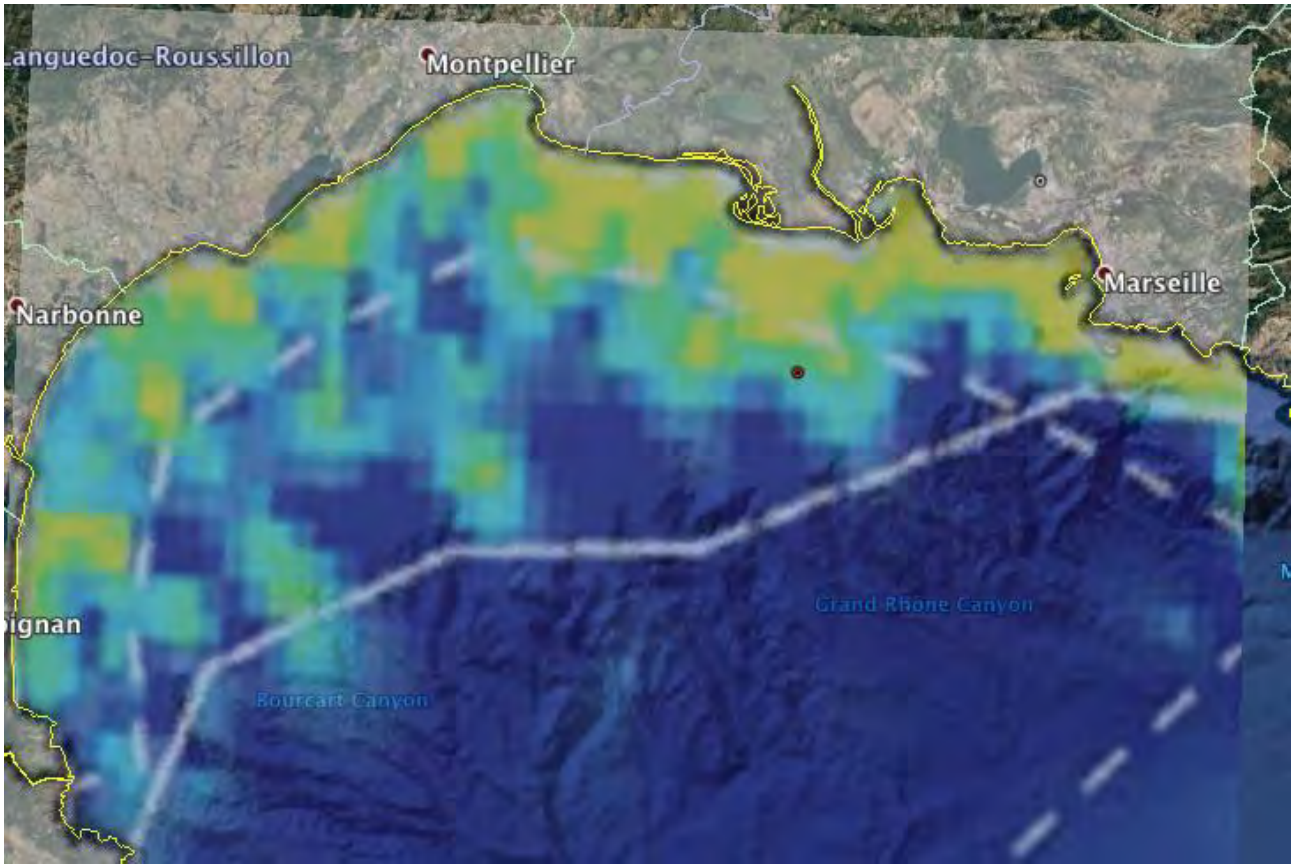


Figure 136: *Larus mihaellis* distribution during winter (*Source: Pettex at al., 2017, mod.*)

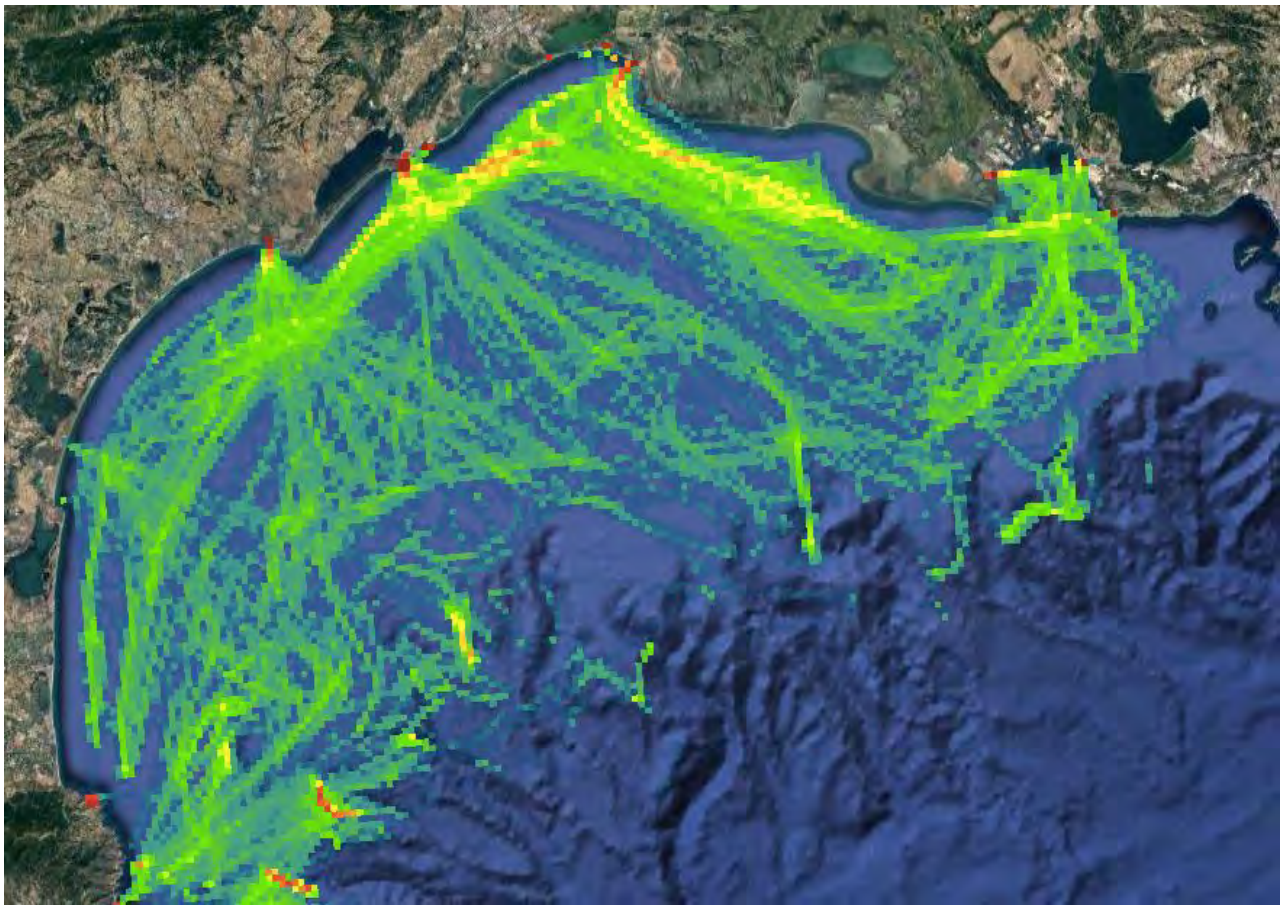


Figure 137: Fishing fleet tracks by AIS, winter (*Source: EMODnet, www.emodnet.eu*)

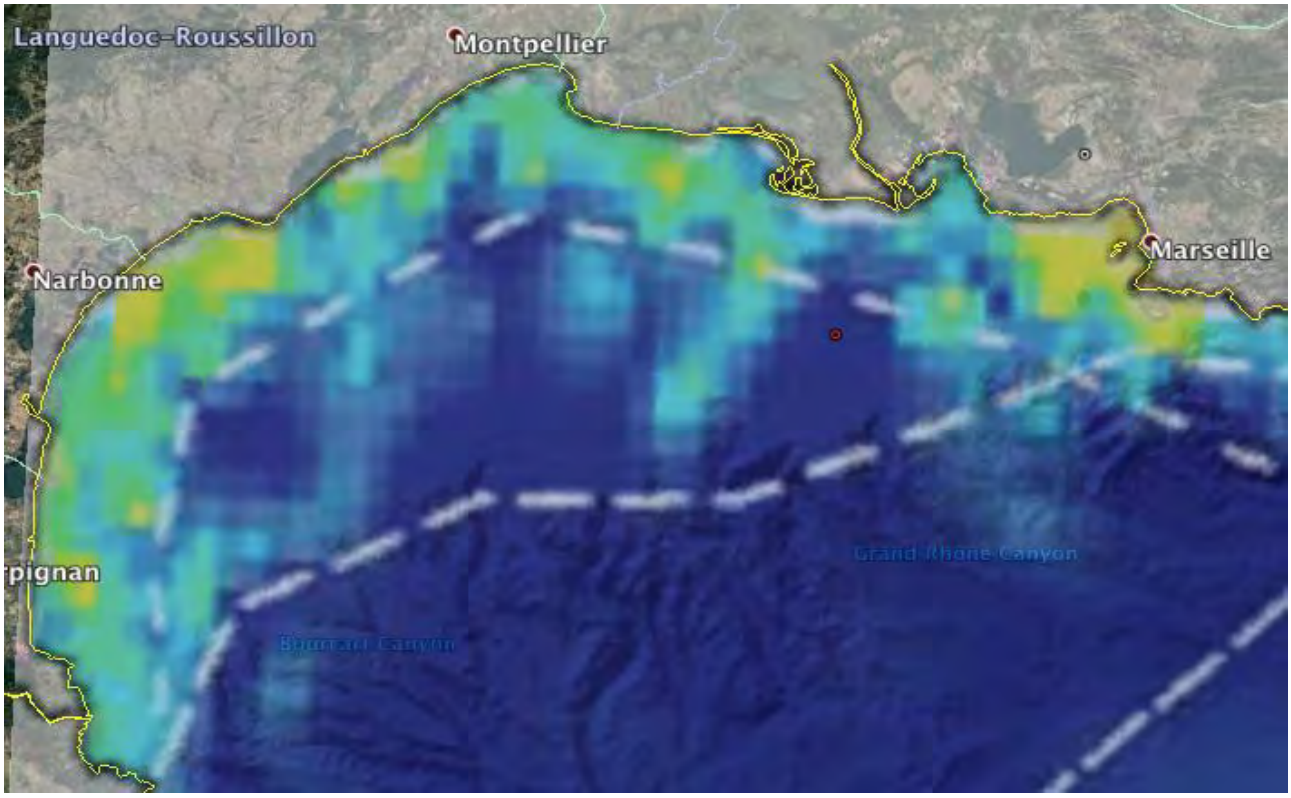


Figure 138: *Larus mihaellis* distribution in summer (*Source: Pettex at al., 2017, mod.*)

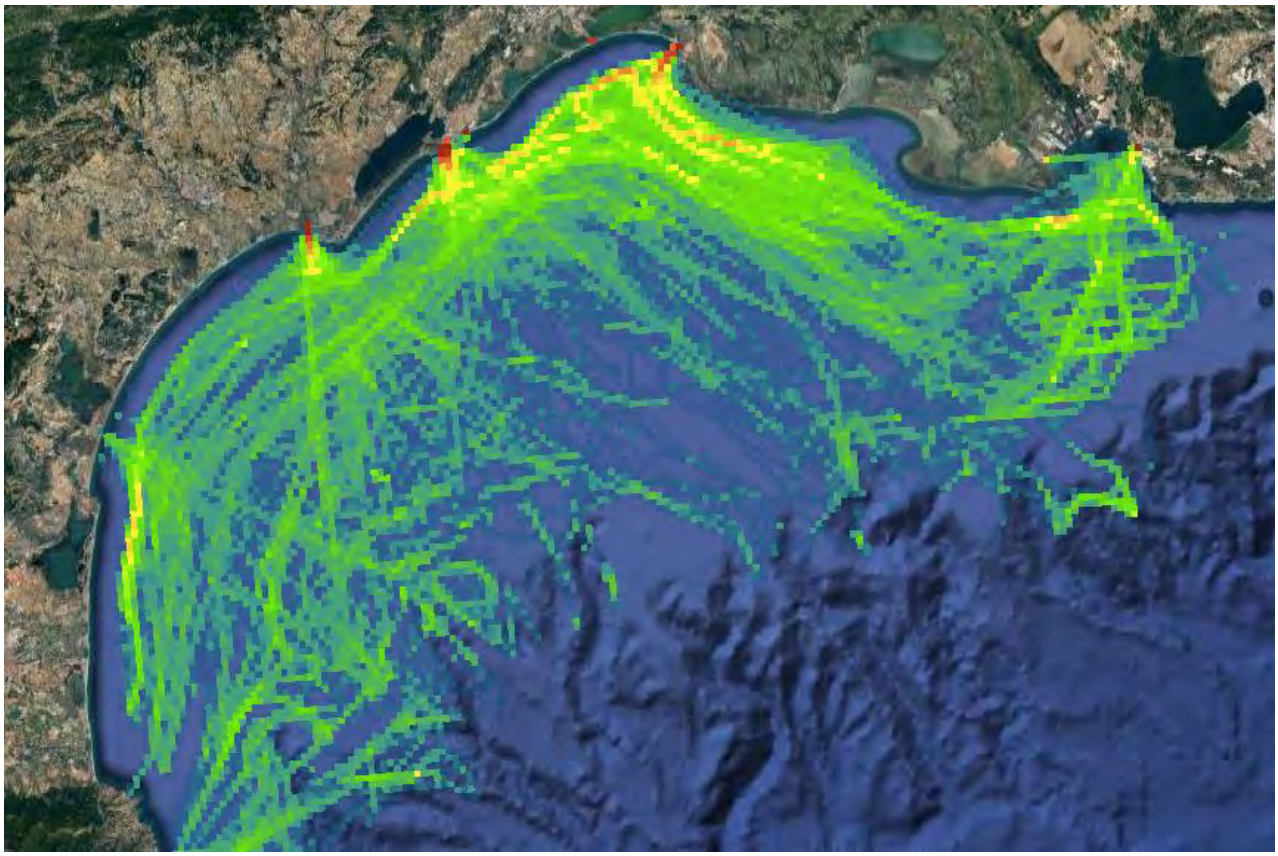


Figure 139: Fishing fleet tracks by AIS, summer (*Source: EMODnet, www.emodnet.eu*)

- **Scenario 1: wind turbine only**

In the following chapter the results of application of CRM are reported. The basic assumption underlying the Band model application is that the BGF platform do not exerts any positive nor negative attraction against the specimens of bird species present in the area of interest. The model calculates the encountering probability of a rotating object on its axe (the rotor) with a randomly moving bird, by a straight trajectory, which speed and height is due to the intrinsic species features, as wingspan and body lenght, and mainly vertical flight height distribution. The present scenario is therefore related to the operation of a standing wind turbine alone, without any additional part or device able to attract birds for behavioural or feeding reasons. The species assessed in this part are those marked as potentially interactig with the BGF, irrespectively of their rarity or conservational status.

Note on uncertainty estimate

As reported in Band model explanation, it's reccommended to assess the uncertainty of risk collision estimate, mainly due to:

1. Uncertainty of bird density, connected to bird survey difficulties;
2. The simplification in speed, body size, trajectories inside the CRM itself;
3. The unknown avoidance rate;
4. The flight height distribution;
5. The likely BGF bird attraction.

- Point 1 can not be resolved in the present work, being the data on density derived from published papers, or in some species, inferred from Natura 2000 breeding pairs, thus intrinsecly not controllable and without confidence intervals. *This can be considered as the main source of bias, likely at such extent to mask all the others. Within this paper, the calculation of confidence intervals is considered as not worty, being the basic bird density affected by a large uncertainty in itself.*
- Point 2 will not be commented, being the CRM widely accepted and validated.
- Point 3, as suggested in literature, will be overcome presenting different avoidance rate and derived collision numbers.
- Point 4, the flight heights distribution reported in Cook et *al*., 2011, are used, as derived from observation with statistical significance. In the present work we have used the median distribution, in order to avoid the presentation of a number of results, possibly masking the general picture.
- Point 5 will be considered in subsequent chapter on the basis of the available literature data.

In general, several sources of uncertainty exist, and at the current design stage of BGF it's considered worth to draw a general picture of the likely risk of bird collision, which numbers can be considered as a first order estimate, being a precise picture affected by the lack of a reliable bird density.

Table 30: Input values in the CRM for the eligible species in BGF area

Species	Scientific name	Body Lenght (cm)	Wingspan lenght (cm)	Flight speed (m/s)	Nocturnal activity %	Flight pattern type	Flight type distribution (Cook,2011)	Flight % within 0-40m	Bird density (ind/km2)	Source
Cori's shearwater	*Calonectris diomedea*	48-56	113-124	14.8	25	Gliding	Puffinus spp.	100	0,19	Pettex et al.
Storm petrel	*Hydrobates pelagicus*	14-18	36-39	7,4	50	Gliding	Puffinus spp.	100	0,035	Pettex et al.
Little gull	*Hydrocoloeus minutus*	25-30	74-79	11,5	25	Flapping	L. minutus	97	0,01 - 0,35	Pettex et al.
Mediterranean gull	*Larus melanocephalus*	60	140	10,8	50	Flapping	L.ridibundus	97	3,1	Computed
Michahellis' gull	*Larus michahellis*	58-70	140-155	12	50	Flapping	L.marinus	84	0,6 - 1,2	Pettex et al.
Northern gannet	*Morus bassanus*	87-100	165-180	14.9	25	Gliding	M.bassanus	97	0,02 - 0,8	Pettex et al.
Great cormorant	*Phalacrocorax carbo*	80-100	130-160	15	25	Flapping	Cormorant	99	0,02	Pettex et al.
Manx shearwater	*Puffinus p. mauretanicus*	35-40	85-90	14	25	Gliding	Puffinus spp.	100	0,39-0,4	Pettex et al.
Levantine shearwater	*Puffinus yelkouan*	30-38	76-89	14,6	25	Gliding	Puffinus spp.	100	0,39 - 0,4	Pettex et al.
Common eider	*Somateria mollissima*	50-71	80-108	17,9	0	Flapping	Eider	83	0,046	Computed
Common tern	*Sterna hirundo*	32-39	72-88	8,3	25	Flapping	Common tern	99	0,91	Computed
Sandwich tern	*Thalasseus sandvicensis*	35-45	86-105	12,1	25	Flapping	Sandwich tern	99	0,86	Computed

Wind turbine producibility has been derived from wind data collected from the Lion Buoy (station 6100002), located at latitude 42.0700°, longitude 4.6600°, the only data available for the Gulf of Lions. Wind speed at 10 m were corrected to refer them to the wind speed at 100 m above sea level using the correction factor as in DNV GL-RP-C205:

Uwind 100m= Uwind 10m+(100/10)^0.12

Wind speed comprises between 4 and 25 m/s were positively considered.

Calonectris diomedea

The collision risk for this species has been estimated on the basis of the flight height distribution (option 3 in CRM), assuming that the median flight height distribution for Manx shearwater sufficently approximate the *Calonectris* flying habitus. This very low flying height remains well below the risk area, represented by the area swept by rotating blades, thus nullyfing the collision risk.

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*year avg*
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	**81,25%**
Daytime areal bird density birds/km2		0	0	0	0,19	0,19	0,19	0,19	0,19	0,19	0	0	0	
Proportion at rotor height	0,0%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		0	0	0	682	746	744	759	723	655	0	0	0	
Avg collision risk for single rotor transit	2,2%													
														per annum
Collisions assuming no avoidance	0,00%	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Collisions by avoidance rate	***95,0%***	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	**0**
birds/month	***99,0%***	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Hydrobathes pelagicus

The collision risk for this species has been estimated on the basis of the flight height distribution (option 3 in CRM), assuming that the median flight height distribution for Manx shearwater sufficently approximate the *Hydrobates* flying habitus, being very similar in all Petrels. This very low flying height remains well below the risk area, represented by the area swept by rotating blades, thus nullyfing the collision risk.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	###	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,25%***
Daytime areal bird density	birds/km2	0	0	0	0,035	0,035	0,035	0,035	0,035	0,035	0	0	0	
Proportion at rotor height	0,1%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		0	0	0	73	78	77	79	77	72	0	0	0	
Avg collision risk for single rotor transit	1,9%													
														per annum
Collisions assuming no avoidance	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
Collisions by avoidance rate	95,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
birds/month	99,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Hydrocoloeus minutus

The collision risk for this species has been estimated on the basis of the specific flight height distribution (option 3 in CRM), reported in Cook, 2011, and using only the median flight height distribution. Although the species has a flying height distribution intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	81,3%
Daytime areal bird density	birds/km2	0,35	0,35	0,35	0,01	0,01	0,01	0,01	0,01	0,01	0,35	0,35	0,35	
Proportion at rotor height	3,1%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		820	788	939	28	31	30	31	30	27	900	811	805	
Avg collision risk for single rotor transit	2,2%													
Collisions assuming no avoidance	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Collisions assuming avoidance rate	**95,0%**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	**0**
birds per month	**99,0%**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Larus melanocephalus

The collision risk for this species has been estimated on the basis of the flight height distribution (option 3 in CRM) of *Larus ridibundus*, assuming that the median flight height distribution of this latter, similar in size and feeding habitus, can sufficiently approximate *L. melanocephalus*. Although the species has a flying height distribution intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates. This species, although showing a high numer of pairs in breding areas near BGF, is mainly coastal, and can extend its feeding areal to the sea only during breeding period.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	0	0	0	3,1	3,1	3,1	3,1	3,1	3,1	0	0	0	
Proportion at rotor height	3,0%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		0	0	0	9462	10109	9953	10211	9928	9252	0	0	0	
Avg collision risk for single rotor tra	3,9%													
Collision assuming no avoidance	0,00%	0	0	0	4	4	4	4	4	4	0	0	0	***24***
Collision assuming avoidance rate	**95,0%**	0	0	0	0	0	0	0	0	0	0	0	0	***1***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
birds/month	**99,0%**	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Larus michaellis

The collision risk for this species has been estimated on the basis of the flight height distribution (option 3 in CRM) of *Larus marinus*, a similar species in size and feeding habitus, and assuming that the median flight height distribution of this latter, similar in size and feeding habitus, can sufficiently approximate *L. michaellis*. The used flight height distribution intercepts the area swept by rotating blades, and the collision risk appears existant, even when applying common avoidance rates. This species is mainly coastal but can largely extend its feeding areal to the sea adopting a scavenging feeding strategy, and exploiting fishery offals, available at sea all year long.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	1,2	1,2	1,2	1,2	0,6	0,6	0,6	0,6	0,6	1,2	1,2	1,2	
Proportion at rotor height	15,6%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		3757	3505	4039	4070	2174	2140	2196	2135	1990	3947	3677	3720	
Average collision risk for single rotor transit	4,7%													
Collisions assuming no avoidance	0,0%	16	16	17	15	7	7	7	8	7	17	16	16	***148***
Collisions assuming avoidance rate	95,0%	1	1	1	1	0	0	0	0	0	1	1	1	***7***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***3***
birds/month	99,0%	0	0	0	0	0	0	0	0	0	0	0	0	***1***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***1***

Morus bassanus

The collision risk for this species has been estimated on the basis of the specific flight height distribution (option 3 in CRM), reported in Cook, 2011, and using only the median flight height distribution. Although the species has a flying height distribution intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates. This is also due to the very low density at sea.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	0,8	0,8	0,8	0,02	0,02	0,02	0,02	0,02	0,02	0,8	0,8	0,8	
Proportion at rotor height	5,0%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		2429	2333	2780	72	79	79	80	77	69	2665	2403	2383	
Avg collision risk for single rotor trai	4,2%													
Collisions assuming no avoidance	0,0%	1	1	1	0	0	0	0	0	0	1	1	1	***7***
Collisions assuming avoidance rate	**95,0%**	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
birds/month	**99,0%**	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Phalacrocorax carbo

The collision risk for this species has been estimated on the basis of the specific flight height distribution (option 3 in CRM), reported in Cook, 2011, and using only the median flight height distribution. Although the species has a flying height distribution slightly intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates. This is also due to the very low density at sea. This species is in fact mainly coastal.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	0,02	0,02	0,02	0	0	0	0	0	0	0,02	0,02	0,02	
Proportion at rotor height	1,0%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		61	59	70	0	0	0	0	0	0	67	60	60	
Avg collision risk for single rotor tran	3,7%													
Collisions assuming no avoidance	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
Collisions assuming avoidance rate	**95,0%**	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
birds/month	**99,0%**	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Puffinus mauretanicus and ***Puffinus yelkouan***

The collision risk for these two species has been estimated on the basis of the flight height distribution (option 3 in CRM), assuming that the median flight height distribution for Manx shearwater sufficently approximate the *two Puffinus* flying habitus. This very low flying height remains well below the risk area, represented by the area swept by rotating blades, thus nullyfing

the collision risk. The two species are considered together, being virtually indistinguishable during surveys at sea. Literature data do not report a separate density for the two species.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/sq km	0,39	0,39	0,39	0,4	0,4	0,4	0,4	0,4	0,4	0,39	0,39	0,39	
Proportion at rotor height	0,1%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		1160	1115	1328	1416	1550	1544	1576	1503	1361	1273	1148	1139	
Avg collision risk for single rotor transit	1,6%													
Collisions assuming no avoidance	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
Collisions assuming avoidance rate	95,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
bird/month	99,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Somateria mollissima

The collision risk for this species has been estimated on the basis of the specific flight height distribution (option 3 in CRM), reported in Cook, 2011, and using only the median flight height distribution. Although the species has a flying height distribution slightly intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates. This is also due to the very low density at sea.

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	0,046	0,046	0,046	0	0	0	0	0	0	0,046	0,046	0,046	
Proportion at rotor height	1,7%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		121	122	153	0	0	0	0	0	0	143	122	117	
Avg collision risk for single rotor transit	3,3%													
Collisions assuming no avoidance	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	***1***
Collisions assuming avoidance rate	95,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
bird/month	99,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Sterna hirundo

The collision risk for this species has been estimated on the basis of the specific flight height distribution (option 3 in CRM), reported in Cook, 2011, and using only the median flight height

distribution. Although the species has a flying height distribution slightly intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates. Although its density at sea is relevant, its flying habitus close to sea surface keep the species outside the risk area.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	0,91	0,91	0,91	0,91	0,91	0,91	0,91	0,91	0,91	0,91	0,91	0,91	
Proportion at rotor height	1,0%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		1539	1478	1761	1831	2004	1997	2039	1943	1760	1689	1522	1510	
Average collision risk for single rotor transit	2,9%													
Collisions assuming no avoidance	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	***2***
Collisions assuming avoidance rate	95,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
bird/month	99,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

Thalasseus sandwichensis

The collision risk for this species has been estimated on the basis of the specific flight height distribution (option 3 in CRM), reported in Cook, 2011, and using only the median flight height distribution. Although the species has a flying height distribution slightly intercepting the area swept by rotating blades, the collision risk remains negligible, when applying common avoidance rates. Although its density at sea is relevant, its flying habitus close to sea surface keep the species outside the risk area.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year avg
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/sq km	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	0,86	
Proportion at rotor height	1,0%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		2121	2037	2427	2523	2761	2752	2809	2677	2425	2327	2098	2081	
Average collision risk for single rotor transit	2,5%													
Collisions assuming avoidance rate	0,0%	0	0	0	0	0	0	0	0	0	0	0	0	***2***
Collisions assuming avoidance rate	95,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	98,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
bird/month	99,0%	0	0	0	0	0	0	0	0	0	0	0	0	***0***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***0***

<u>Consideration</u>

The wind turbine of BGF platform has resulted to give a negligible impact on seabird population, and this is due to four main factors:

- Seabird flight height distribution is mainly skewed to the sea surface;
- Pelagic seabird density at sea is low. Nevertheless, it worth to notice that their distribution is linked to marine frontal zones, variable in time;
- Blade clearance from sealevel is enough to ensure a safe zone for most seabird species;
- BGF distance from coast is enough to minimize the presence of coastal and estuarine species.

On the other hand, some species (gulls, eiders) have a vertical distribution intercepting blade swept areas, and gulls density at sea, mainly related to their ability to exploit fishery offals, in presence of an attractive source as BGF fish farm, can hardly be regarded as in natural conditions.

Scenario 2: wind turbine + fish farm

Seabirds are attracted to large offshore structures such as production platforms (Wiese et *al*., 2001).
Causes for this attraction include:

- Structural stimuli
- Food concentration
- Oceanographic processes
- Lights and flares.

It was observed that:

- Birds were **7 times more dense** (birds/Km2) within a 500 m radius of a platform than birds in the surrounding waters (Tasker et *al*., 1986);
- Bird densities at rigs were **6 to 7 times** greater after "spudding" (commencement of drilling) than before (Baird, 1990);
- Seabird concentration around offshore oil plattforms (Grand Banks) were **19-38 times** higher than on survey transects leading to it (Wiese & Montevecchi, 2000).

The existence of structure as platform in an open sea area have the effect of creating a sort of artificial reef, where the presence of hard substrata can diversify and push to the surface the benthos. Wake effect behind structure can attract other organisms as fish or birds that can directly feed on benthos or on zooplancton close to this latter. The general effect is thus of increasing habitat complexity and making available resources likely to be restricted to seabottom in open sea. This "artificial reef effect" concentrates in space preys (benthos, zooplancton, fish) and their predators (seabirds), increasing prey availabilty and accessibility. Moreover, the aerial structure of the platform can make available roosting refuges at sea for birds, or attracting them by flares or lights.

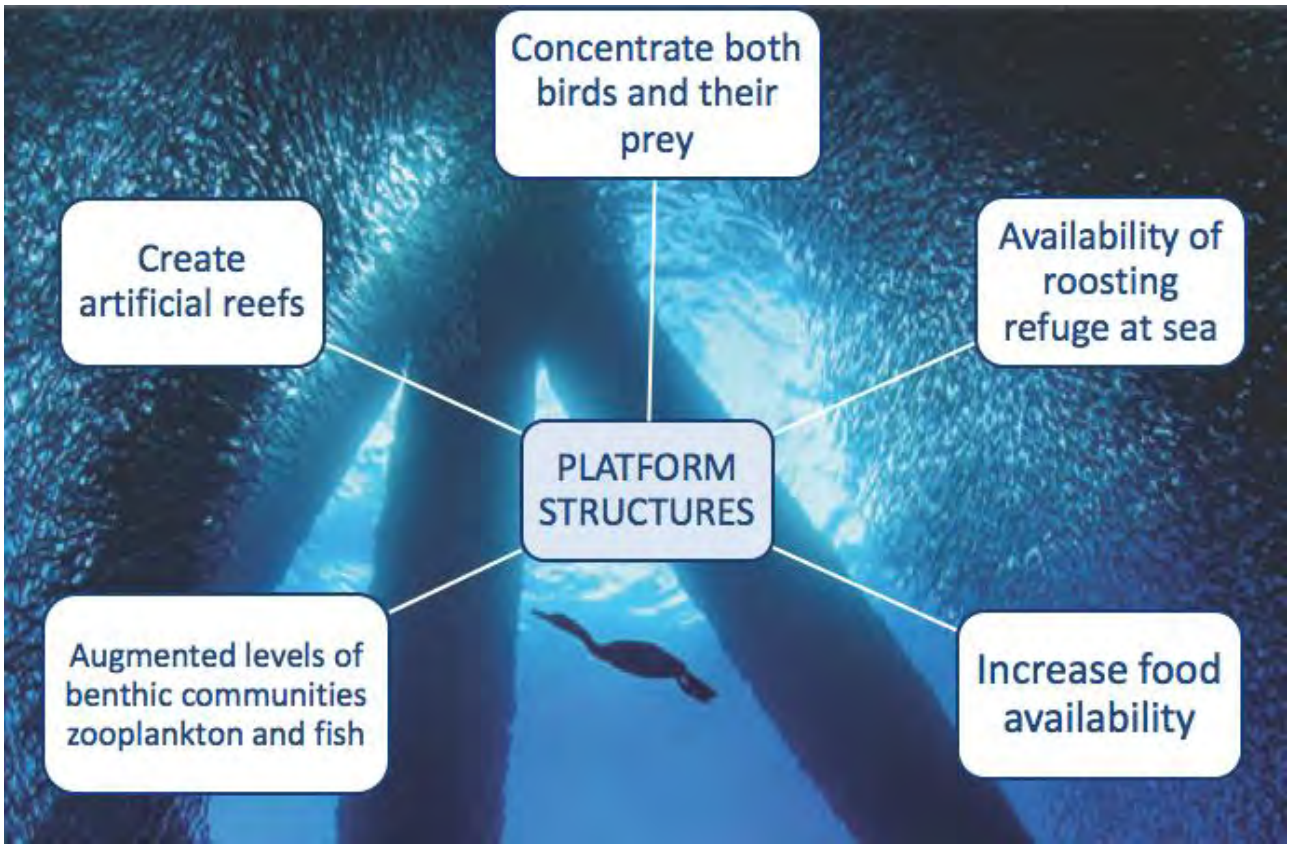


Figure 140: Platform structures bird attraction

The BGF platform is intended to produce 4000 ton/cycle of market-size fish, thus approximately doubling this figure in terms of fish food consumption. The release of organic matters, as faeces and nutrient are then expected to be massive.

The interaction between aquaculture activities and seabirds leads to a combination of attractive and repulsive effects, that together determine the sebird abundance on fish farm area (ref).

Amongst attractive mechanisms, it worth recall:

1. Artificial reef effect, as above for rigs and platforms;
2. The establishment of a fouling benthic community, supporting other trophic levels, or directly accessible, as mussels for Eiders;
3. An increase in benthic biomass and diversity beneath cages, under moderate organic matter deposition;
4. A secondary attraction due feed dispersal, shadow and wake effects, preys concentration that all together contribute to enhance fish presence;
5. Attractive smells for petrels, as Dimetilsufides or Pyrazine (Nevitt, 2006);
6. Occasional presence of carrons or escapees;
7. Attractive lights.

On the other hand, a labour-intensive farm husbandry can discourage bird presence, increasing human presence, noise or directly displacing specimens from abitual areas.

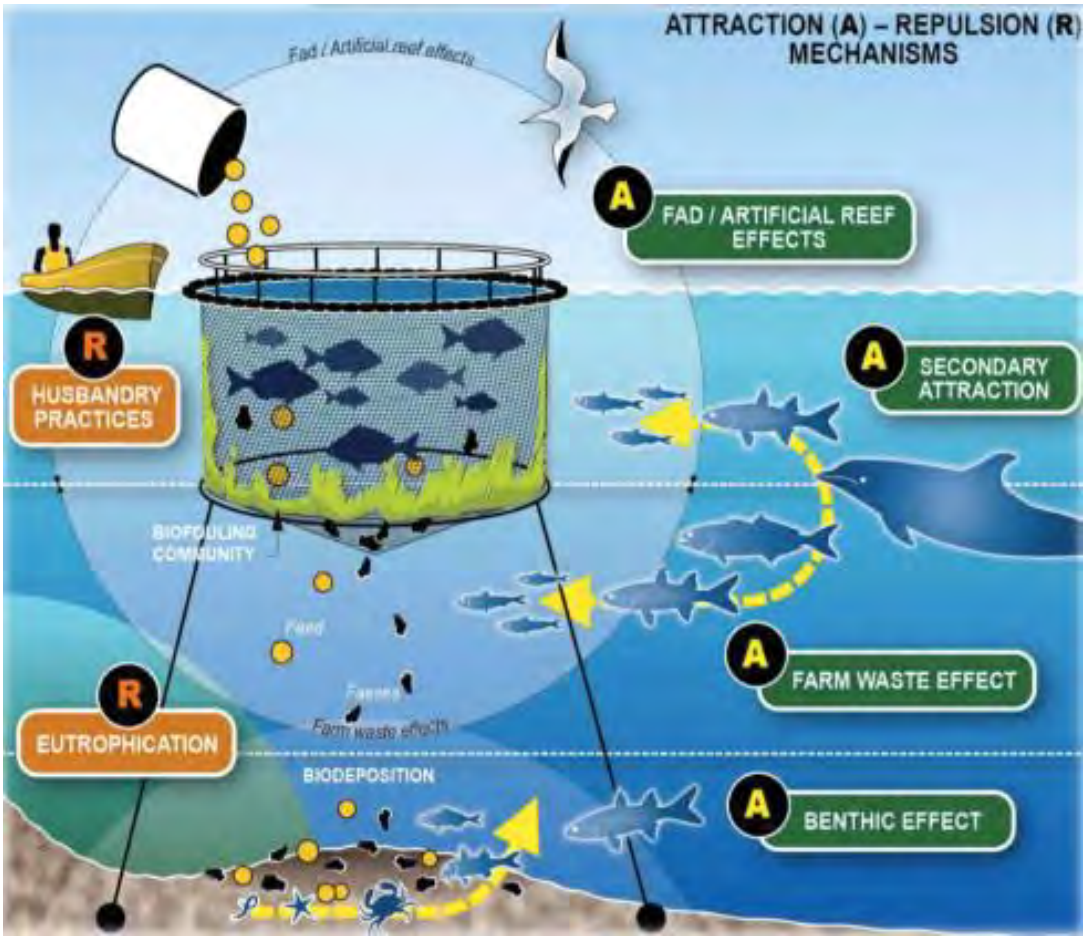


Figure 141: Attraction/repulsion mechanisms in fish farming, (*Source: Callier et al., 2018*)

While a group of factor leading to positive attractivity can be controlled or mitigated, as:

- *Sheltering/roosting*
- *Lights emissions*
- *Fish escapees*

Some others cannot realistically be eliminated:

- *Smell emissions*
- *Organic matter release*
- *FAD/Artificial reef effects*

On these bases, it's likely that a BGF installation, fitted by both a fish farm and a roosting area, can modify the bird presence in the area. Buschmann et *al*. (2006), reported an abundance increase from 2 to 5-fold for divers and scavengers on salmon fish farms. Nevertheless, recent reviews of avoidance rates for marine bird report a number of effects of displacement and avoidance at various levels of offshore windfarms, different amongst species and sites. Literature confirms that gulls' attraction to windfarm is in close connection to presence of fishing vessels in the nearby zone.

Therefore, it can not be excluded the possibility of two opposite effects, as windfarm avoidance and fish farm attraction, that would combinate to determine an actual bird density around BGF.

Literature doesn't offer solid reference for a multi-purposes platform, where the co-existence of a mutiplicity of activities and a complex three-dimensional structure may offer several niche to marine birds.

While the most species of seabird present in Gulf of Lions display a flight height distribution that is rather safe against the wind tubine features hypotesized for the BGF, ***Larus michaellis*** is the main species potentially at risk of strike, and for which, in case of an increased number of specimens around BGF, the number of collision could be higher.

The number of collision has therefore been recalculated, on the basis of the 5-fold density increase around fish farm, as in Buschmann et *al*. (2006), using the median flight height distribution and four avoidance rates.

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*year avg*
Proportion operational time of wind turbine		91%	96%	91%	76%	69%	66%	67%	76%	69%	91%	92%	91%	***81,3%***
Daytime areal bird density	birds/km2	6	6	6	6	3	3	3	3	3	6	6	6	
Proportion at rotor height	15,6%													
Total daylight hours per month		291	294	369	401	454	459	466	432	376	343	293	281	
Total night hours per month		453	378	375	319	290	261	278	312	344	401	427	463	
Flux factor		18784	17526	20195	20348	10870	10702	10979	10676	9949	19735	18387	18600	
Avg collision risk for single rotor transit	4,7%													
Collisions assuming no avoidance	0,0%	81	80	87	73	36	33	35	38	33	85	80	80	***741***
Collisions assuming avoidance rate	95,0%	4	4	4	4	2	2	2	2	2	4	4	4	***37***
	98,0%	2	2	2	1	1	1	1	1	1	2	2	2	***15***
birds/month	99,0%	1	1	1	1	0	0	0	0	0	1	1	1	***7***
	99,5%	0	0	0	0	0	0	0	0	0	0	0	0	***4***

The significativity of the present figure will be considered further in a following chapter, but it's now possible to see that numbers of collisions are relevant. *Larus michaellis* is a species classified as Least Concern under IUNC categories, and which populations at both global and local level are large and with an expanding trend. The conservationist concern can be considered as very low, albeit a relevant number of fatalities could be a source of a possible public concern.

Migratory birds

France is located on two major migration routes throughout North-West Europe:

- the "Atlantic" migration route,
- the so-called "Rhone Valley / Mediterranean migration route".

These two main roads are part of an extensive network of migratory routes that connects Europe to Africa.

In general, it can be distinguished:

- the pre-nuptial migration, which concerns birds that reach breeding sites after wintering in southern Europe and Africa (main directions of movements: South / North; South West / North East);
- the postnuptial migration, which takes place after Birds' reproduction and which allows birds to reach winter quarters (main directions of movements: North / South, North East / South West).

These phenomena affect all migratory birds at different scales. In fact, not all birds migrate to Africa: some species in northern Europe migrate to the south of the North Sea (geese, etc.) and descend further south in the event of cold spills (leakage movements).

Migration periods vary enormously from one species to another and according to climatic conditions. Pre-nuptial migration is considered to be from late January to May and post-breeding passage begin at the end of June to end in November.

Some species spend only a few weeks in Mediterranean regions, time to lay and raise young, and then go back to the South.

During the year, we therefore distinguish:

- the breeding period, which includes looking for the nesting site, parrying, laying, brooding and raising chicks until fledging;
- the internship period, which corresponds to youth dispersal, postnuptial migration, overwintering and pre-nuptial migration.

Migratory diurn movements

Species migrating during the day may be found among the following families: Cormorants, Ardeidae, Anatidae, Diurnal raptors, Limicoles, Laridae, Columbidae, Picidae, Larks, Wagtails, Pipits, Accentors, Tits, Sparrows, Corvids, Rings, Sparrows.

The flows are very important and take place more or less all the year, with peaks of abundance quite marked between March and May and between July and November.

Hundreds of thousands of birds pass through France every year during the day and can be counted.

Nocturnal migratory movements

In addition to the species of the previous category, which can also migrate at night in greater or lesser quantities, the species migrating at night are mainly Ardeidae, Anatidae, Limicoles, Rallidae and Passerines. Among these, Sylviidae, Muscicapidae, Turdidae, Alaudidae, etc represent the most important families.

The flows are very important and take place at well-defined periods of the year, with peaks of abundance for each species or family.

The nocturnal migratory flow is generally far superior to the visible flow.

It is clear that apart from very specific investigative means such as radar, trapping or thermo-sensitive cameras, it is not possible to directly perceive these migratory flows reliably. Indirect methods by nocturnal listening or observation of the lunar disc with the telescope are partial and often very biased.

Leak movements

In particularly bad weather conditions, such as winter cold spells or autumn storms, large leakage movements can occur. The species concerned are the Anatidae, the Limicoles, the Rallidae, the Raptors and the Passerines in the first case, the seabirds sensu lato in the second.

The flows can be very important. They take place at well-defined periods of the year, especially in October-November for storm-related leaks, and between December and February for winter cold spells.

These exceptional movements, linked to particular meteorological episodes, are important because they intervene at a crucial moment in the survival of individuals or even populations.

Local movements

These movements concern breeding birds as well as migratory migrants or wintering birds. These are short-distance trips, most often for food research purposes.

The flows are very important and take place all year long. Their spatial or temporal distribution is variable with modes however recurrent.

Tens of thousands of birds are concerned. Without further investigation, it is not always easy or possible on the ground to separate local movements from actual migratory movements.

Flight altitude of birds

The flight altitude is very variable, depending on the species, the time of day and the seasons. The parameters that influence the height at which species migrate are both intrinsic to the species and extrinsic.

Among the intrinsic factors, it can be pointed out that strong variations exist within families or biological groups.

Passerines generally migrate at low altitude during the day and at higher altitudes at night; here again very important variations exist according to the meteorological conditions and the species. In particular, it is known from the fine radar studies that migratory birds raise their average flight altitude at night compared to the day.

It should be known that without special means of detection (radar, etc.), most birds flying at more than 200 m of altitude escape the observers.

Similarly laterally, with obvious bias related to species size and number of individuals within groups, the detection radius of in-flight species can be reasonably estimated at 200 meters.

It is also known, thanks to radar studies, that birds fly much more concentrated during the day and more generally when visibility conditions are good. On the other hand, at night birds fly on much larger migratory fronts (Eastwood, 1967).

More recent and much more precise studies have been conducted in the Netherlands using a modified boat radar to define bird migration altitudes for potentially deadly migratory management projects. These studies aimed to determine Anatidae travel by tide (Spaans et al., 1995, 1996), the altitude of nocturnal flight of ducks (van der Winden & al., 1996, Dirksen et al., 1997) and Limicoles (Dirksen et al., 1995, 1996, van der Winden et al., 1997).

They conclude with the following facts:

- at most study sites, many birds fly less than 100 m at night, frequently even below 75 m altitude;
- there is a general trend for higher flying altitudes in the downwind, regardless of the season;
- there is also a general trend for lower headwinds, regardless of the season;

- these last two observations vary according to the sites and the species;
- there are significant differences in flight altitude between species.

At present stage, the narrow swept area by BGF rotor make any quantitative collision assessment not significant when compared with the width of potential migration corridors. Moreover, bird density at sea is unknow and any calculation by the CRM model unfeasible, while it remains questionable that the BGF site, 22 km offshore, can actually experience regular migration passages.

The assessment is therefore only at a qualitative level.

Some bird groups, known as migrating near coastline, have been excluded at the present stage, in absence of any information on migration routes.

The birds included in present table are only those listed ad "B" (breeding) or "W" (wintering) in Natura 2000 site assessment.

Within the 3 selected sites, 147 bird species potentially migrating close the BGF platform has been identified.

Only 25 % of them have been so far recorded in papers as at different risk level when interacting with windfarms. For the remaining species, the lack of information is evident and cannot be overcome.

Table 31: List of migratory species in the BGF area

Common Name	Scientific Name	Family	Red List France	Risk level	Source	Risk level	Source
Moustached Warbler	*Acrocephalus melanopogon*	Acrocephalidae	LC				
Common Kingfishers	*Alcedo atthis*	Alcedinidae	LC				
Northern Pintail	*Anas acuta*	Anatidae	LC				
Northern Shoveler	*Anas clypeata*	Anatidae	LC				
Common Teal	*Anas crecca*	Anatidae	LC				
Mallard	*Anas platyrhynchos*	Anatidae	LC	1	BTO, 2011		
White-fronted Goose	*Anser albifrons*	Anatidae	LC	1	BTO, 2011	AVG	Langston, 2010
Greylag Goose	*Anser anser*	Anatidae	LC	1	BTO, 2011		
Bean Goose	*Anser Fabalis*	Anatidae	LC	3	BTO, 2011	AVG	Langston, 2010
Tawny Pipit	*Anthus campestris*	Motacillidae	LC				
Grey Heron	*Ardea cinerea*	Ardeidae	LC				
Purple Heron	*Ardea purpurea*	Ardeidae	LC				
Squacco Heron	*Ardeola ralloides*	Ardeidae	LC				
Short-eared Owl	*Asio flammeus*	Strigidae	LC	2	BTO, 2011		
Common Pochard	*Aythya ferina*	Anatidae	VU				
Tufted Duck	*Aythya fuligula*	Anatidae	LC				
Greater Scaup	*Aythya marila*	Anatidae	LC	2	BTO, 2011	LOW	Langston, 2010
Ferruginous Duck	*Aythya nyroca*	Anatidae	NT				
Eurasian Bittern	*Botaurus stellaris*	Ardeidae	LC				
Barnacle Goose	*Branta leucopsis*	Anatidae	LC	1	BTO, 2011	AVG	Langston, 2010
Cattle Egret	*Bubulcus ibis*	Ardeidae	LC				
Common Goldeneye	*Bucephala clangula*	Anatidae	LC	2	BTO, 2011	LOW	Langston, 2010
Eurasian Thick-Knee	*Burhinus oedicnemus*	Burhinidae	LC				
Greater Short-toed Lark	*Calandrella brachydactyla*	Alaudidae	LC				
Dunlin	*Calidris alpina*	Scolopacidae	LC				
Curlew Sandpiper	*Calidris ferrungi nea*	Scolopacidae	NT				
Little stint	*Calidris minuta*	Scolopacidae	LC				
Eurasian Nightjar	*Caprimulgus europaeus*	Caprimulgidae	LC				
Kentish Plover	*Charadrius alexandrinus*	Charadriidae	LC				
White Stork	*Ciconia ciconia*	Ciconiidae	LC				
Short-toed Eagle	*Circaetus gallicus*	Accipitridae	LC				
Western Marsh-Harrier	*Circus aeruginosus*	Accipitridae	LC				
Hen Harrier	*Circus cyaneus*	Accipitridae	LC				
Montagu Harrier	*Circus pygargus*	Accipitridae	LC				
Long-tailed Duck	*Clangula hyemalis*	Anatidae	VU	1	BTO, 2011	LOW	Langston, 2010
European roller	*Coracias garrulus*	Coraciidae	LC				
Tundra Swan	*Cygnus columbianus bewickii*	Anatidae	LC	3 - 4	BTO, 2011	HIGH	Langston, 2010
Whooper Swan	*Cygnus cygnus*	Anatidae	LC	3 - 4	BTO, 2011	HIGH	Langston, 2010
Mute Swan	*Cygnus olor*	Anatidae	LC	3 - 4	BTO, 2011	HIGH	Langston, 2010
Great White Egret	*Egretta alba*	Ardeidae	LC				
Little Egret	*Egretta garzetta*	Ardeidae	LC				
Common Coot	*Fulica atra*	Rallidae	LC				
Common Moorhen	*Gallinula chloropus*	Rallidae	LC				
Collared Pratincole	*Glareola pratincola*	Glareolidae	LC				
Common Crane	*Grus grus*	Gruidae	LC				

Table 31: Continue

Common Name	Scientific Name	Family	Red List France	Risk level	Source	Risk level	Source
Oystercatcher	*Haematopus ostralegus*	Haematopodidae	NT				
White-tailed Sea-eagle	*Haliaeetus albicilla*	Accipitridae	LC				
Booted Eagle	*Hieraaetus pennatus*	Accipitridae	LC				
Black-winged Stilt	*Himantopus himantopus*	Recurvirostridae	LC				
Red-backed Shrike	*Lanius collurio*	Laniidae	LC				
Bar-tailed godwit	*Limosa lapponica*	Scolopacidae	NT				
Wood Lark	*Lullula arborea*	Alaudidae	LC				
Bluethroat	*Cyanecula svecica*	Muscicapidae	LC				
Eurasian Wigeon	*Mareca penelope*	Anatidae	LC				
Gadwall	*Mareca strepera*	Anatidae	LC				
Velvet Scoter	*Melanitta fusca*	Anatidae	VU	2	BTO, 2011	LOW	Langston, 2012
Common Scoter	*Melanitta nigra*	Anatidae	LC	2	BTO, 2011	LOW	Langston, 2012
Smew	*Mergellus albellus*	Anatidae	LC				
Goosander	*Mergus merganser*	Anatidae	LC	2	BTO, 2011		
Red-breasted Merganser	*Mergus serrator*	Anatidae	LC	2	BTO, 2011	LOW	Langston, 2012
Black Kite	*Milvus migrans*	Accipitridae	LC				
Red Kite	*Milvus milvus*	Accipitridae	NT				
Red-crested Pochard	*Netta rufina*	Anatidae	LC				
Eurosian Curlew	*Numenius arquata*	Scolopacidae	NT				
Black-crowned heron	*Nycticorax nycticorax*	Ardeidae	LC				
Western Osprey	*Pandion haliaetus*	Pandionidae	LC				
Honey-Buzzard	*Pernis apivorus*	Accipitridae	LC				
Ruff	*Calidris pugnax*	Scolopacidae	LC				
Carribean flamingo	*Phoenicopterus ruber*	Phoenicopteridae	LC				
Eurasian Spoonbill	*Platalea leucorodia*	Threskiornithidae	LC				
Glossy Ibis	*Plegadis falcinellus*	Threskiornithidae	LC				
Golden Plover	*Pluvialis apricaria*	Charadriidae	LC				
Grey Plover	*Pluvialis squatarola*	Charadriidae	LC				
Great Crested Grebe	*Podiceps cristatus*	Podicipedidae	LC	1	BTO, 2016	LOW	Langston, 2012
Black-necked Grebe	*Podiceps nigricollis*	Podicipedidae	LC	1	BTO, 2016	LOW	Langston, 2012
Purple Swamphen	*Porphyrio porphyrio*	Rallidae	LC				
Spotted Crake	*Porzana porzana*	Rallidae	LC				
Baillon's Crake	*Porzana pusilla*	Rallidae	LC				
Western Water Rail	*Rallus aquaticus*	Rallidae	LC				
Pied Avocet	*Recurvirostra avosetta*	Recurvirostridae	LC				
Eurosian Woodcock	*Scolopax rusticola*	Scolopacidae	LC				
Dartford Warbler	*Sylvia undata*	Sylviidae	NT				
Little Grebe	*Tachybaptus ruficollis*	Podicipedidae	LC				
Common Shelduck	*Tadorna tadorna*	Anatidae	LC				
Little bustard	*Tetrax tetrax*	Otididae	NT				
Wood Sandpiper	*Tringa glareola*	Scolopacidae	LC				
Redshank	*Tringa totanus*	Scolopacidae	LC				
Lapwing	*Vanellus vanellus*	Charadriidae	NT				

The Gulf of Lions is considerd likely to host a migratory path, mainly coastal and passing over or at sight of Languedoc and Camargue wetland areas, with a direction SW to NO from Late February to April, in case of the pre-nuptial migration. Bird track record by radar and observation (Henin, 2006) revealed that flocks can also move over the sea, and the flight altitude is mainly over the 200 m above sea level; while movement 0-200 m seem to be related to local displacement for

feeding and resting. Moreover, nocturnal flock at sea seem to be more disperse than diurnal flocks, and several evidences indicate as flight height is lower in bad weaters or during headwinds.
Species recorded by Henin, 2006, at S.Maries de la Mer, at a presumable landing site after Gulf crossing, are reported in the following table.

Table 32: Species recorded at S. Maries de la Mer during migration period (Henin, 2006).

	3d week Jan	1d week Feb	2d week Feb	3d week Feb	1d week Mar	2d week Mar	3d week Mar	*Total by sp.*
Anas platyrhynchos	922	900	1070	1100	800	765	470	***6027***
Anas crecca	1547	1035	1145	1506	730	470	215	***6648***
Mareca strepera	1363	600	2560	582	175	82	37	***5399***
Mareca penelope	400	500	320	0	250	0	0	***1470***
Anas acuta	0	70	70	64	0	0	0	***204***
Spatula querquedula	0	0	0	0	0	20	24	***44***
Spatula clypeata	654	370	470	450	130	174	99	***2347***
Tadorna tadorna	0	0	70	80	89	89	68	***396***
Netta rufina	2500	600	235	6	2	60	36	***3439***
Athina ferina	6000	2800	900	900	670	234	120	***11624***
Duck Indet.	1000	0	0	200	0	80	0	***1280***
Goose indet.	5	0	0	0	0	0	0	***5***
Cygnus olor	0	19	3	7	37	42	23	***131***
Anser anser	29	12	0	0	0	0	0	***41***
Fulica atra	5000	3500	3410	1846	1780	1830	2025	***19391***
Total	**19420**	**10406**	**10253**	**6741**	**4663**	**3846**	**3117**	58446

From the above table, it results that 2 species, *Anas platyrhynchos* and *Anser anser*, are considered in literature as at low-risk level of impact; a third species, *Cygnus olor*, is reported as at high risk of collision.

While numbers of these species are relevant, density at sea remain unknown and a quantitative collision risk assessment unfeasible at the present stage.

<u>Artificial light effects on seabirds</u>

Artificial nocturnal lighting on platforms may affect the natural behavior of seabirds, (Rich & Longcore, 2006).

It can interfere with:
- Development
- Activity patterns
- hormone-regulated processes, such as the internal clock mechanism

It may provoke:
- direct mortality,
- indirect negative effects through the depletion of their energy reserves.

Figure 142: Nocturnal lights on an oil rig

Migratory species crossing the area of a platforms may be attracted to offshore light sources, especially in deteriorating weather conditions which result in restricted visibility (e.g. low clouds, mist, drizzle). This attraction can be fatal and may involve large numbers of individuals of several species of birds, as in migrating multi-specific flocks.

Some research demonstrated that artificial light interferes with the magnetic compass of the birds, one of several orientation mechanisms and especially important during overcast nights.

Magnetic orientation is also based on specific light receptors in the eye and shown not only to be both light-intensity dependent (Ritz et *al*., 2000), and wavelength dependent: migratory birds require light from the blue-green part of the spectrum for their magnetic compass orientation *(*Wiltschko & Wiltschko 1995, 2001, Muheim et *al*., 2002*)* whereas red light, the long-wavelength component of light, disrupts magnetic orientation.

Birds are attracted and disoriented by red and white light containing visible long-wavelength radiation, while they are less disoriented by blue and green light containing less or no visible long-wavelength radiation.

In salmon farming practice, the use of cage lighting is widespread mainly to retard sexual maturations, thus advantaging somatic masses growth.

Petrels have a high sensitivity for wavelength in the range of 406-566 nm (blue-violet).

Blue lights (approx 480 nm) used in aquaculture may result attractive for Petrels, miming the bioluminescent zooplankton they feed on.

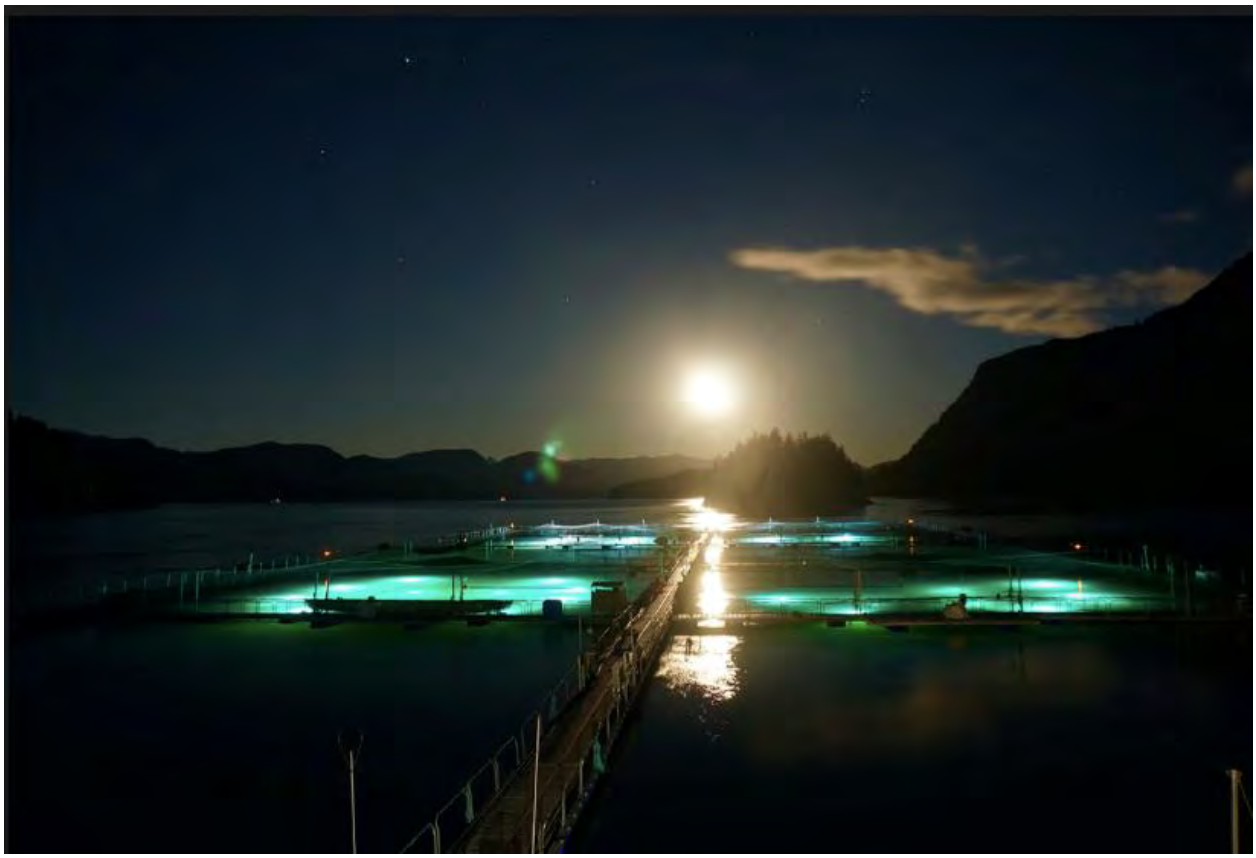


Figure 143: Salmon cage lighting

Several **Petrels** species and **Gannets** are able to dive, during preys hunting, down to 50 m. The use of aquaculture underwater lights should therefore be carefully considered.

Petrels may enter the BGF pool by diving, being attracted by light sources, at risk of entangling and drowning.

Figure 144: Petrels diving on hunting fish

Storm-petrels and other procellariforms forage at night on vertically migrating bioluminescent prey and are, therefore, naturally attracted to light of any kind in an environment which is otherwise mainly dark at night. Large attractions and mortalities of birds have been documented by offshore platforms (oil rigs) mostly during overcast nights with drizzle and fog.

Lights and flares attract bird, especially storm-petrels (*Oceanodroma spp.*) and shearwaters (*Puffinus spp.*), (Weir, 1976). Storm-petrels often fly directly into lights and flares resulting in death or injury by impact or burning (De Groot, 1996).

Bird mortalities magnitude are determined by obstacle presence in an air space where birds are flying, the time of the year, location, height, light and cross-sectional areas of the obstacle and weather conditions.

The species involved (Merkel, 2010) are, in temperate areas:

- Eiders
- Petrels
- Guillemot
- Long-tailed duck
- Murres

Sensitivities to different wavelength are *species-specific*, as well as attraction-avoidance to any colour.

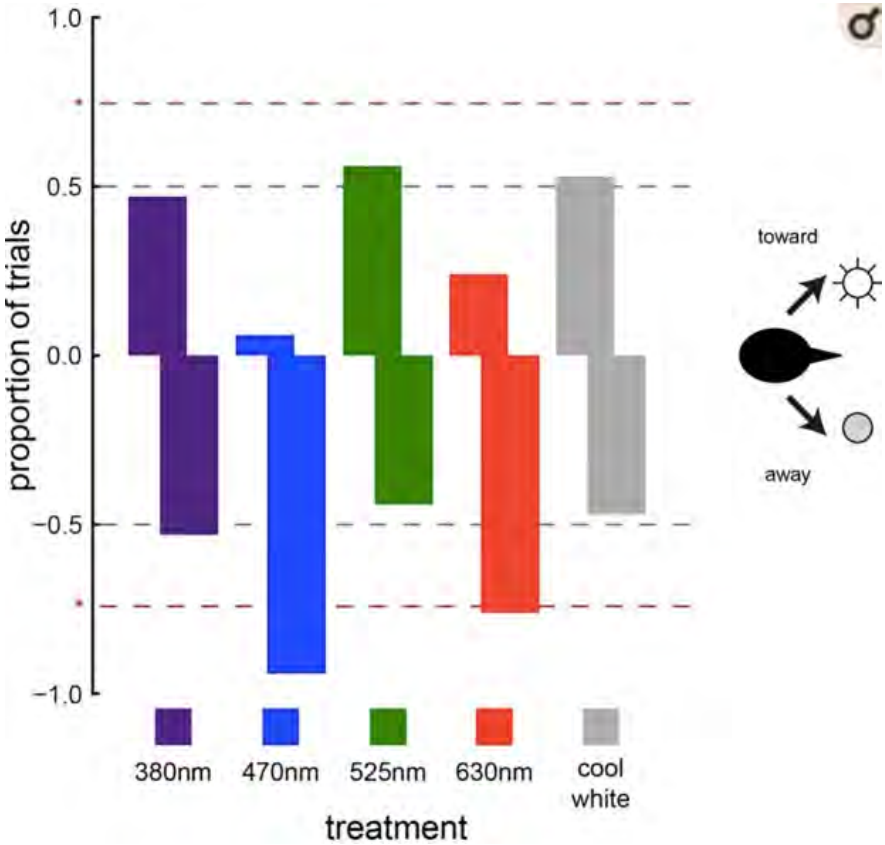


Figure 145: Wavelenght avoidance attraction in murres (*Source: Goller et al., 2018*)

5.1.2 Impact on mammals

Sound propagates efficiently through water and marine mammals rely on the use of sound to communicate with conspecifics, for predator avoidance, to locate and capture prey, mate selection and social interactions. Marine mammals have an acute sense of hearing with a high sensitivity over a wide frequency range (Nedwell et *al*., 2004). This reliance on sound in their general ecology makes marine mammals particularly vulnerable to the effects of underwater noise.

Any anthropogenic noise could impact a marine mammal if the sound falls within its audible range; noise disturbance can have a range of effects depending on the sound type or source level. Loud, intense noise sources such as explosions have the potential to cause lethal physical non-auditory injury to marine mammals, while other noise sources can cause auditory damage, or behavioural responses, induces stress and/or mask biologically important signals.

Given the relatively low noise levels emitted from operational wind turbines, it is not likely that sound levels are high enough to cause auditory injury beyond a few metres of the device and only if animals remain there for extended periods of time. The impcat of noise generated by the wind turbine of the BGF farm is considered against the most common species in the area:

1. Bottlenose dolphin (*Tursiops truncatus*)
2. Stiped dolphin (*Stenella coeruleoalba*)

3. Grampus griseus
4. Fin whales (*Balaenoptera physalus*), considering Minke whale (*Balaenoptera acutorostrata*) as model

The introduction of noise into the underwater environment may impair an animal's ability to detect calls or may disrupt its normal behaviour in some way. Noise impacts can be thought of in terms of 4 zones of influence (Richardson et *al*., 1995). The zone of audibility is the range at which animals can only just detect the anthropogenic sound source. The zone of masking is the range at which the sound exposure interferes with the signals produced by the animal, at a given frequency, and thus lowers the probability of the animal's signal being detected. This means the distances over which animals can communicate will be greatly reduced. The zone of responsiveness is smaller and is the impact range around the sound source where animals are expected to show physiological or behavioural responses to the sound. The zone of injury is the smallest zone but potentially with the highest impact. This is defined as the range at which the received sound levels are high enough to induce either direct physical injury or loss of hearing sensitivity (hearing damage).

The likelihood of an animal experiencing one or more of these effects is defined by the spatial relationship of the receiver and the sound source, the hearing sensitivity and acoustic characteristics of the vocalisations of the receiver, and the acoustic characteristics of the anthropogenic noise. The behavioural response of animals to sound appears to be influenced by a number of factors including food motivation, the context of exposure, and the animal's previous exposure history. This means that the way in which an individual responds to sound can vary between both individuals and sound exposure events.

The hearing ability of marine mammals is commonly described using audiograms; this is a plot of the hearing sensitivity of a species at different frequencies, which indicates the range of frequencies detectable by a species and can highlight where hearing is most sensitive. The hearing threshold can be defined as the received sound level in the vicinity of the ear that is just audible to an animal. Hearing thresholds depend on the frequency of the sounds and can vary strongly across species. An audiogram displays hearing threshold as a function of frequency. A lower sound pressure level value on an audiogram display reflects a low hearing threshold at a given frequency and hence a high auditory sensitivity. Audiograms for mammals are typically V- or U-shaped reflecting the fact that hearing sensitivity declines towards the edge of the hearing range.

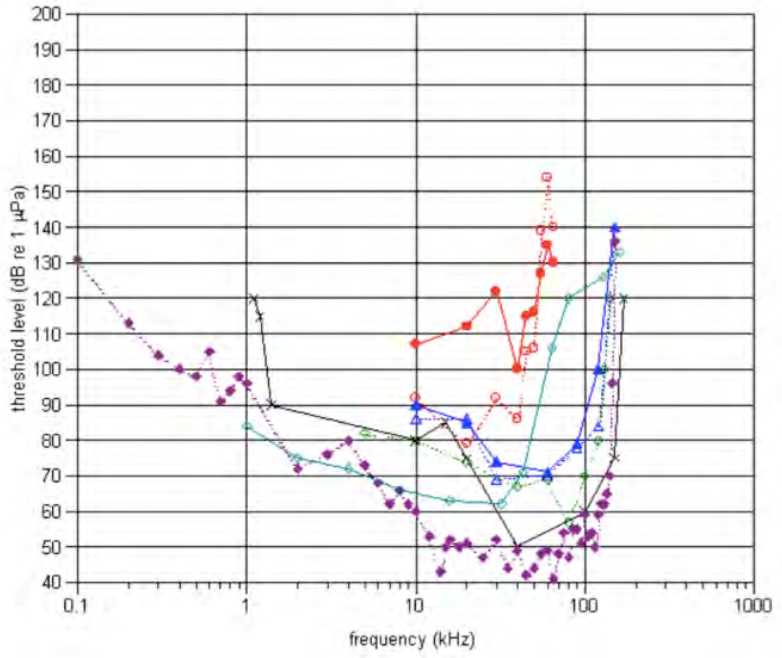


Figure 146: Audiograms for Bottlenose dolphin, *Tursiops truncates* (*Source: several authors, from Nedwell et al., 2006*)

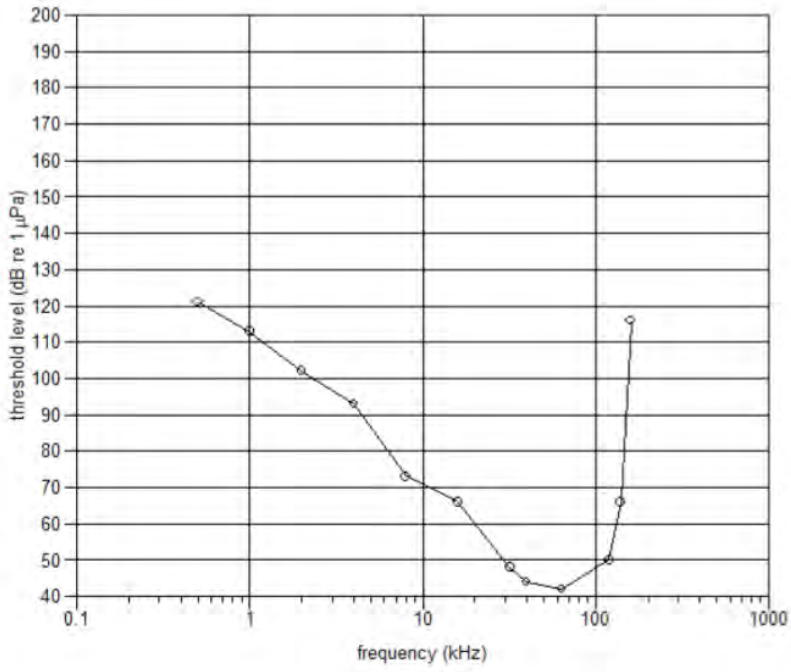


Figure 147: Audiogram for Striped dolphin, *Stenella coeruleoalba* (*Source: Nedwell et al., 2006*)

In general, small to medium-sized odontocetes have good hearing across a broad range of frequencies (4-100 kHz) and are most sensitive to sounds above 10 kHz (Richardson et *al*., 1995), but can hear sounds below this level.

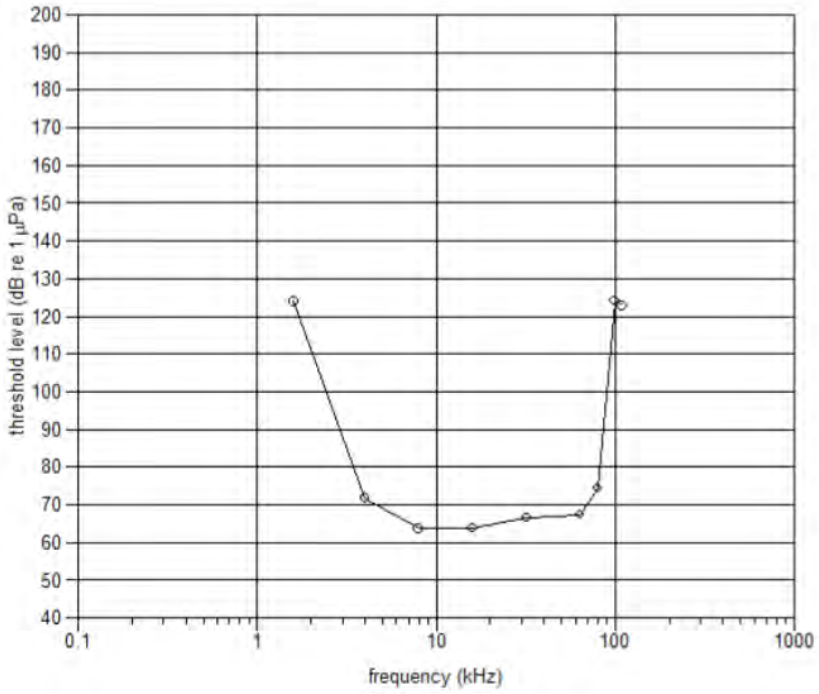


Figure 148: Audiogram for *Grampus griseus* (*Source: Nedwell et al., 2006*)

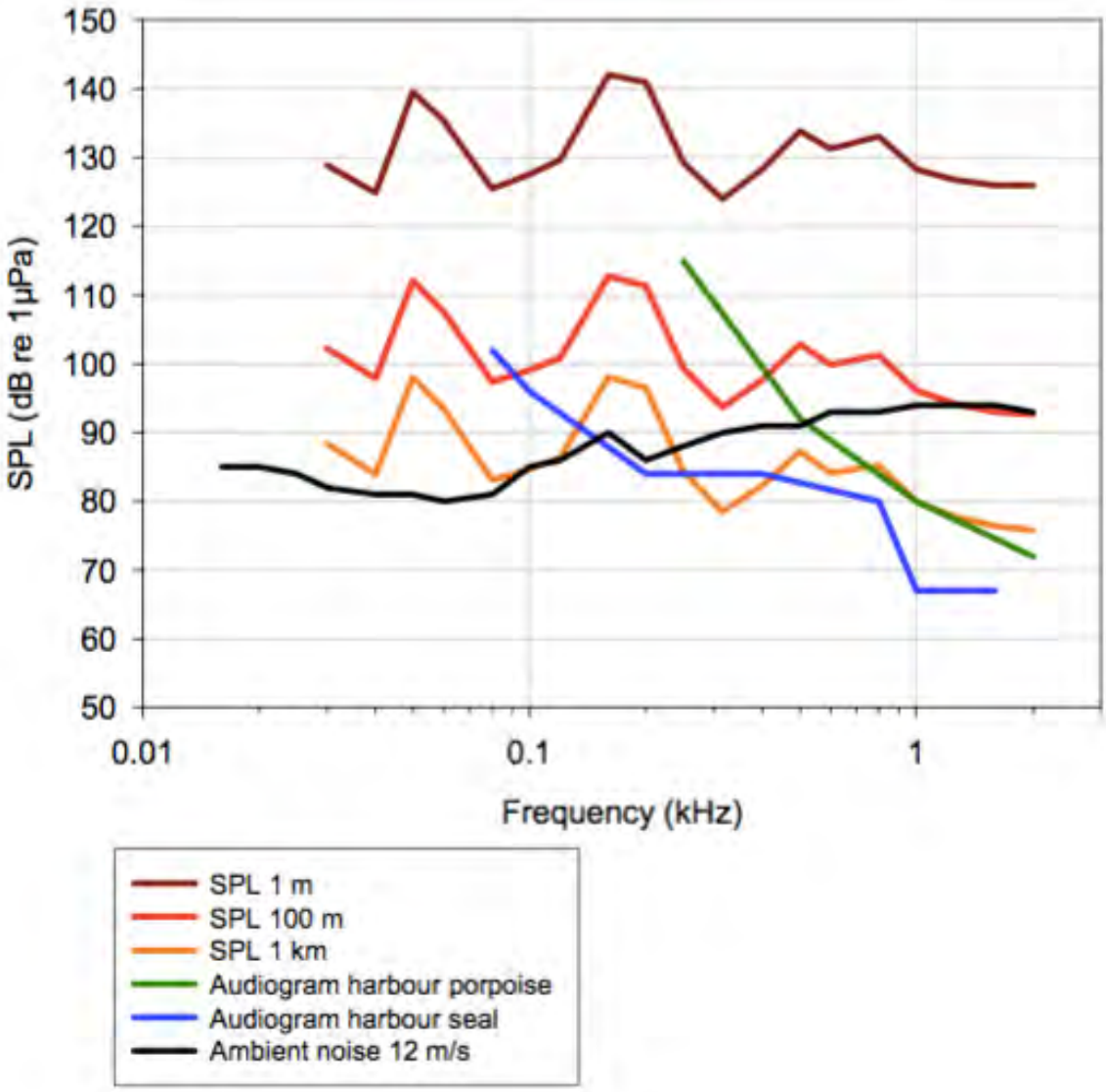


Figure 149: Operational noise of a 1,5MW wind turbine, at different distances. Background noise and hearing abilities of Porpoise and Seal displayed. ***(Source: Betke et al. 2004, mod.)***

Figure 149 shows sound pressure levels of an 1.5 MW turbine in operation at wind-speeds of 12 m/s (Beaufort = 6) at 1 m, 100 m and 1 km distance along with the ambient noise extrapolated from data by Betke et *al*. (2004) and the audiograms of Harbour porpoises and seals. It can be seen that at 100 m distance turbine noise would be audible to both harbour porpoises and harbour seals. At 1,000 m the signal to noise ratio is too low for detection in harbour porpoises.

Masking of biological relevant signals by offshore wind farm noise might become a key-issue for species known or suspect to use signals in frequencies similar to the introduced noise. For example, most delphinids are highly vocal, producing a wide-array of burst-pulsed sounds and whistles known or suspected to be used in communication (Richardson et *al*., 1995; Tyack 1998;

Herzing 2000; Janik 2005). For whistles of bottlenose dolphins, the active space - the area in which another individual can perceive the signals of a conspecific – is 20-25 km at maximum source levels (169 dBrms re 1 µPa; frequency range of the fundamental = ~ 3 – 10 kHz; mean = 9 kHz; sea state = 0; Janik 2000a). This active space will be reduced when the sound level of the masking sound equals the ambient noise in the frequency of the signal. However, as noted above, the story might be more complicated with signals of relatively long duration and it might be added here, that delphinid communication is often comprising an exchange of information (see Janik 2000b; Miller et *al*., 2004) that might be very likely disrupted or 'masked' even by intermittent signals.

When considering the high-frequency content of vocalisations in most delphinids and the low-frequency nature of operational noise, it may be argued that masking by operational noise might be negligible. However, there are exceptions from that rule: Burst-pulsed sounds are often lower in frequency than whistles (Richardson et *al*., 1995) and at least bottlenose dolphins produce low-frequency bray-calls which are associated with feeding. Given that larger turbines are most certainly noisier and some delphinids use rather low- frequency calls for communication / foraging, it cannot be excluded that even operational noise of wind-turbines will interfere with biologically relevant sound signals.

Although there are no empirical data on minke whale (or any baleen whale species) hearing, there is theoretical evidence (from the frequency of their vocalisations) that they are more sensitive to low frequency sounds than odontocetes. Specifically, it is reasonable to assume that baleen whales are sensitive to the same frequencies they vocalise at, i.e. primarily below 1 kHz, but sounds up to 8 kHz have been documented. Although baleen whales react behaviourally to low frequency calls from conspecifics, observations of these reactions do not provide accurate indications of hearing thresholds (Erbe, 2002). Therefore, baleen whale species are assumed to hear sounds at low and medium frequencies (20 Hz to >3 kHz), with the likely highest sensitivity between 100 and 200 Hz (Erbe, 2002).

Due to the scarcity of audiogram data for baleen whales in general, it has been derived a predicted audiograms using the best information available for minke whales.

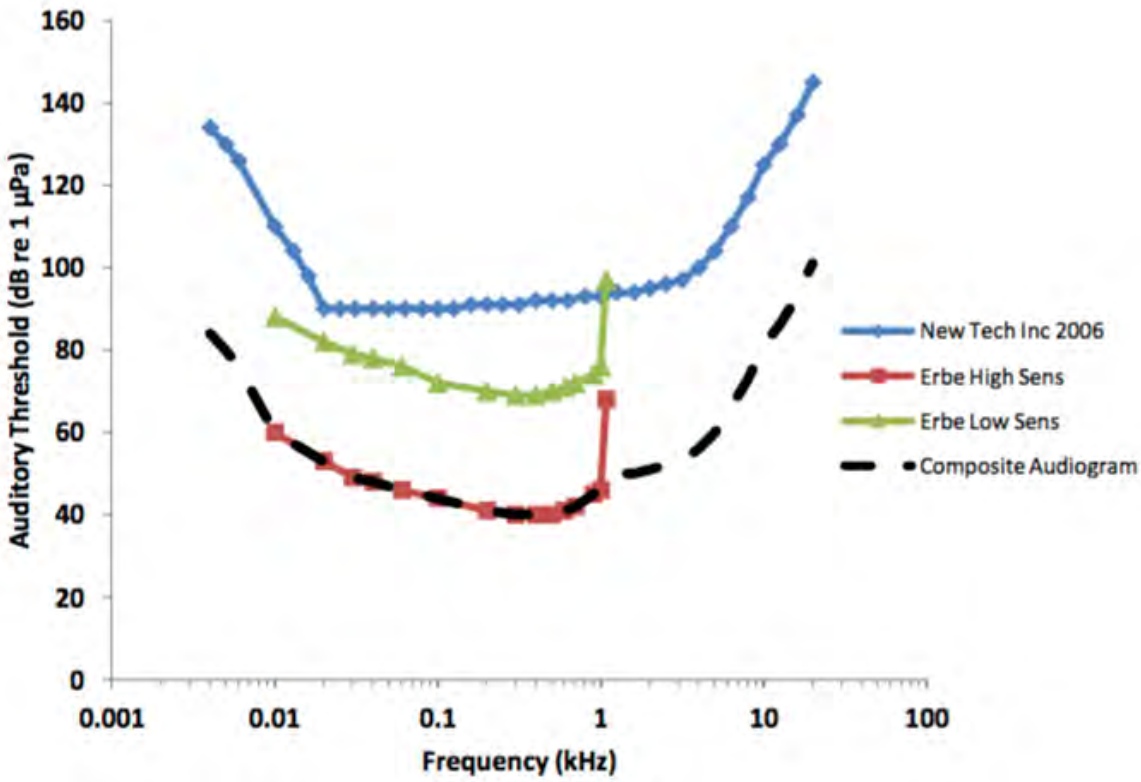


Figure 150: Predicted audiogram for Balaenoptera acutorostrata ***(Source: Marmo et al., 2013)***

For Fin whale, (Balaenoptera acutorostrata), present in the NW mediterraneana sea, Erbe, 2002, reports a best sensitivity between 20 and 150 Hz, and a vocalisation between 10 and 200 Hz.

When considering the likely sound emission by the wind turbine of the BGF platform, it may be argued that they might be in the range between 10 to 1500 Hz, basing on available data on smaller windturbines.

This range is hardly heared by odontocetes, and only at very close distance from the platform. The frequency and the associated sound level are well below a threshold of TTS, and unable to cause permanent damage to animals. Nevertheless, they may have a masking capability, in case of low level of ambient noise, although dolphins vocalization is is spread at much higher frequencies.

Regarding Fin Whales, and partially Sperm wahles, their vocalization overlaps with frequencies emitted by a wind turbine, and a masking effect is likely to be present up to a distance at which the ambient noise hides it.

A sound level of 120 dB at frequencies of 150 Hz at the source, when considering a transmission loss of 60 dB at 10 km, fall to 60 dB, thus approximating the ambient noise level. Therefore, a Fin whale specimen up to a relevant distance can perceive wind turbine noise, greater in absence of other relevant ambient noise. In approaching the BGF platform, wind turbine noise may display a masking effect over biologically relevant sounds.

Collision risk

A collision can be defined as a physical contact between a device or its pressure field and an

organism that may result in an injury. Animals may avoid collisions by moving away (avoidance) or by escaping at close range (evasion). Collision risk will vary with age of organisms, with juveniles more at risk than adults due to their reduced swimming abilities or experience.

The potential for animals to escape collisions with a marine structure will depend on their body size, social behaviour, foraging tactics, curiosity, habitat use, underwater agility and sensory capabilities. From the perspective of collision risks, the structure of a marine devices behaves differently as floating or submerged structures, mooring equipment and structures or parts of them having the potential to act as traps.

Submerged structures can attract marine life in the same way than artificial reefs or FADs. Seabed standing anchor blocks are likely to function like other natural or artificial seabed structures and hence pose little novel risks for vertebrates in the water column. Cables and chains extending up through the water column will have direct parallels with mooring devices used in other offshore industrial applications as well as static fishing gear. With a lowflow disruption, bow-wave effects in strong currents will be reduced but acoustic strumming or chain noise may be significant. As well as providing different sensory cues, the implications of collisions will also differ as vertebrate species of concern will be much larger relative to the structure and so be less likely to be swept around them by the flow. Additionally, various cetacean species (particularly mysticetes) are known to be entangled in static lines used in fishery so cables, chains or other lines anchoring renewable structures as well as power cables may have entanglement potential for such species.

Floating structures may simply act as static boxes. In collision terms, species most at risk are bird and mammal species that frequently cross the air-water interface to breath and haul-out and large fish that swim close to the surface (e.g. basking sharks). Collision risks for surfacing mammals and birds will depend on the how aware they are of the presence of the surface structures. Semi-aquatic species are likely to use floating devices as landing/roosting/breeding or haul-out sites and risks of injury may be associated with getting onto/off the structures and any contact with exposed moving or articulated parts. Nearest equivalent natural structures are floating logs and sea ice while industrial structures include fish-farm cages, oil related floating storage and offloading structures and booms/rafts.

While cetaceans do not haul-out, they do regularly surface for air and collisions could either occur with animals swimming into them or the structures pitching down onto breathing animals in heavy seas.

A platform is a discrete object that marine vertebrates can either collide with or avoid; however, the combination of several structures raises the possibility of traps being created. Traps are most likely to be a significant issue for species that need to surface regularly for air or where water flow is sufficiently high to limit the animal escape options once the trap has been entered. This may be the case of the net cages located into the BGF pool, where a diving bird or a cetacean may enter and being not able to find a straight way to the surface for breathing, facing large obstacles as net bootms and walls.

Rather than being indifferent to objects in the water column, marine vertebrates show behavioural responses to their presence in water, either approaching or avoiding them. Behavioural reactions remain poorly understood, but detection distances can be determinant. These will depend on the sensory systems of the species at risk, the visual, acoustic or other environmental signatures of the devices and the background conditions. In daytime and clear waters, underwater structures may be visible at ranges of thousands of meters above the surface and tens of meters underwater, and hence give sufficient room for visual species to exhibit avoidance and evasion if necessary. At night or in turbid environments, structures may be visually undetectable and provide little or no opportunity for a behavioural response. In addition to time of day and turbidity, other environmental variables are likely to be important. Depth will influence light levels as well as species' distributions and the amount of time air breathing species have to avoid devices.

Marine structures have a potential range of ecological implications, ranging from no impacts, to the potential removal or injury of individuals to declines in populations. If avoidance responses occur then the habitat exclusion is likely to occour. In case of significant collision concerns, the choice of methods of mitigation is mandatory. Measures that increase the options for avoidance are clearly advantageous, reducing the number of close encounters between device and animal but they also have to be considered in relation to their potential for habitat exclusion, as in case of a too loud alert device.

Ship strikes are a known cause of mortality for both whales and dolphins worldwide (Pace D.S. 2006). Resultant injuries tend to fall into 2 categories, lacerations from propellers, and blunt traumas from impact with the hull. Blunt traumas result in fractured skulls, jaws or vertebrae, in conjunction with large haematomas (IWC 2006). This latter case can probably results ininjuries that do not cause the immediate death of the animal, possibly leaving it vulnerable to death from secondary infections, complications or predation.

Four main drivers are thought to influence the number and severity of ship strikes,

- Shape hull and navigation speed;
- underwater noise – high levels of ambient noise can result in difficulty in detection of approaching vessels. There may be habituation to underwater noise, and the underwater pathways of sound is also one possible reason why ships are often undetected, as in case of underwater reflections, multiple sound signals and overtopping of propellers noise (Laist D.W. et *al.,* 2001);
- Weather conditions, that can increase the level of ambient noise;
- Cetaceans behaviour, which is species specific, with juveniles and sick individuals more vulnerable. Cetaceans often show an apparent reduced perception of collision threat, possibly by distracted by other activities such as foraging, or social interaction. (IWC 2006).

Being highly mobile underwater, marine mammals have the capacity to both avoid and evade marine renewable devices. This is as long as they have the ability to detect the objects, perceive them as a threat and then take appropriate action at long or short range. However, several factors can affect this ideal scenario:

1) **Detection failure**: The acoustic and visual signature of a marine structure as BGF is unknown. Environmental circumstances such as darkness, turbid water, background noise from rough weather or ship noise may impair perception distances and hence affect escape options.

2) **Diving constraints**: Marine mammals are accomplished divers and typically dive close to aerobic dive limitations. This means that animals do not have unlimited time underwater and may have few options other than reaching the surface at the end of a dive. Moreover, buoyancy can dramatically vary among marine mammals from negative to neutral to positively buoyant. Irrepressible positive buoyancy is a particular problem for whales when surfacing from depth and therefore constrains manoeuvring options.

3) **Attraction**: Marine devices may not be perceived as a threat but instead attract marine mammals, acting as a FAD or artificial reefs.

4) **Distraction**: Marine mammals undertaking activities underwater as transits, social interactions or complex foraging tactics, may show a reduced awareness of objects in the water column. When acoustically locked onto a prey, an echolocating cetacean may reduce the interpulse intervals of its clicks such that becoming acoustically blind to objects at greater distance than its targeted prey. Therefore, cetaceans hunting around submerged devices run an enhanced risk of close encounters without active acoustic detection.

5) **Illogical behaviour**: marine mammals are reputed for an intelligent behaviour, and consequently they should act logically when facing with a threat. However, this is not always the case. Sometimes cetaceans refuse to swim over or past a perceived barrier and ultimately become trapped despite the barrier representing no real danger.

5.1.3 IMPACT ON FISH

The hearing ability of fish varies greatly in different species. Typically, fish perceive sound via particle motion in the inner ear through the sound-induced motions in the fish's body. The detection of sound pressure is restricted to those fish which have gas-filled swim bladders; however, particle motion can be somehow detected also by fish without swim bladders. Fish with swim bladders that are mechanically coupled to the inner ear have the higher sensitivity to variations in sound pressure, being able to detect sounds over 3 kHz with the best sensitivity between a 300 to 1000 Hz (Popper et *al*., 2003). These species are described as *sound specialists*.

Fish that do not have a mechanical way of coupling the sound-induced motions in the body with the inner ear have relatively low sensitivity, being able to detect sounds up to 500 – 1000 Hz, with best hearing capability between approximately 100 and 400 Hz. (Popper et *al*., 2003). These fish can be categorised as *sound generalists*.

Table 33: Hearing sensitivity of some Atlantic fish species (*Source: Nedwell & Howell, 2004b*)

Species	Common name	Family	Swimbladder connection	Sensitivity
Anguilla anguilla	European eel	Anguillidae	None(1)	Medium
Clupea harengus	Herring	Clupeoidea	Prootic auditory bullae(2)	High
Cottus scorpius	Sculpin	Cottidae	No swimbladder(1)	Low
Gadus morhua	Cod	Gadidae	None(1)	Medium
Limanda limanda	Dab	Pleuronectidae	No swimbladder(1)	Low
Melanogrammus aeglefinus	Haddock	Gadidae	None(1)	Medium
Merluccius merluccius	European hake	Merluccidae	None(1)	Medium
Pleuronectes platessa	Plaice	Pleuronectidae	No swimbladder(3)	Low
Raja clavata	Thornback skate	Rajidae	No swimbladder(1)	Low
Scomber scomber	Atlantic mackerel	Scombridae	None(1)	Medium
Sprattus sprattus	Sprat	Clupeoidea	Prootic auditory bullae(2)	High

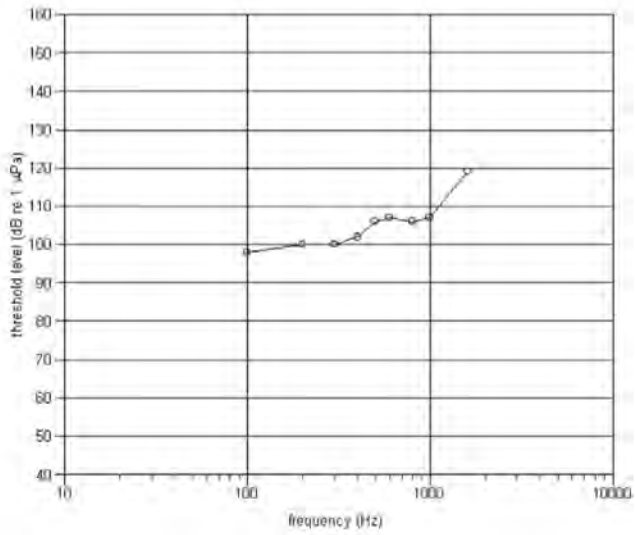


Figure 151: Audiogram for Seabass, *Dicenthrachus labrax* (*Source: Nedvell et al., 2004*)

Seabass, the species potentially cultured in the BGF located in the Marseille area, is potentially able to perceive the frequencies transmitted by a wind turbine. The behavioural response to this and the welfare implications are under investigation in Deliverable 3.4 This section will be therefore update when data will be made available.

A BGF marine installation would be composed by several dozens of energy devices WEC, a wind turbine and would also include a large fish farm. In order to assess the underwater noise field originating from such multiple sources, it would be necessary to know the details of the sound emitted by every device, and the mutual spatial arrangement between the devices. A potential element of difficulty might be represented by the possible sound resonance inside the concrete caissons. It would also be necessary to know the acoustic environment (i.e. water depth, sound speed profile, seabed type and background noise level) to properly simulate the sound propagation among devices in the array, and from the array to the surrounding area.

The shape complexity of the BGF and its overall response to sound transmission can not be modeled with regard to sound emissions, even due to the presence of empty spaces and different

materials. An appropriate monitoring program on the real-scale installation can only fulfill such task.

Electricity cables are known to produce small electric and magnetic fields, which have the potential to affect migration and prey detection in electro-sensitive fish species such as sharks and rays. Electro-sensitive organisms are able to detect two types of E field: localized polar and larger scale uniform E fields.

The main electro-receptive marine organisms are the Elasmobranchs (sharks and rays). Other electro-sensitive species do not have any specialized electroreceptors, but can to detect induced voltage gradients associated with water movement and geomagnetic emissions. The actual sensory mechanism of detection is not yet deeply understood, and some evidences indicate that the E fields that these species are sensitive is associated with peak tidal movements, able to create fields in the range of 8-25µv/m.

With the only exception of Lampreys, marine teleost fishes do not own electroreceptors and therefore are not sensitive to electric fields. In general, teleost fish are unable to react to weak electric field.

Elasmobranch species rely on their keen electric sense in detecting preys, orientating into ocean currents, and feeling their magnetic compass headings. The electrosensory organs, the Ampullae of Lorenzini, have an electric sensitivity 1,000 to 10,000 times greater than other marine fish. The Ampullae of Lorenzini (AoL) consist of a series of pores opening at the surface of the skin, leading to canals filled with a conductive mucopolysaccharide, with an impedance level similar to seawater. At the end of the canals are located clusters of alveoli with receptor cells situated on their walls, which enable the fish to detect very weak voltage gradients (down to 0.5µV/m) in the surrounding environment. When an elasmobranch encounters a polar E field, it can identify the emission source on the base of the differential voltage potential at the pores with reference to the internal potential of the body. In a uniform E-field the different length and orientation of the Ampoullae canals allows the animal to compare voltage gradient change.

In most sharks the pores are evenly distributed between the dorsal and ventral surfaces of the head. In the dorso-ventrally flattened rays and skates the pore pattern is concentrated on the ventral surface, mainly near the mouth. This allows for an accurate location of bioelectric fields of preys buried into the sediment. The E-sense is primarily used when the animal comes in close proximity to the target, and the other senses (such as hearing or smell) are used at greater distances from the E field. This means that the E-sense is triggered for the final stages of feeding or detecting.

Species sensitive to natural E-field have also been shown to react to artificial sources of electric fields. Electro-sensitivity and response thresholds have only been studied for a few species of sharks, skates and rays. Time varying fields appear to occur in nature, for example as output from muscle activity, and may be used by some animals for prey or mate detection. It would therefore be likely that time varying electric fields (e.g. from AC cables) have some potential for affecting electro-receptors marine animals. Electric fields of varying strengths are able to modify species behavior in laboratory experiments, primarily as interference with prey location or by inducing field avoidance.

Some possible impacts associated with power cable induced electric fields may include:

- Interference with prey location and mate detection for species with electro-receptors;
- Cable avoidance in elasmobranches associated with electric fields of 100µV/m or greater;

- Barrier to migration to some elasmobranches.

Some Authors reported that benthic species such as skates/rays and sharks use electroreception as their principal sense for locating preys. More pelagic species, such as tope, porbeagles or salmonids, may encounter E fields only during specific periods such as the reproductive season or as juveniles' life stages in shallow water nurseries or throughout migration. Hence, the potential for an impact is considered highest for species that depend on electric stimuli to detect benthic prey and mates, early life stages that use electroreception to detect predators or migratory routes, which take them into shallow coastal waters (CMACS, 2005).

The induced electric fields expected (1.5 – 40 µV/m) from a 33 KV cable are within the range considered to be detectable by elasmobranchs (0.5 – 1000 µV/m). Gill and Taylor (2001) found that this field strength could cause an attraction response in dogfish at 0.1 m from the source, at an induced electric field below 100µV/m, the level reputed to cause an avoidance behavior in elasmobranchs.

The effects of magnetic fields generated by power cables on marine life have been studied on a few of organisms. Although these fields tend to be below the earth's background geomagnetic field, it is possible that sensitive marine organisms differently perceive the magnetic field generated by the cable, when use the earth's geomagnetic field to orientate themselves. Depending on the magnitude and persistence of the field, the impact could be a trivial temporary change in swimming direction, as seen with eels encountering a HVDC cable, or a more serious delay to the migration (CMACS 2005). Nevertheless, the most of teleost fish and macro-invertebrates are scarcely electro-sensitive, and severe impacts at a community level are not expected.

Possible affects associated with power cable produced magnetic fields may include:

- Small or large-scale disorientation (navigation) to migrating species (e.g. salmonids and anguillids (eels))
- Barrier effects to migration

The main key species, present in the study area, and reputed to be sensitive to magnetic fields is Eel (*Anguilla anguilla*). Eels can swim over or stay buried in the surface of the seabed, and would therefore be likely to come into close contact with the magnetic field of any cable buried under the seabed (Gill & Bartlett, 2010).

Eels are are considered as an endangered species in the IUNC red list.

On the other hand, Elasmobranches can detect and respond to B (magnetic) fields in the range of 25- 100µT. The expected B field from a typical 33kV cable range from 0.9 to 1.5 µT at the cable surface and therefore elasmobranches are not expected to be impacted by the magnetic field that is likely to be produced by the H2OCEAN network of cables and risers. However, organisms may exhibit behavioral responses at much lower levels than those, which may result in physiological impact. In particular they may exhibit avoidance reactions at relatively low levels, and a linear cable may appear to them as an impenetrable barrier. Such barriers may have the potential of separating species from their feeding or breeding grounds.

In the report for CMACS, 2005 is stated that, although the information available on magnetic fields is limited, it does suggest that potential interactions between B field emissions, of the order likely to be associated with wind farm cables (and wave devices), and coastal organisms could occur from the cellular up to the behavioral level. Burial of the cables under the seabed will offer an

effective protective barrier to electro/magneto-sensitive species from the strongest magnetic and induced electric fields generated in proximity of the cable.

Collision risk is considered to be a real potential risk during platform operational time, and almost all species of marine finfish are at some risk of collision impacts. Whilst it is reasonable that pelagic fish will be the most likely to be impacted by collisions with floating devices, demersal species that undertake vertical migrations and may also be potentially impacted. The resonance chamber of a WEC, represents a novel threat never experienced before by any marine fish species.

The group of species at risk will vary depending on the type of device and its location within the water column. Demersal fish that spend all their life near the seabed will not be affected by the moving parts of wave power generating devices that operate near the surface, while it is possible that they may benefit from the tri-dimensional habitat provided by the platform and moorings for these devices. Pelagic species of fish will be at greater risk of interaction with devices. Their diurnal vertical migration behavior forces them to occupy all depths in the water column at some time during the day.

In addition, some other factors may influence the possibility of of collision:

- Size: Very small and larval specimens exploiting viscous flow regime follow the flow streamlines around moving parts and hence avoid collision. The collision risk increases with increasing fish size.
- Schooling behavior: A school behaves as a large “super organism” rather than having an individual behavior. Schools move together in polarized formations and their predator escape behavior is coordinated.
- Seasonality: Risk will also vary with seasonal abundance, due to the change in geographic distribution, migrations and spawning periods.

Fixed submerged structures (such as anchors, mooring lines, connections, risers) are likely to attract marine life in a similar way than artificial reefs or fish aggregating devices (FADs). Mooring equipment such as anchor or connectors are likely to act like other natural or artificial seabed structures and hence pose few novel risks for vertebrates in the water column.

Deployment of MOI platformes in the open sea will present a very low risk level, being the floating object isolated at sea with a very low rprobability of casual encountering. However, water depth at the point of deployment will be critical and moving parts should be off the bottom to reduce interaction with benthic fish. High flows, combined with swimming speeds, can produce high approach velocities and consequently reduced avoidance or evasion response times.

However, marine fish are likely to show a behavioral response to the presence of marine devices. While the ability of fish to perceive their environment is well understood, their behavioral reactions to marine renewable devices is unknown. At long range they have the option to avoid the area of device, swimming around it, and at closer distance they can evade the structures. Fish perceive their environment using sight, hearing, and chemoreception. Their ability to detect devices will depend on the sensory capabilities of the species, the local visibility and level of noise emitted by the device. The potential for animals to escape collisions with marine renewable devices will therefore depend on their body size, social behavior (especially schooling), foraging tactics, curiosity, habitat use, and underwater agility.

Table 34: Sensitivity of marine fish to impact from installation of a renewable energy device

Species	Displacement	Collision risk	EMF	Marine noise
Spurdog (*Squalus acanthias*)	Not sensitive	Unknown	B	Unknown
Lesser spotted dogfish (*Scyliorhinus canicula*)	Low	Unknown	E, B	Unknown
Basking shark (*Cetorhinus maximus*)	Not sensitive	Unknown	B	Unknown
Thornback Ray (*Raja clavata*)	Low	Unknown	E, B	Low
Sardines (*Sardina spp.*)	Not sensitive	Unknown	Not sensitive	Low
Mackerel (*Scomber scombrus*)	Not sensitive	Unknown	Not sensitive	Low
Eels (*Anguilla anguilla*)	Not sensitive	Unknown	E, B	Unknown

5.4.1 Impact on reptiles

As per Mysticetes, sea turtles are sensitive to low frequencies. Martin et *al*. (2012), report the audiogram for *Caretta caretta*.

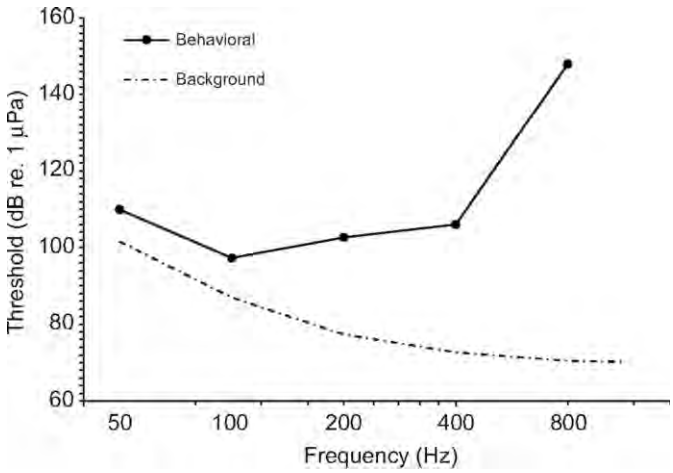


Figure 152: Audiogram for *Caretta caretta* (*Source: Martin et al., 2012*)

Hearing ability of turtles is rather weak, and the wind turbine low frequencies can be perceived mainly at high sound pressure levels, therefore in close BGF proximity, in a possible order of magnitude of hundreds of meters.

Due to the vagrantive behaviouor of Seaturtles, and their very low density at sea, the BGF impact on them can be consider as negligible.

5.1.5 Impact on benthic communities

Model overview

The DoW of the present project request the evaluation of the impact of aquaculture offshore farm integrated in the overall installation. Some models were therefore evaluated, and the most informative software package available has revealed to be AquaModel, produced by System

Science Applications, Inc. Irvine, CA, and USA. Being applied in different eco-regions, the model has been validated during several rounds (Rensel et *al*., 2006, 2007; Kiefer et *al*., 2011; O'Brien et *al*., 2011).

AquaModel is a computer model for cage aquaculture that simultaneously calculates and displays real-time feed ingestion, growth, respiration, excretion, and egestion by cultured fish. The model is composed of interlinked sub-models of fish physiology, hydrodynamics, water quality, solids dispersion and both pelagic and benthic assimilation. The system provides a 3-dimensional simulation of growth, metabolic activity of caged fish, associated flow and transformation of nutrients, oxygen, and particulate wastes in adjacent waters and sediments. It's embedded within a Geographic Information System (GIS) program designed for oceanographic use (EASy).

The GIS software EASy provides a 4-dimensional framework (latitude, longitude, depth, and time) to run simulation models and analyze field measurements as graphical, numerical and statistical outputs. It is an advanced, PC-based geographical information system designed for the storage, dissemination integration, analysis and dynamic display, of spatially referenced series of diverse oceanographic data.

The model calculates and displays images of physiological effects of fish aquaculture including respiration (oxygen consumption), nitrogen excretion (mostly ammonia and minor amounts of urea that both rapidly converts to nitrate in the environment) and phytoplankton growth (resulting from the nitrogen excretion and zooplankton grazing in the modelling domain). In the same time, it simulates discharge and flux of carbon-containing solids from fish faeces and waste feed that eventually sink and are deposited on the sea-bottom. The wastes can also be re-suspended and re-transported laterally when near bottom current velocities exceed threshold values. In these favourable conditions, the wastes can be assimilated by the food web without causing significant change of the sea-bottom community to anaerobic bacteria.

The benthic sub-model of AquaModel has some resemblance to other aquaculture models as DEPOMOD (Cromey et Al., 2002a, 2002b), being both partially derived from the G-model of carbon degradation (Westrich & Bernier, 1984).

The system has the capability to contain environmental information obtained from satellite-ocean thermal and colour sensors and field surveys or remote sensing and reporting of currents, nutrients, oxygen, chlorophyll and other related parameters.

AquaModel graphically renders dynamically in time, within their proper geo-spatial context, model outputs as diverse types of plots, including vector, contour, false colour images and includes a built-in data-contouring feature. Vertical structure of data, critical in oceanographic applications, is depicted as vertical contours for transect or depth profiles at selected point locations. There are over 50 different X-Y plots available for different parameters viewed as vertical profiles or horizontal cross sections that are dynamically updated in real time simulations.

AquaModel consists of 4 components: a 2 or 3-dimensional description of water circulation, a description of the growth and metabolic activity of the cultured fish within the farm, a description of the planktonic community's response to nutrient loading, and a description of benthic effects.

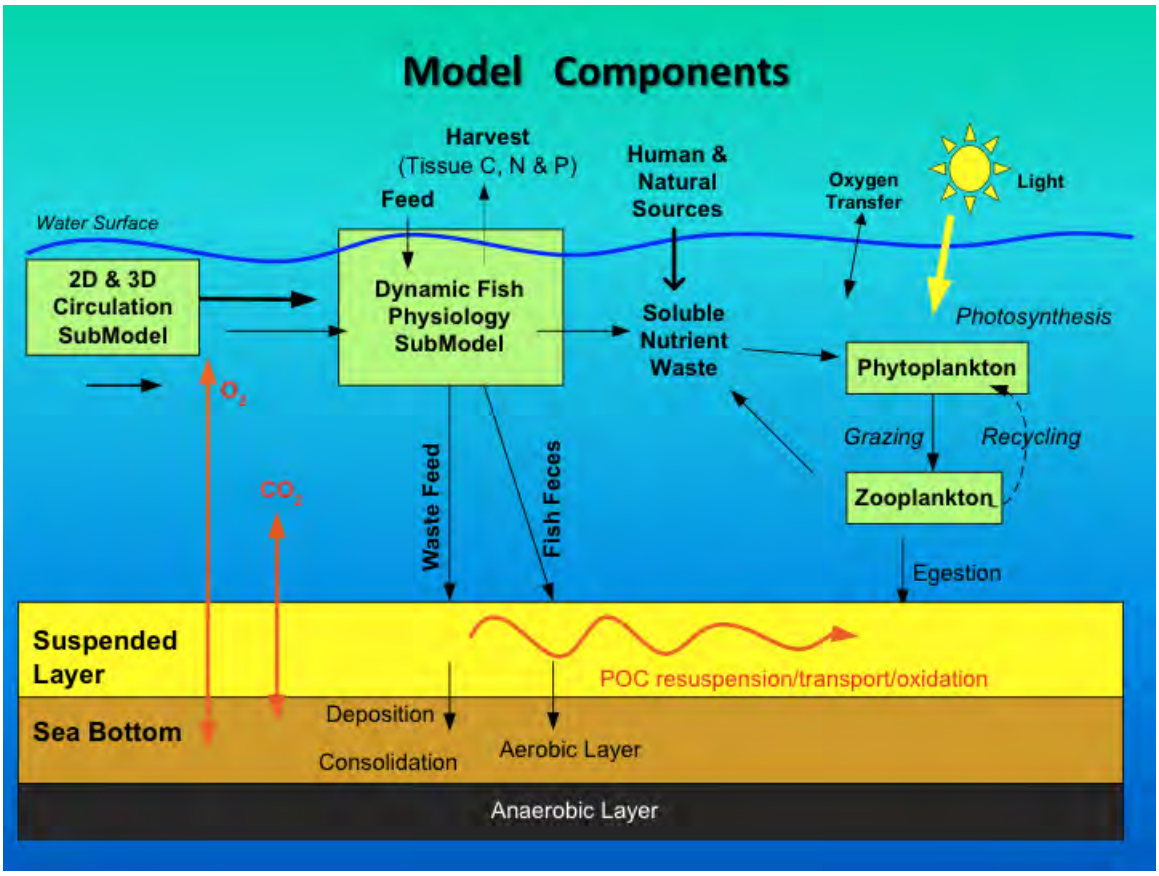


Figure 153: Aquamodel main computational components

The primary benthic parameter of interest is the amount of total organic carbon, but the model also simulates the status of sulphides, interstitial dissolved oxygen, aerobic and anaerobic bacteria biomass, carbon dioxide and related parameters in the sediments. The fate of waste feed and fish faecal matter is separately tracked. The software is supplied by pertinent metabolic coefficients and functions to simulate bass, bream, salmon and other species.

All the parameters of the model, including pen array centre, location in the Cartesian coordinate system, cell (grid) size, farm dimensions, fish loading and feed rates, are set interactively by menu selection.

Circulation Module

The circulation routine flushes cages with ambient waters and transports wastes away from them. The computations during each step of the simulation occur within each element of a 3- dimensional grid of rectangular cells that constitute an array of such cells. The users enter the size, orientation, and geospatial location of the array as well as the number and dimension of the cells. The array of cells begins at the sea surface and extends to the sea floor.

The system of equations describing circulation is a simple finite element description of advection and dispersion. Each element of the array is treated as a box model in which materials flow across the 6 interfaces of each element, top, bottom and the four sides. Each element is treated as instantly

mixed throughout. These movements are determined by a simple, finite difference calculation that is common in simulations of coastal water flow. The maintenance of conservation of mass is a key constraint upon the calculations.

In water, dissolved and suspended materials move across the side boundaries of the array; however, the values for the concentrations of dissolved and particulate materials at the boundaries remain constant and equal to the initial ambient concentrations of tracers entered by the user at the start of the simulation. The array has then to be sufficiently large such that the exchange across the boundary does not significantly perturb the results of calculations.

The flow field can be set in either of two modes:

- In the 3 dimensions, the exchange of water between adjacent cells has no constraints other than the conservation of mass. Convergent and divergent motion can be represented within the array as well as local eddies. In addition, the water depth can vary within the array. Unfortunately, such detailed descriptions of motion are difficult to measure at small scales and thus rarely measured in coastal waters. Thus, such types of description come from coastal circulation models that include such drivers of circulation as winds, tides, and local gradients in water density due to thermal exchange as well as evaporation and precipitation.
- In the "2-dimensional mode", at any time step of the simulation both horizontal and vertical motions are uniform throughout the array. There is neither divergence nor convergence flow within the array. In the case of horizontal motion both advection and turbulent exchange between adjacent sides of the cells are equal throughout the array. In the case of vertical motion exchange between adjacent sides of cells are also equal throughout the grid, but restricted to turbulent exchange in which flow across the upper and lower sides of adjacent cells is equal. The flow consists of two layers, an upper mixed layer and the lower stratified layer. The depth intervals of the mixed layer and the stratified layers vary with season as a sinusoidal oscillation. In this mode the depth of the water column is uniform throughout the array.

The bottom flow can also be reduced by a percentage set by the user that would cause waste particles to remain upon the bottom and not be re-suspended.

The model operates with a variety of inputs to drive physical circulation from simple built-in sinusoidal tidal amplitude models, to current meter data and several types of leading circulation model outputs. Current meter inputs are the best for single net pen fish farm sites with relatively homogeneous flows over small areas in coastal areas that have recurring, mostly tidal-origin flow processes. When this is not possible, AquaModel also accept output from far field 3D circulation models such as ROMS, FVCOM and ADCIRC.

Fish Physiology and Farm Module

In AquaModel simulations, a fish farm is characterised by its two main properties, its physical layout and its stocking, feeding, and harvesting regime. The physical layout requires entry of the following types of information:

- The number of cages
- The location of the cages as described by their geographic co-ordinates (latitude, longitude and depth)

- The size of the cages length, width, height
- The fractional difference between the current speed within the cages and ambient current speed.

Farm operations require entry of the following information for each cage:

1. Fish species.
2. Fish metabolic model as described below. Although the system of equations describing growth and metabolism is invariant with species, the coefficients found within the equations likely vary with species
3. Mean weight of fish in grams (wet weight) at initial stocking or at selected time intervals
4. Density of fish in number of fish per cubic meter at initial stocking or at selected time intervals
5. Feed rate in grams dry weight of feed per day. This rate can be entered manually or calculated automatically as an optimal feed rate
6. Estimate percentile of uneaten feed loss from the cages.

The routine describing the metabolism of modelled fish is based upon basic bioenergetics studies. It includes equations for oxygen-limited metabolism, together with the processes of ingestion, egestion, assimilation, respiration, excretion, and growth. Carbon, nitrogen, and oxygen fluxes are computed, and the rates of these fluxes vary with operation in different environmental conditions. The environmental variables that determine metabolism are:

1. Water temperature
2. Ambient oxygen concentration, determining of the concentration of oxygen within a cage
3. Ambient current velocity, determining oxygen concentration within the cage as well as a determinant of the respiration rate required by fish to swim at a given speed to maintain their position within the cage.

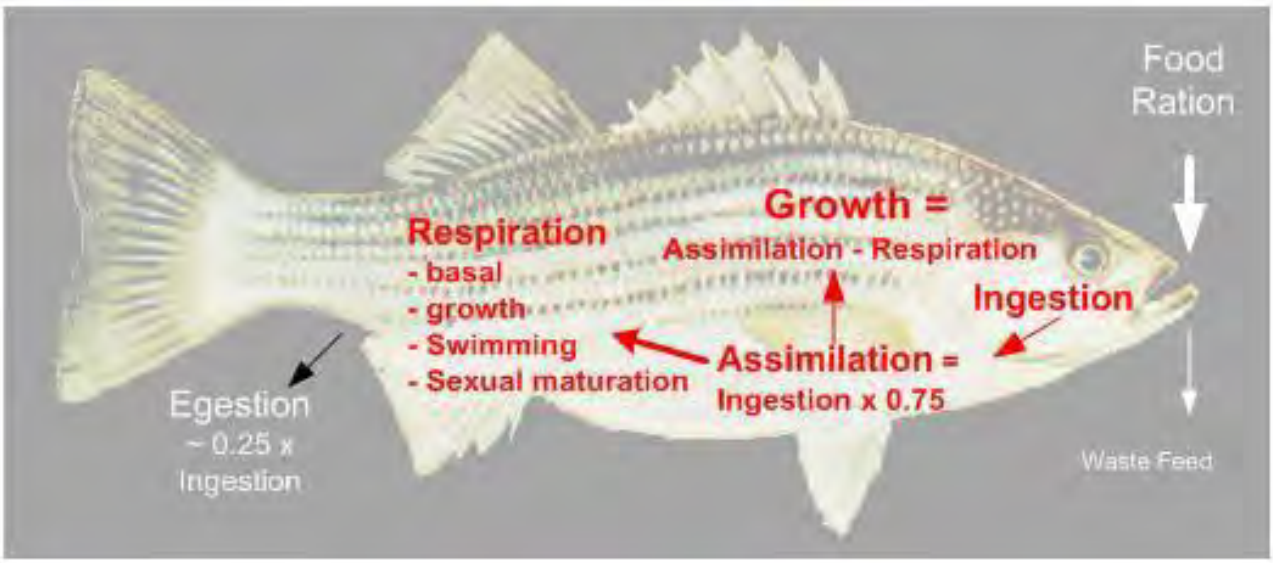


Figure 154: Metabolic relation in Aquamodel physiological routine

The physiological routine consists of a series of functions describing the fluxes of carbon, nitrogen, and oxygen as determined by the basic features of metabolism, ingestion, egestion, assimilation, respiration, and growth. Specifically, each element is tracked according to these basic features, which are related to each other by conservation of mass in the following equations:

- ***ingestion rate = egestion rate + assimilation rate;***

This is determined by both the rate of supply of food and rate at which the fish can assimilate ingested food;

- ***assimilation rate = rate of respiration + rate of growth, in absence of reproductive demands.***

The assimilation rate will be a function of the fish size (age), the temperature of the water and the concentration of oxygen within the cage. The assimilated nutrients are then either consumed by respiration or contribute to the fish growth;

- ***respiration rate = resting rate of respiration (i.e. basal) + respiration rate of activity (i.e. swimming) + respiration rate of anabolic activity (i.e. growth)***

The respiration rates, which include both the consumption of oxygen and excretion of nitrogen, are determined by three processes, basal metabolism, swimming metabolism, and anabolic metabolism demanded by growth. Basal metabolism is a function of temperature and size; swimming metabolism is a function of the fish size and its swimming speed, and anabolic metabolism is proportional to growth rate. The growth rate is simply calculated by subtracting the rate of respiration from the rate of assimilation.

- ***rate of faeces production = egestion rate.***

Egestion is assumed to be a fixed fraction of ingestion as determined largely by the nutrient composition of the feed. The rate of egestion is in fact the rate of faeces production;

- ***rate of loss of uneaten feed = feed rate – ingestion rate.***

When supply of food exceeds the sum of the rate of egestion and the rate of assimilation, a fraction of the food will be uneaten and contribute to the particulate waste produced by the cage.

Plankton Module

The plankton module describes the cycling of nitrogen and oxygen by plankton within each element of the array, either within the farm and the surrounding waters. This model is similar to the PZN models that have been published by Kiefer & Atkinson (1984) and Wroblewski et *al*. (1988).

The main cycle describes the transformations of nitrogen among three compartments: inorganic nitrogen, organic nitrogen in phytoplankton, and organic nitrogen in zooplankton. The three biological transforms are:

- Photosynthetic assimilation of inorganic nitrogen by phytoplankton, being a function of temperature, light level, DIN (dissolved inorganic nitrogen consisting of ammonia, nitrite and nitrate) concentration;
- Grazing by zooplankton on phytoplankton, as a function of temperature and concentrations of zooplankton, and phytoplankton;
- Excretion of DIN by zooplankton, which is a function of temperature and the concentration of zooplankton.

All three components are transported by advective and turbulent flow as described above. The model displays predator-prey oscillations, which dampen over time and reach a steady state. In order to calculate the concentrations and rates of loss by respiration and production by photosynthesis, a constant flux ratio of oxygen to nitrogen of 6 moles O2 /mole N, consistent with the Redfield ratio is assumed. The inputs to this model consist of the time series of exchange coefficients produced by the hydrodynamic model, surface irradiance, and water temperature as well as concentrations of dissolved oxygen, dissolved inorganic nitrogen, cellular nitrogen in phytoplankton and zooplankton. Outputs of this model consist of a time series of the concentrations of dissolved inorganic nitrogen and oxygen, phytoplankton (traced as chlorophyll), and zooplankton.

Benthic Module

The benthic loading component of the model is based upon several literature citations and functions found in the DEPOMOD model (Cromey et *al*., 2002a, 2002b) that in turn was based on the G-model of carbon degradation (Westrich and Bernier, 1984 and subsequent papers). Despite some limitations in user controls and flexibility, DEPOMOD is presently the international standard for assessing the impact of loading of organic carbon in sediments underlying fish farms and in some countries calculations by this software are a requirement for obtaining fish farm permits.

As uneaten feed and faeces produced by fish in each cage sink through the water column, they are transported downstream of the cage. Since uneaten feed is larger and denser than faeces it must be treated separately. Not only will these different classes of particles sink at different rates and be transported different distances from the farm, but as they reach the bottom boundary layer, their shear thresholds for deposition and re-suspension will also differ, leading to further separation. Eventually, both uneaten feed and faeces will either be consumed by the benthos or consolidated into the sediments and no longer subject to re-suspension. Thus, there are three categories of particulate waste: uneaten feed, faeces, and consolidated waste contributed by both the uneaten feed and faeces that have been deposited for a sufficient length of time on the bottom that are no longer erodible. During simulation process, waste particles produced in the farm are “collected” over a specified time interval as “capsules” that sink through the water column at a rate determined by the user. As these capsules sink, the ambient currents transport them through the 3-dimensional array of

cells.

The waste particles are however not subject to turbulent dispersion as is the case for the dissolved wastes. As the capsules approach the bottom, the waste particles are "released" and evenly distributed into an underlying cell that is part of the grid of the suspension layer in the water column. The length and width of these cells are the same dimensions as the cells within the overlying water column, but their depth is user selectable. Once released into the suspension layer the particles will be treated as suspended particles and subject to both advection and turbulent dispersion.

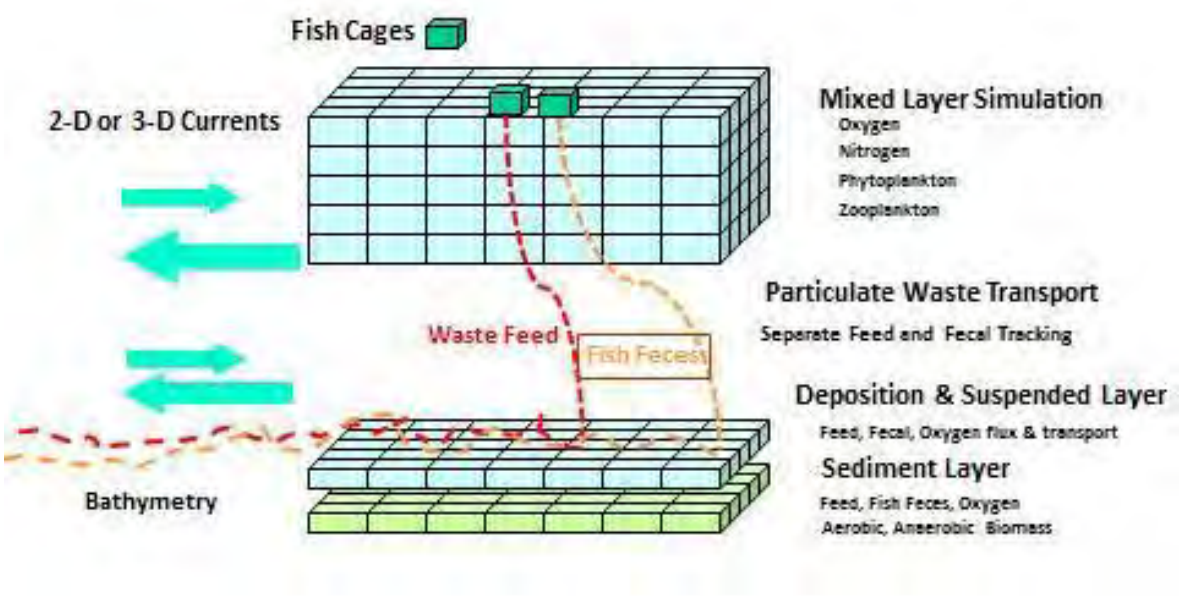


Figure 155: AquaModel dispersion module

When shear between the sediment and the bottom water decrease below a threshold value, waste particles in the suspension layer are deposited into the sediment layer. Furthermore, the rate of deposition not only increases with the concentration of particles in the layer but will also increase with decreases in shear. When shear at the interface exceeds a threshold value, waste particles in the sediment layer will be re-suspended into the suspension layer and thus subject to additional transport (and dispersion) from the site. The thresholds for deposition and re-suspension differ with the size, density, and stickiness of the particles and thus will differ between feed and faeces. When shear at the bottom falls between the threshold for deposition and the threshold for re-suspension, the particles in the suspension layer will remain in suspension and then be dispersed or deposited in response to shear.

The wastes deposited in the sediment will then be subjected to aggregation and compaction, and will consolidate into organic particles that will no longer be re-suspended. A simple first order rate decaying function is applied, by which a fixed fraction of the mass of feed and faeces in the sediments consolidates each day.

Dynamic of the Benthos

The different fish farm wastes found in the sediments (uneaten feed, faeces, and consolidated waste) are energy and nutrient sources for the benthic community, from microbes to macrobenthos and wild fishes. Thus, the concentration of waste in the vicinity of a farm will depend upon the previous history of deposition and re-suspension, but also upon the previous history of growth and re-mineralization by the benthos. The sediment layer is simplified as a single layer despite the fact that vertical profiles within sediments usually indicate sharp, predictable biological and chemical gradients.

The functions are based upon the assumption that they provide a prediction of average biological and chemical conditions within the layer.

The components of the routine consist of four dissolved compounds species, oxygen, sulphate, hydrogen sulphide and carbon dioxide, which flow between the suspension and sediment layer by diffusion. It also consists of particulate organic carbon (POC) produced in overlying waters from farm waste or the planktonic community, and the benthos, which consists of two groups of macro and microscopic organisms that mediate the transformations.

Figure below shows the components and process that are described by the benthic routine.

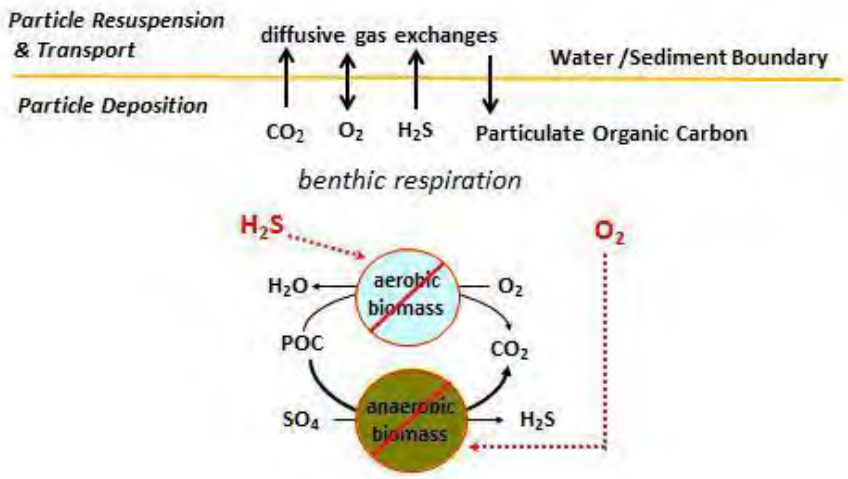


Figure 156: Aquamodel benthic metabolic pathways

The aerobes respire particulate organic material (POC) and oxygen in order to grow and meet other metabolic needs. The main by-products of their metabolism are carbon dioxide and water. If either the concentration of oxygen or POC decreases below saturating concentrations, rates of growth and respiration will decrease. Furthermore, at the lower extremes of oxygen or POC availability, aerobe growth will stop and respiration will be reduced to a basal level. The anaerobes, which here consist only of the sulphate reducing micro-organisms, respire POC and sulphate in order to grow and meet other metabolic needs. The main by-products of their metabolism are carbon dioxide and hydrogen sulphide (or other reduced sulphur compounds). If either the concentration of sulphate or POC decreases below saturating concentrations, rates of growth and

respiration will decrease. Additionally, at the lower extremes of oxygen or POC growth will stop and respiration will be reduced to a basal level. If produced at a sufficient rate, the hydrogen sulphide will inhibit the growth of the aerobes. On the other hand, oxygen inhibits the growth of the anaerobes.

The above figure indicates that the size and growth rate of the aerobes can be limited by the supply of oxygen from the overlying water column. The rate of supply of oxygen to the sediments is determined by the diffusion of oxygen from the suspension layer into the sediment layer, and the rate of diffusion will be determined by the difference in the concentration of oxygen in the suspension layer and the sediment layer.

The thickness of the diffusion boundary layer at the interface is less than a millimetre in most open waters, and varies with the velocity of flow in the suspended layer. If the current speed in the suspension layer increases, the thickness of the boundary layer will decrease and the rate of diffusion will increase. The concentration of oxygen in the sediments is assumed to be in quasi-steady state such that the rate of oxygen consumption by the aerobes, which varies with the concentration of oxygen and the concentration of particulate organic carbon within the layer, is equal to the rate of oxygen supplied by diffusion.

A similar argument can be presented for regulation by POC deposition and sulphate diffusion for the anaerobes. However, because of the high concentrations of sulphate in seawater, the rates of diffusion of sulphate into the sediments layer are sufficiently high to rarely constraint the growth rate and biomass of the anaerobic community in the upper sediments.

The increase in organic loading decreases the concentration of oxygen in the sediments, thereby releasing anaerobic organisms from their oxygen limitation of growth. As a consequence, the biomass of anaerobes will increase and possibly competing for POC with the aerobes and producing hydrogen sulphide. The latter may inhibit the metabolism and growth of the aerobes. Consequentially, if the gross metabolism of the aerobic community declines, oxygen concentrations will increase inhibiting the gross metabolism of the anaerobes. Such interactions will tend to drive the system toward a well-defined steady state determined by the rate of organic loading, as well as the temperature, concentration of oxygen, and current velocity in the suspended layer above the bottom.

The importance of these dynamics to the management of fish farms is that provided the organic loading rate of the sediments is not too large, the respiratory activity of the benthic community will re-mineralise the most part of the particulate organic material thereby releasing carbon dioxide into the sediments and water column. These predictions from the benthic routine have been confirmed by field studies, as those of Findlay and Watling, 1997, and modeling work of Chamberlain and Stucchi, 2007.

The benthic routine indicates that, under a slight organic enrichment, the major response of the sediment under the farm will be an increase in the density of aerobic organisms and a corresponding increase in benthic respiration that will prevent the accumulation of farm waste and actually embellish food supply for the benthic food web.

Fish Growth Parameters Selection

The following Table displays the average monthly temperatures used as a basis for metabolic

computations on fish stocks farmed in the BGF platform, as derived from data available at CMEMS website.

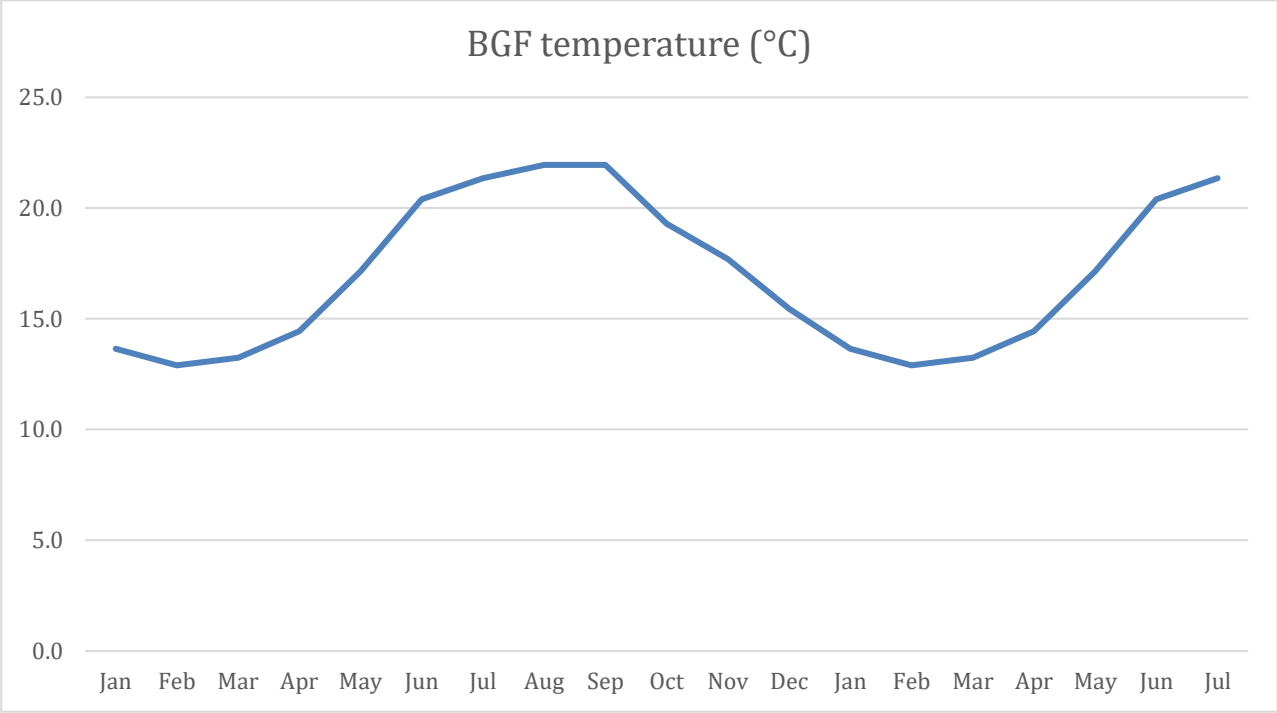


Figure 157: Temperature curves estimated for BGF site, year 2016 – data from CMEMS, IBI Analysis Forecast Phys 005-001

Fish are expected to attain the desired market size (>400 g) at around 17 months of farming cycle, with minor differences between cages due to the encountered temperature pattern through their life cycle, as a consequence of the first stocking time.

Fish growth pattern, biomass evolution, stocking plan and feed consumption has been calculated by BGF project Partner Sagro Ltd, in the frame of Deliverable 9.1. The growth curve for Sea bass used in Aquamodel simulations is calculated for the Marseille site, simulating a likely growth on the above given ambient conditions, and matching the growth curve available from Project Partners.

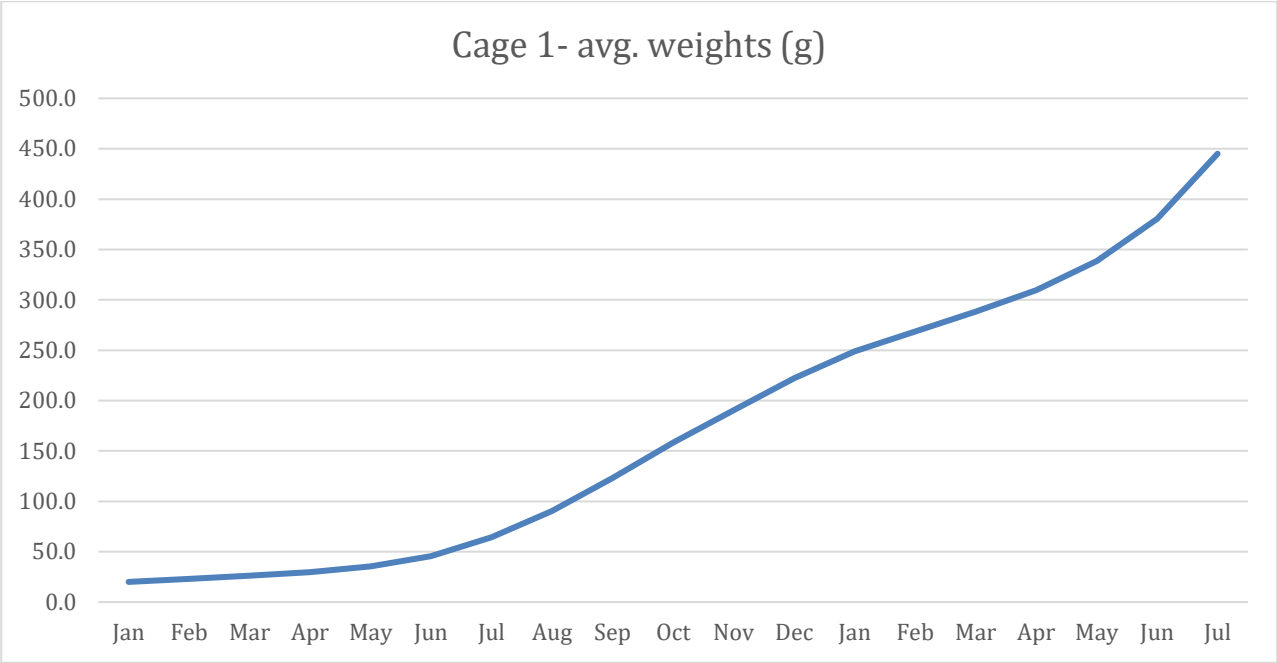


Figure 158: Sea bass average weight

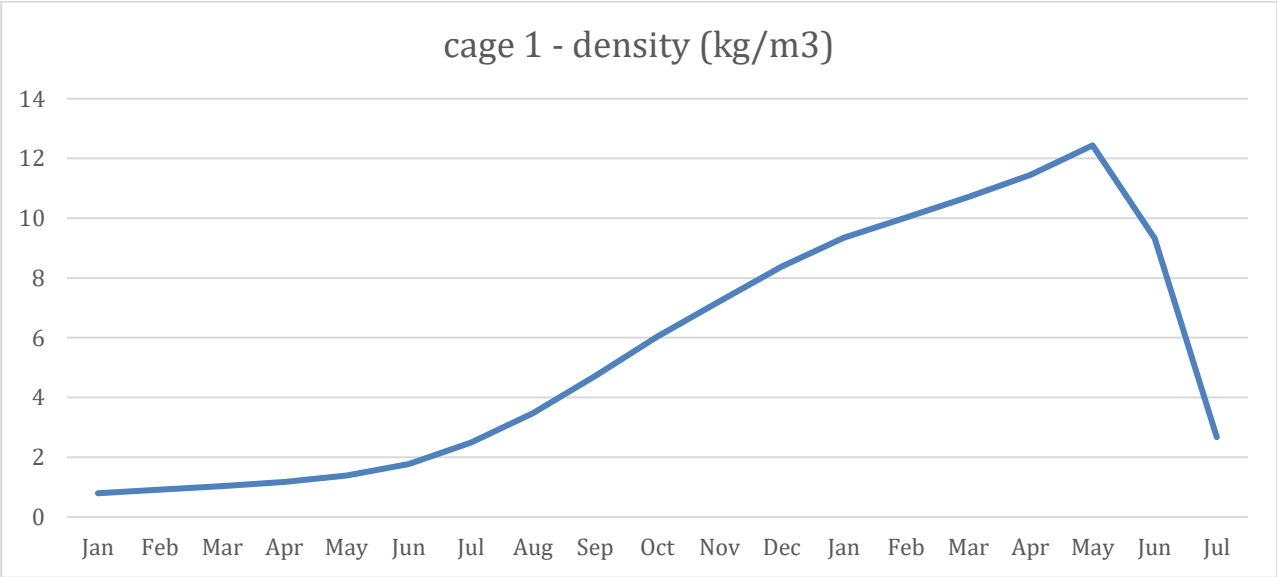


Figure 159: Sea bass cage density

While growth functions are notably the same for several fish species, some coefficients have been modified to fit the desired weight increase. In the present case the growth function originally developed for a similar temperate-water species has been re-elaborated.

In particular, the specific growth rate SGR has been reset to reach its maximum at a temperature of 21 °C, considered as the most favourable for the species, to decrease abruptly over 25 °C.

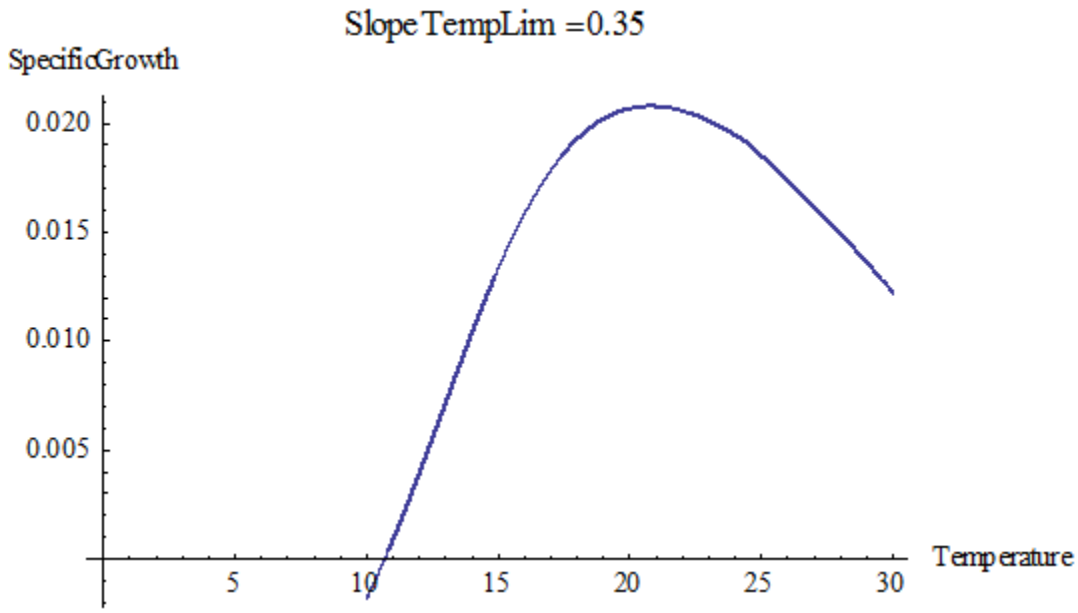


Figure 160: Specific growth curve used in AquaModel computations

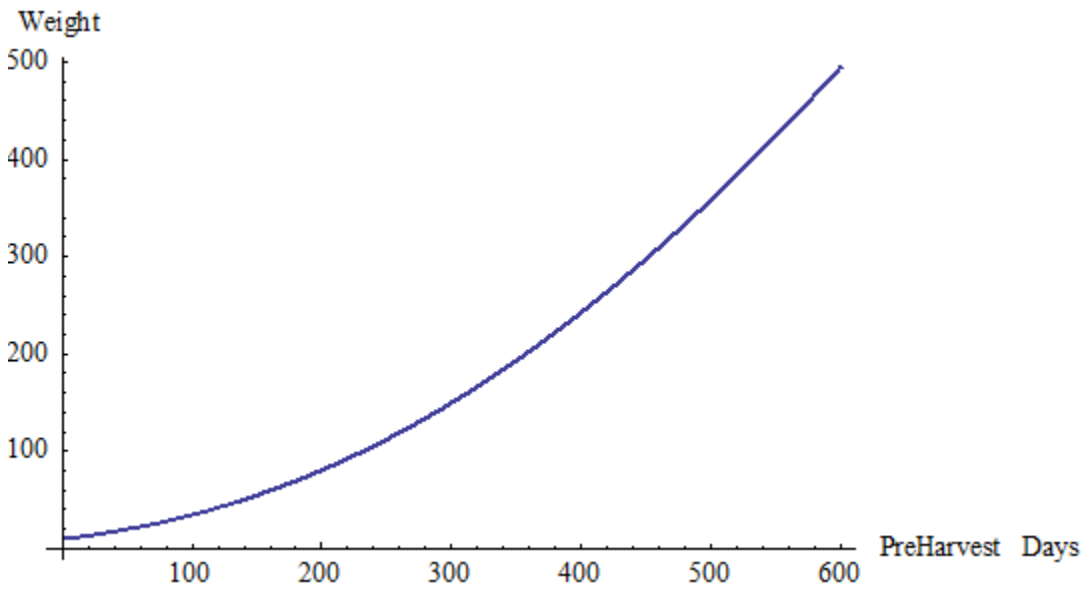


Figure 161: Length-time growth curve used in AquaModel computations

Faecal Settling Rates

Several authors have reported a consistent amount of faeces being released per kg of distributed food: 100-250 g/kg of food is the value from Cho et *al*. (1994), similarly to Talbot & Hole, 1994.

In Mediterranean aquaculture, Dosdat, 1992, 1996, reported 300-400 g per kg of fish produced. This figure, uses a Food Conversion Rate FCR of 1.6, bringing to a similar amount of 167-223 g/kg food distributed.

Faecal settling rates for salmonids are largely described in literature: Findlay and Watling, 1994,

Elberizon and Kelly, 1998, Panchang et *al*. (1997), Chen et *al*. (1999), Reid et *al*. (2009), recently reviewed the literature and found considerable variability because of differences in diet, water viscosity, fish size and study methodologies.

The mean settling rates varied from 2 to 8 cm/sec and rate was related to fish size as expected. Cromey et Al., 2002a, found settling rates of 3.2 cm/sec on average.

Determination of faecal setting rates gives some constraint, being fecal pellet sinking rates for marine species often not-normally distributed. Fish faecal pellets also have a high water content, thus their nature in seawater is close to liquid (Vita et *al*., 2004).

Magill et *al*. (2006), reported rates for gilthead Sea bream, *Sparus auratus*, and Sea bass *Dicentrarchus labrax*, raised in seapens in the Mediterranean Sea. They collected faecal matter from sediment traps suspended below net pens and transferred the contents to the laboratory for a re-suspension trial in 2 m high Plexiglas cylinders. Using video tracking methods, applied to over 1000 particles for each species, they found an average settling rates of 0.70 cm/sec for sea bass fecal matter. These authors carefully documented that the settling rates were not uni-modal, with over 70% of particles in volume displaying a settling speed over 2.5 cm/sec.

The smaller particles, in the range from 0.01 to 0.1 mm, settle at an average rate of 0.37 cm/sec. The amount of these particles is estimated as 8.3 % in volume.

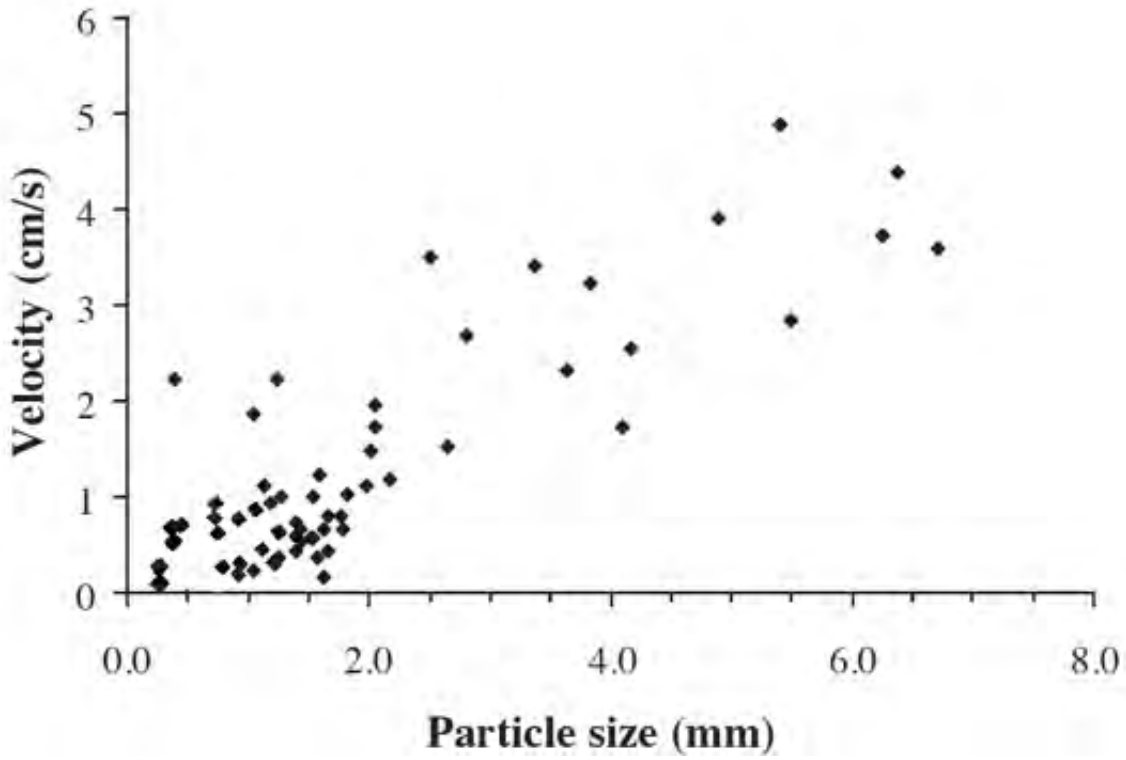


Figure 162: Sea bass faeces settling velocities (*Source: Magill et al., 2006, mod.)*

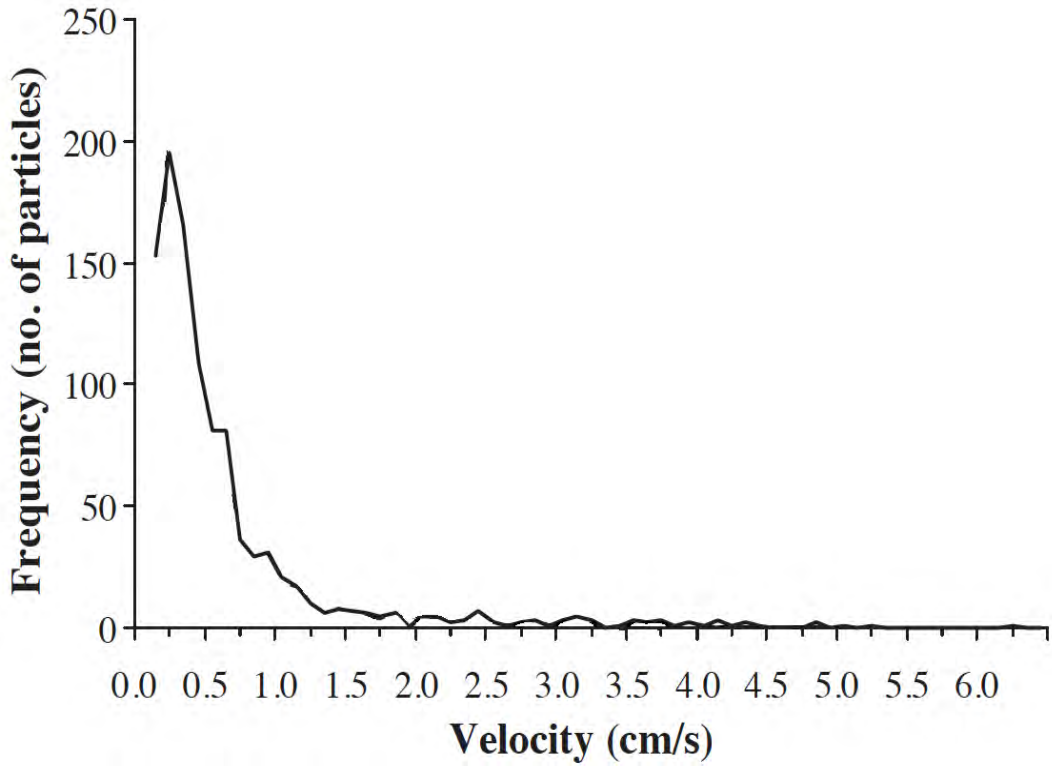


Figure 163: Frequency distribution of Sea bass faeces by velocity
(Source: Magill et al., 2006, mod.)

Table 35: Volumes of faeces particles and correspondent settling velocities, from Magill et Al., 2006, modified. Velocities reported are the top of the range, e.g., 1.0 includes all speed from 0.0-1.0 cm/s. Total volume of all particles settling within the settling velocity range. Mean settling velocity of the particles within the range, e.g., 0.3 is the average of 0.0-1.0 cm/s range

Sizes		Units					
50 g	Vol.	%	5.7	5.2	26.1	9.9	53.1
	Avg. speed	cm/s	0.44	1.47	2.48	3.41	4.37
80 g	Vol.	%	5.0	2.3	11.9	59.2	21.6
	Avg. speed	cm/s	0.34	1.45	2.48	3.66	4.88
280 g	Vol.	%	8.0	30.8	28.3	32.9	
	Avg. speed	cm/s	0.41	1.34	2.31	3.54	
All sizes	Vol.	%	5.8	9.3	19.8	38.1	27.0
	Avg. speed	cm/s	0.40	1.41	2.46	3.56	4.63
All data	Vol.	%	8.3	14.1	19.6	34.7	23.3
	Avg. speed	cm/s	0.37	1.43	2.46	3.56	4.63

Other Authors (Piedecausa et *al*., 2009) studied the settling rate of feed and faecal pellets of Sea Bass and Sea Bream, also in relation to change of their physical and chemical properties during immersion time.

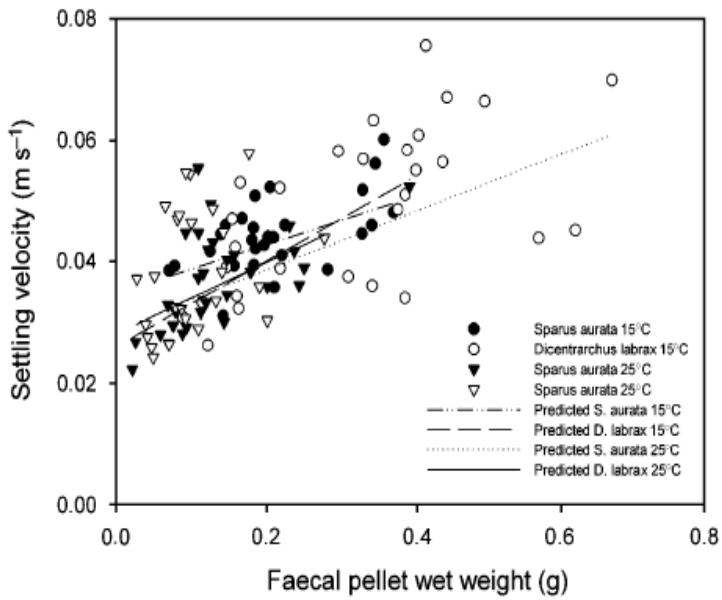


Figure 164: Faecal settling velocity of *S. aurata* and *D. labrax* at different temperatures (*Source: Piedecausa et al., 2009, mod*)

The settling velocity is found to vary with changes of shapes due to hydration.

The settling speed is also reported as not influenced by water temperature and trials showed a positive correlation between pellet weight and settling speed.

Settling rates of smaller faecal pellet, from 0.02 to 0.74 g, is reported to fall between 2.2 to 7.5 cm/sec. Perez et Al., 2014, reported similar values for Argirosomus regius.

Shape is variable and not correlated to fish size. They become quickly disaggregate into smaller particles with different shapes and buoyancy, mainly as an effect of water turbulence created by fish feeding activity, and settling behaviour between large and small particle can be quite different, from fast-sinking to buoyant.

This erratic behaviour has been described also in Magill et *al*. (2006).

Waste Feed Settling Rates

In comparison to fish faeces, waste feed particles are easily studied and quantified by settling columns. Settling velocity is related to pellet shape, density, porosity as well as to medium density and viscosity.

Feed manufacturers easily adjust the settling speed of extruded feeds by regulating the steam pressure and temperature in the extrusion process. This leads to a different degree of gelatinisation of starch in the pellet and to a controlled degree of "inflation" (and thus porosity) of the granule, thus affecting the receipt and entrainment of the vacuum-sprayed oils and additives. This process can be modified even on farmers' demand, and each factory can adjust sinking speed at different rates, from fully floating for raceways farming, to quick-sinking for offshore cages.

Vassallo et *al*. (2006), working on commercial extruded feed pellets for Mediterranean species, found sinking speed between 8.7 and 14.4 cm/sec;

Piedecausa et *al*. (2009), reported a sinking rate of 6.8-13,6 cm/sec for commercial pellets

between 2 and 8 mm diameter, and the speed appears to be affected by immersion time, leading to hydration and subsequent changes in density, porosity and shape.

Pellets between 2 and 4 mm, as likely used for fish production in BGF offshore farm, are described with a speed between 6 and 12 cm/sec, within an immersion time of 10 min approx, referable to the site bathymetry (90 m).

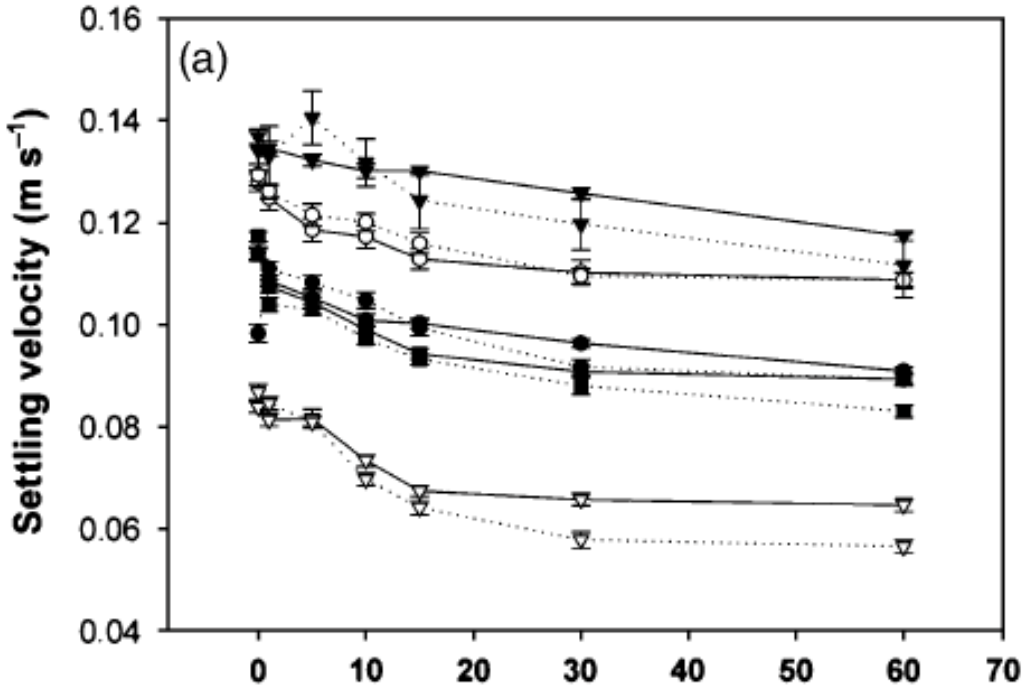


Figure 165: Settling speeds of feed pellets at different temperatures (*Source: Piedecausa et al., 2009, mod.*)

Therefore, a settling speed value of 8.0 cm/sec has been considered as representative of Sea bass feeds, to be used in farming in Gulf of Lions condition.

Waste Feed Loss Rates

The cost of fish feed represents one of the major annual investments in raw materials of an aquaculture company. It should be noted that maximization of growth performance is attained also through the minimization of feed losses, considered as a key-factor affecting a company's profitability.

Most commonly, devices such as submerged video cameras, echo sounders or Doppler-effect devices are capable of revealing in real time the delivery of an unnecessary amount of feed pellets and supply feed-back signals to feed distributors.

Waste feed is fast-sinking, scarcely soluble, and richer in carbon and nitrogen than waste faeces and thus will have a longer environmental persistence, and therefore the adverse effects will be more pronounced compared to fish faeces (Tlusty et *al*., 2000).

Waste feed can be eaten by wild fishes and invertebrates and this has been demonstrated to act as a significant mitigating factor (Vita et *al*., 2004; Fernadez-Joven et *al*., 2007; Holmer, 2010).

In other models, as in Cromey et al. (2002), for Bass and Bream farming, and in Perez et al. (2014), for Meagre (*Argyrosomus regius*) farming, it has recently been proposed a feed loss rate of 3%.

This value looks appropriate for an automatic feeding system as adopted in BGF platform, equipped by feed-back devices able to halt food releasing in case of overfeeding.

Deposition Threshold

Below a given, species-specific current flow, faecal and food wastes will settle down to the bottom and lie in the same position, thus entering in a "depositional" condition.

At higher rates of flow, in "erosional" conditions, wastes can be re-suspended and move over the bottom until current velocity decreases and leave them to settle again.

Most modern fish farms are located where hydrodynamic features can lead either to deposition or re-suspension of sediments and associated wastes, either in case of storms with associated long-length waves or by intense bottom currents.

During this process, particles can be eroded into smaller sized particles and moved in several ways and become available to the food web for assimilation, even at great distances. Some fraction of the deposited materials will remain steady even under all the most erosive conditions, in a process known as "consolidation".

The deposition threshold is defined as the near bottom water velocity at which fish faecal and waste food particles settle out. The literature for salmonids report values which are not well defined, but Cromey et *al*., 2002a, 2002b, used 4.5 cm/sec as a combined value for faecal and feed threshold; since the faecal matter of Sea bass is likely more dense than salmon faecal matter, its threshold has been increased to values of 6.0 cm/sec for fish faeces and 8 cm/sec for feed wastes.

Re-suspension Threshold

Several recent studies have indicated that re-suspension and consequent displacing of fish farm wastes are key factors in modelling of fish farms effects on marine sediments (Panchang et *al*., 1997; Cromey et *al*., 2002a, 2002b).

A prior estimate of threshold for re-suspension speed for salmon wastes (feed and faeces together) is 9.5 cm/sec, at 2 m above the bottom (Cromey et *al*., 2002a, 2002b, Cromey & Black, 2005).

Literature for faecal matter re-suspension rates in marine fish species is scant, but in absence of definite values for Sea bass, the re-suspension speed has been set to a value close to the only reported in literature (Cromey et *al*., 2002a, 2002b; Cromey & Black, 2005) .

Consolidation Rate

For long-term modelling of the effects of fish farming on the sea bottom chemistry and fauna, an important consideration is related to the degree of consolidation of waste particles. As described by Cromey et *al*., 2002a, 2002b, this is the stickiness of materials that may remain consolidated upon

the bottom, despite elevated rates of flow over the bottom. There is evidence that the rate increases with elapsed time at slow velocities, but it has not specifically been studied for fish wastes. Since this factor is poorly known or described, in the present study values have been selected from 1% to 5 %/day, these values gave the most realistic results in calibration runs.

Organic Carbon Oxidation Rates

Benthic effects are mainly influenced by the rate at which carbon is deposited and subsequently oxidised by bacteria or assimilated by the food web. The rate of organic matter degradation by microorganisms is often estimated using a first order kinetics or a Michaelis-Menton kinetics approach with similar result in cases where substrate, instead of microbial biomass, is limiting. When a new fish farm begins operating over a sedimentary bottom, the biomass of microorganisms at the water interface and in the sediments will increase in accordance to the load of organic matter released by the farm. Within reasonable bounds, after the farm operates for some period of time, the microbial biomass (and other benthic organisms, if time for communities succession is sufficient) approximate a steady state to process the wastes. When the amount of carbon deposited exceeds the capacity of aerobic processing, sediment bacterial communities shift to anaerobic sulphide reducing metabolism which tends to disadvantage the most sensitive invertebrates, either infauna or epifauna. Generally, up to 1 to 1.5 percent total organic carbon added to the top 2 cm will not result in the shift to anaerobic conditions, depending on sediment porosity and water temperature.

Sediment re-working by burrowing organisms is also known as an important factor in sediment deep layers oxygenation (Valdemarsen et *al*., 2009; Holmer, 2010).

In temperate areas, up to 5 grams of TOC can be added per square meter per day (Findlay & Waitling, 1997), although the tolerance of benthic communities may be scattered in dependence of local factors, as patchy distribution of sediment properties and of benthic communities as well (Hargrave, 1994; Karakassis et *al*., 1999).

In the present study, the background levels of TOC has been considered at a relatively low level, at 1 % of sediment WW, as reported by several authors (Thilstone et *al*., 2003) in the area. A part of this carbon is also including refractive carbon, as those from shells or "old" debris.

Tlusty et *al*., 2000, demonstrated that fish faecal matter has a very high solubility potential, loosing approximately 50% of its organic matter in a 12-day exposure to water flow. Food and faeces are therefore mostly in the "non-refractive" forms of carbon, unlike less decomposable carbon in refractive forms, such as organic matters from terrestrial origin.

For the Marseille site, conservative choice of 1.0% /day carbon oxidation rate in sediments and in settling in water column has been done.

The chosen value in input in the model (10 mgC/m^2/day) has been tuned at the aim of taking in account the likely microbial community adaptation to an increased organic load, as commonly experienced under heavy organic loads as in the case of a large fish farm (Mackin & Swider, 1989; Holmer & Kristensen, 1992).

Release of Nitrogen by Reared Fish

In teleost fish, the main output derived by protein metabolism is Ammonia (NH4+). A significant proportion (5-15%) of nitrogenous wastes are also excreted as Urea, and gills are the main excretory organs for both compounds, accounting for as 80-90% of total nitrogen excretion (Dosdat et *al*., 1996). A part of nitrogen is also lost through faeces, and from faeces can leach quickly to the ambient waters (Tlusty et *al*., 2000; Piedecausa et *al*., 2009) at a steady rate of 0.1 % of faeces DW.

In order to predict fish nitrogen excretion, several authors have underlined the importance of feeding, fish size and temperature parameters on different species (Paulson, 1980; Ramnarine et *al*., 1987; Dosdat, 1992; Jobling, 1981).

Total nitrogen excretion is related to the food conversion ratio (FCR) (Fivelstad et *al*., 1990), considered a useful indicator for assessing nutrient outputs from fish farms (Einen et *al*., 1995).

Sea bass is an ammoniotelic species, with 75% to 90% of the total excreted dissolved nitrogen as ammonia. The part of nitrogen excreted as ammonia can vary from 56% at high temperatures to 71% at low temperatures (Spyridakis et *al*., 1989; Vitale-Lelong, 1989). Other Authors reported different results, where 30–35% of ammonia produced over nitrogen ingested was found (Ballestrazzi et *al*., 1994, 1996, and Dosdat et *al*., 1996); a wider range, from 30 to 60% is reported in different aquaculture conditions (Lemarié et *al*., 1998). Such differences between studies could be related to feed differences in quality and quantity, and to temperature and water quality conditions (Dosdat et Al., 1996). The same Authors found that urea represented 13% of the total excretion at 16 or 20 C° for Sea bream and Sea bass, close to the value (14%) reported for rainbow trout (Kaushik, 1980) and Atlantic salmon (Fivelstad et Al., 1990).

Fish nitrogen retention varied from zero at 10 C° to 25% at around 24 C°. The latter agreed with the results of Ballestrazzi et Al., 1994, 1996. In contrast, Hidalgo et Al., 1987, found a maximum nitrogen retention efficiency of 14.5% with 20–30 g fish.

In the present simulation, the displayed behaviour of Nitrogen is referred to as Total Nitrogen, thus comprehensive of Ammonia + Urea.

Feed consumption in the BGF farm would attain a maximum level of approx 1100 ton/month, just before harvesting period. The food hypotesized has the characteristics of commercial feeds, with a water content of 10% and a carbon content of 53%.

A percentage of 3% of uneaten food is also retained in the model.

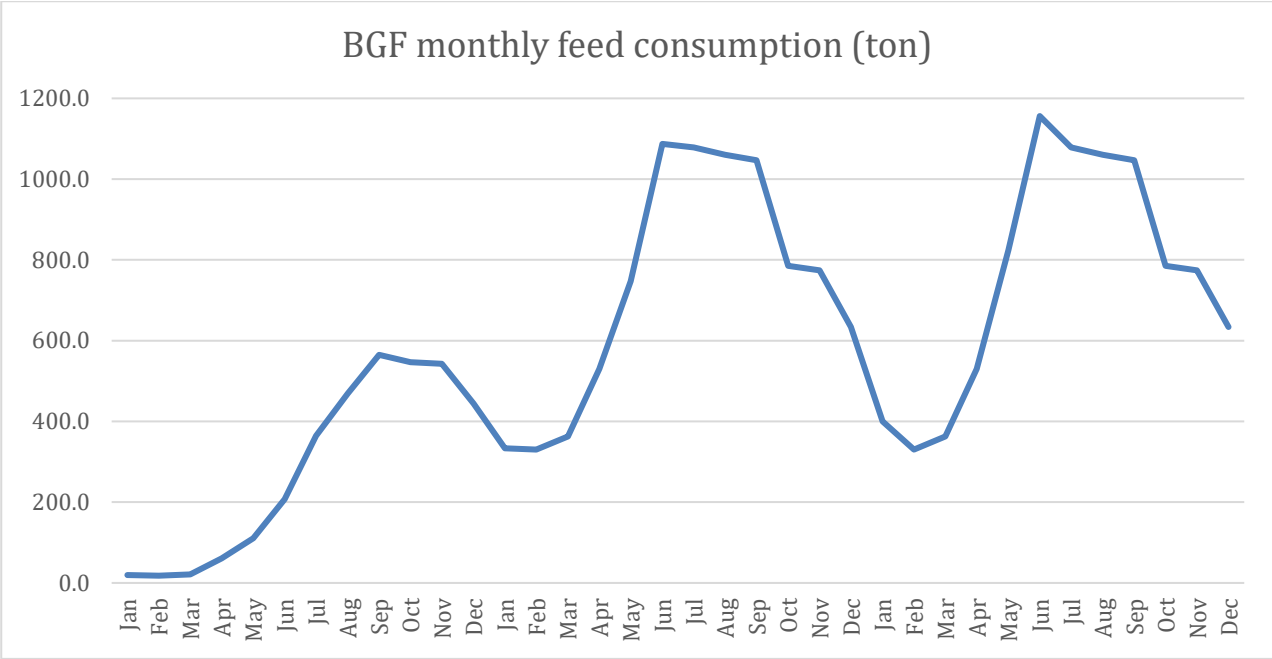


Figure 166: Temporal evolution of total feed consumption

Farm Biomass

The farming cycle of Sea bass in BGF has been designed to lead to a gross fish production of 4.000 tons per year. This result is reached after the 3rd year of production by a stocking policy of 4 batches of 3.500.000 fingerlings each per year, starting by an average weight of 20 g (D 9.1).

The above result is reached by maximizing the yield per cage, moving quickly to market all fish at size (>400 g), and re-stocking the empty cage, maintaining a correct farming density (<15 kg/m^3).

The available cages in BGF farming system are 6. Fish are grown in the same cage until they reach a maximum of biomass of 1200 ton: over this threshold the stock is harvested within 2 months.

Therefore, the evolution of overall biomass in the farm is conditioned by the above farming and harvesting policy in association, that determine a sudden decrease in standing stock in some months: the resulting biomass evolution is beyond the possibility of any modelling.

In fact, while the growth of fish can be predicted, the harvesting policy after attaining the desidered size is not connected to any biological law, but just an operators' choice.

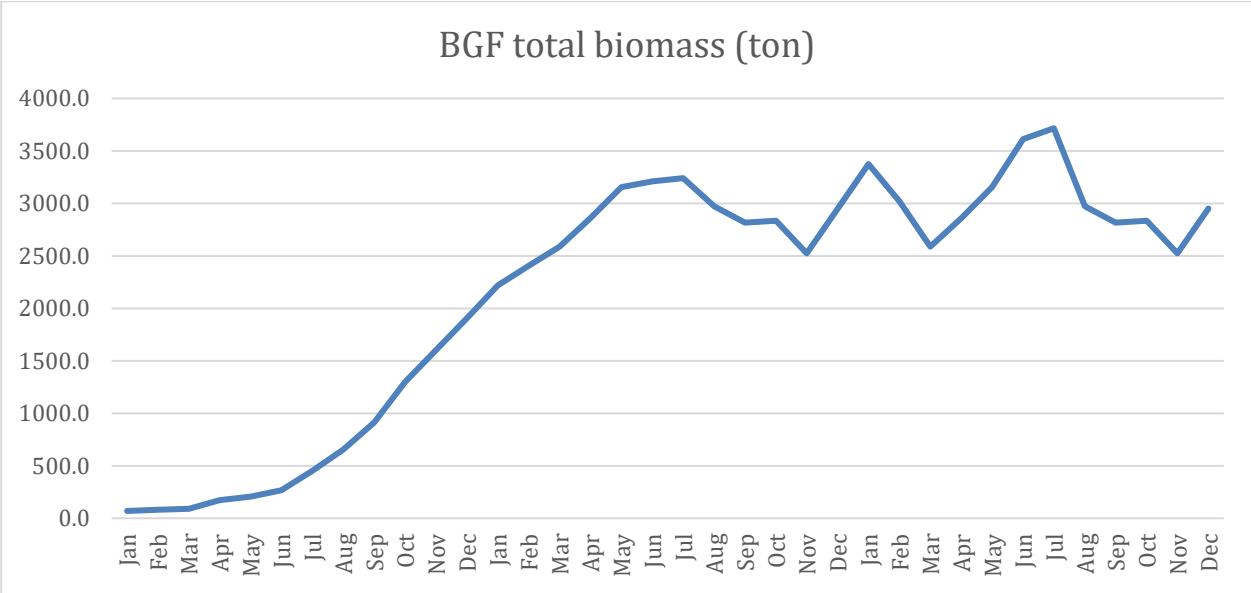


Figure 167: Temporal evolution of total biomass in Farm

Primary Coefficients for Marseille Simulation – Benthic computation

The computational array was formed by a number of 41x41x6 cells, each one of 50x50x15 m, covering an area of 2050x2050 m, down to a depth of 90 m.

The array was centered at:

- Latitude: 44.1277 N
- Longitude: 4.7093 E

The simulation has been run for a period of 3 years, from 01.01.2016 to 01.01.2019, corrispondent to the the flow field temporal extension derived from CMEMS.

The following coefficients were used in the model setting:

Table 36: Benthic coefficient in AquaModel computation

Benthic coefficient	Unit	Value
TOC sediment	%dryW	0.0015
Oxygen in sediment	ppm	4
Ambient TOC deposition	g C/m^2/day	0.2
Oxygen in seawater	ppm	6
Aerobic biomass	g C/m^2	0.26
Anaerobic biomass	gC/m^2	0.05
Sediment CO_2	g/m^2	0
Sulfide in sediment	mM/m^3	0
Mixing depth winter-summer	M	80-40
Surface temperature	°C	13-24
Bottom temperature	°C	13-16
Inorganic Nitrogen	Micro-Moles/m^3	0.3

Table 37: Depositional coefficient in AquaModel computation

Depositional coefficients	Unit	Faecal	Feed
Sinking speed	cm/sec	1	8
Deposition threshold	cm/sec	4	8
Re-suspension threshold	cm/sec	8	10
TOC Consolidation rate	% /day	0.01	0.05
TOC Oxidation rate	% /day	0.01	0.01
Feed Carbon content	% dry weight		0.53
Feed Water content	% dry weight		0.1
Feed Waste %	%		3

Spatio-temporal evolution of benthic parameters
The cumulative waste deposition

The following maps report the cumulative deposition of faeces and uneaten feed on the bottom.

This map has to be intended as an integral of deposition: in other words, display the total amount of organic carbon received over one square meter of bottom, irrespective of any process of benthic digestion. Snapshots are displayed at a rate of four/year, at month 3, 6, 9, 12, 15, 18, 21, 24, 27,30, 33, 36. Current vectors are referred at 22,5m of depth, below BGF platform at maximum current exposition of nets. Cages are outlined at the center of map.

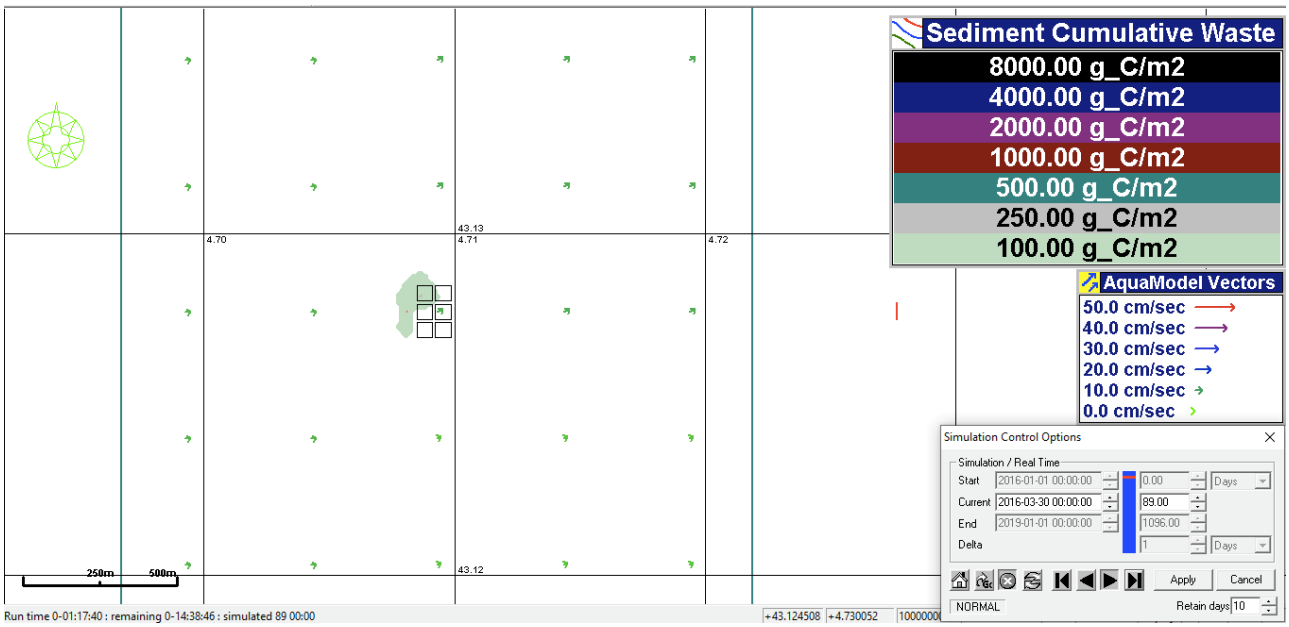


Figure 168: Cumulative wastes; date March, 1st year

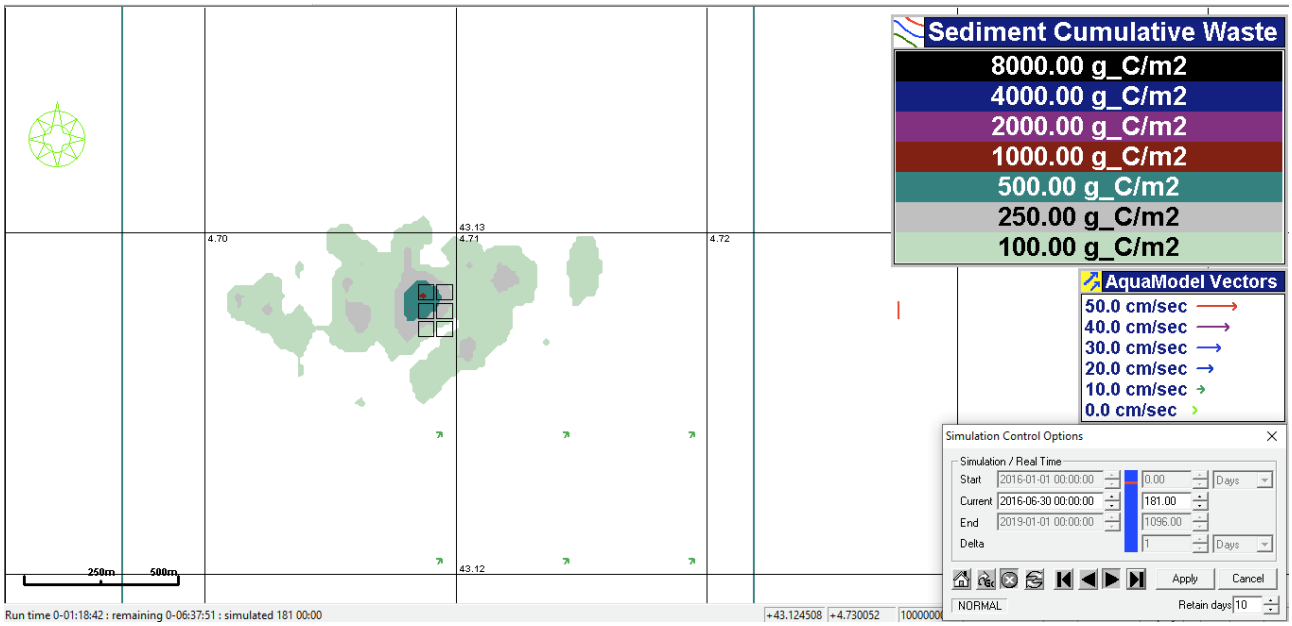


Figure 169: Cumulative wastes; date June, 1st year

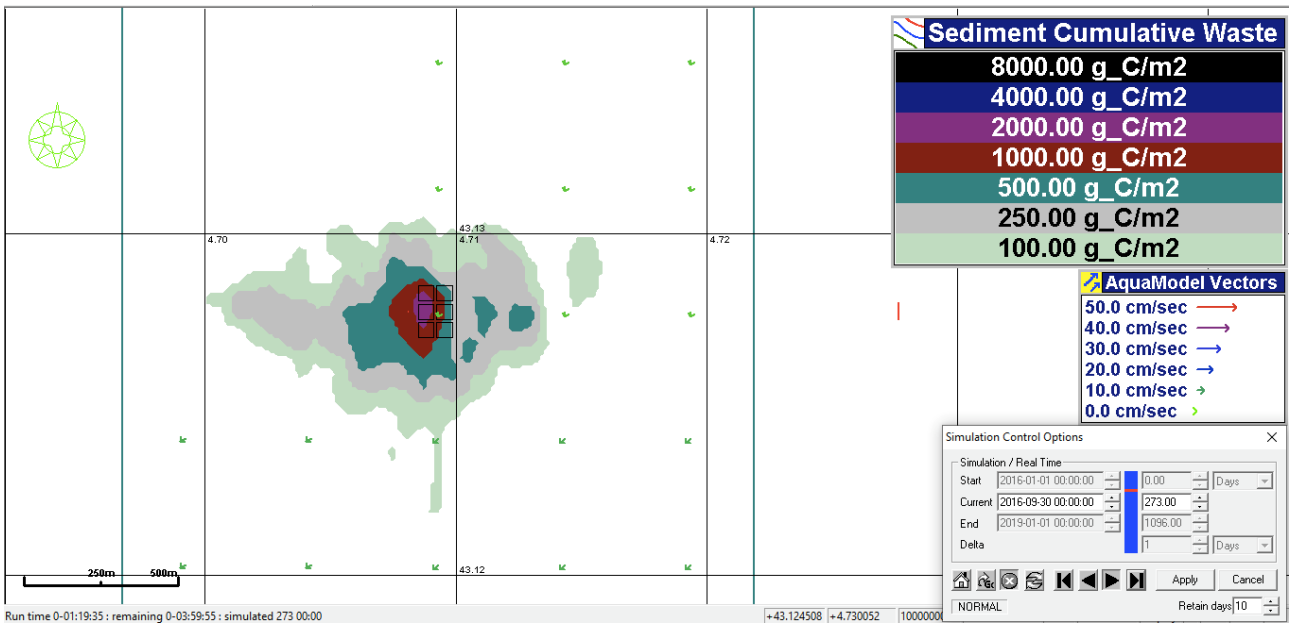


Figure 170: Cumulative wastes; date September, 1st year

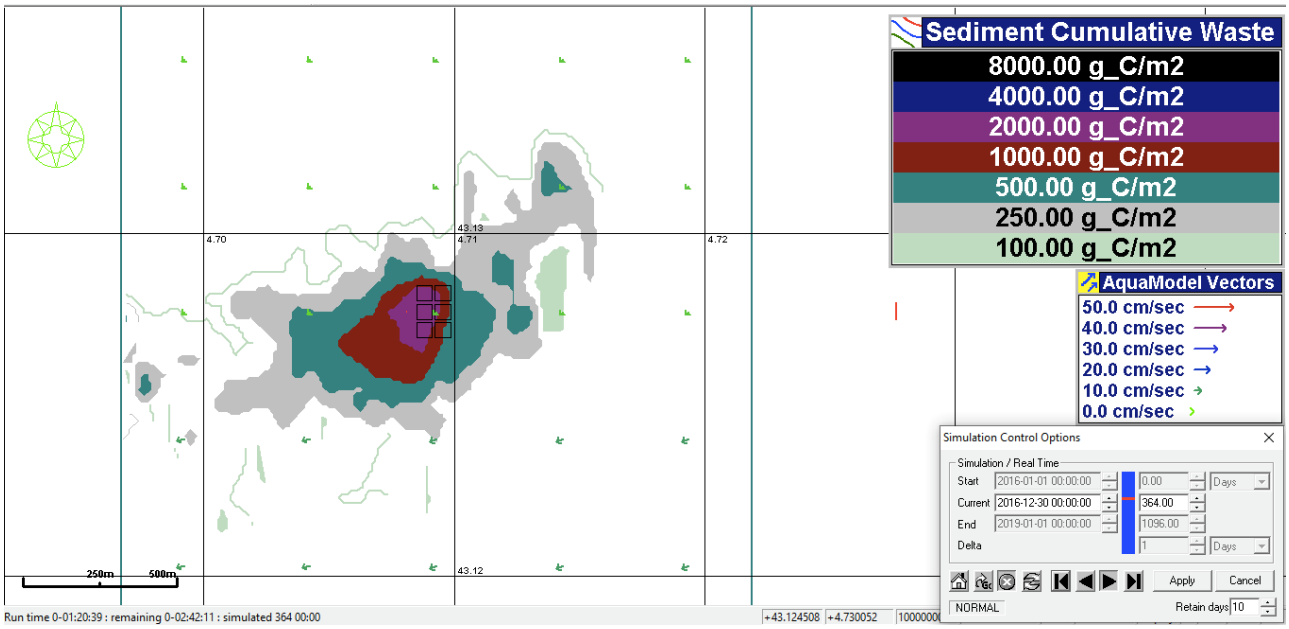


Figure 171: Cumulative wastes; date December, 1st year

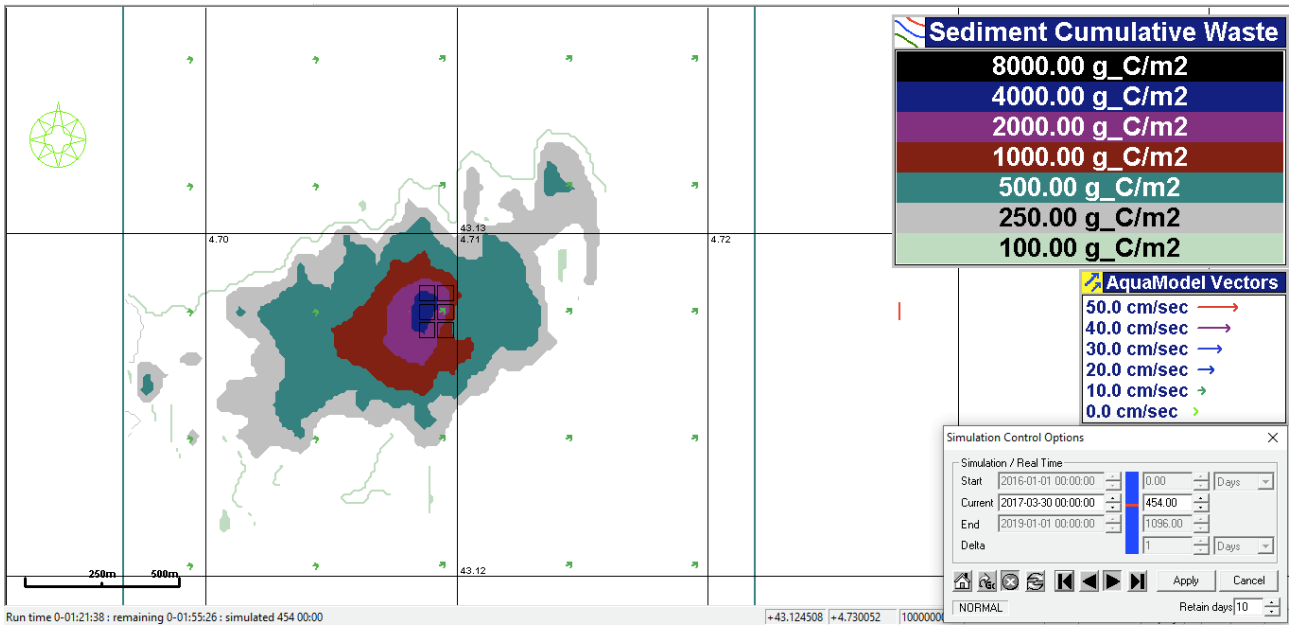


Figure 172: Cumulative wastes; date March, 2nd year

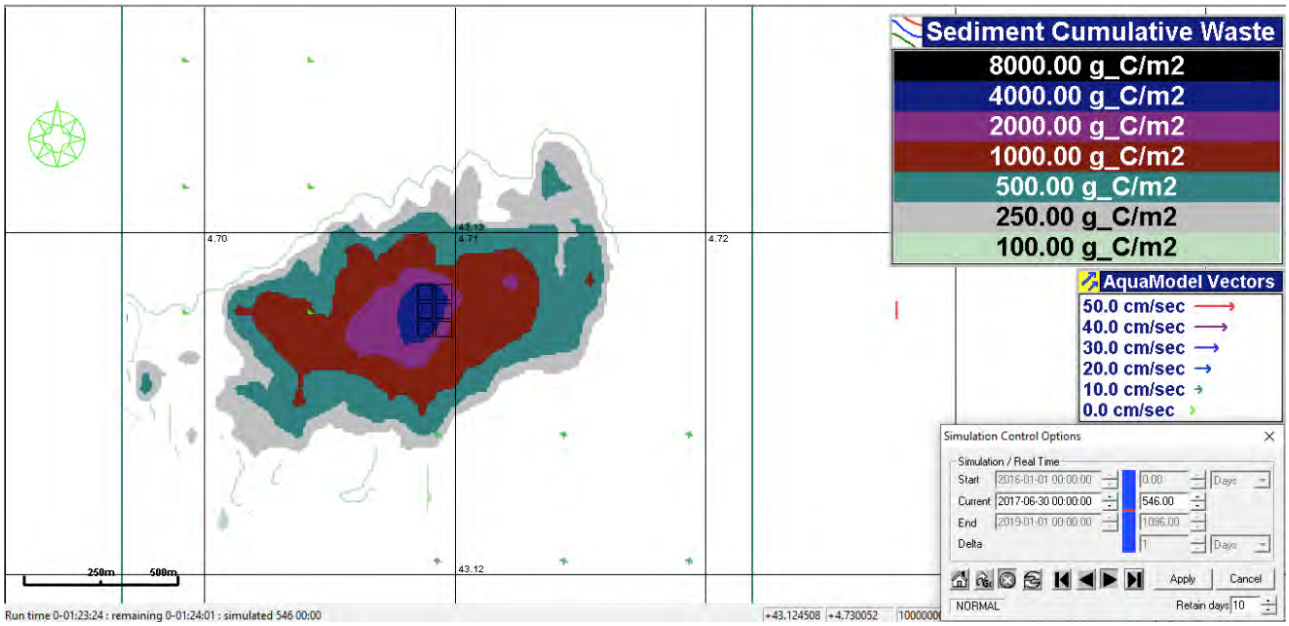


Figure 173: Cumulative wastes; date June, 2nd year

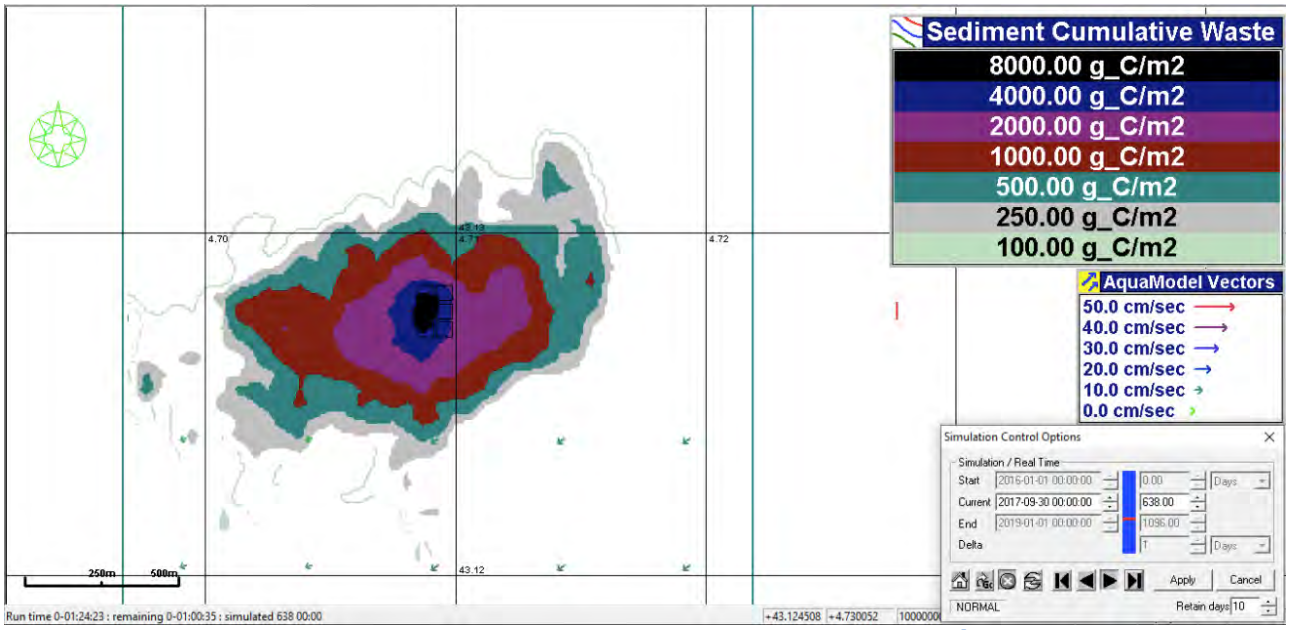


Figure 174: Cumulative wastes; date September, 2nd year

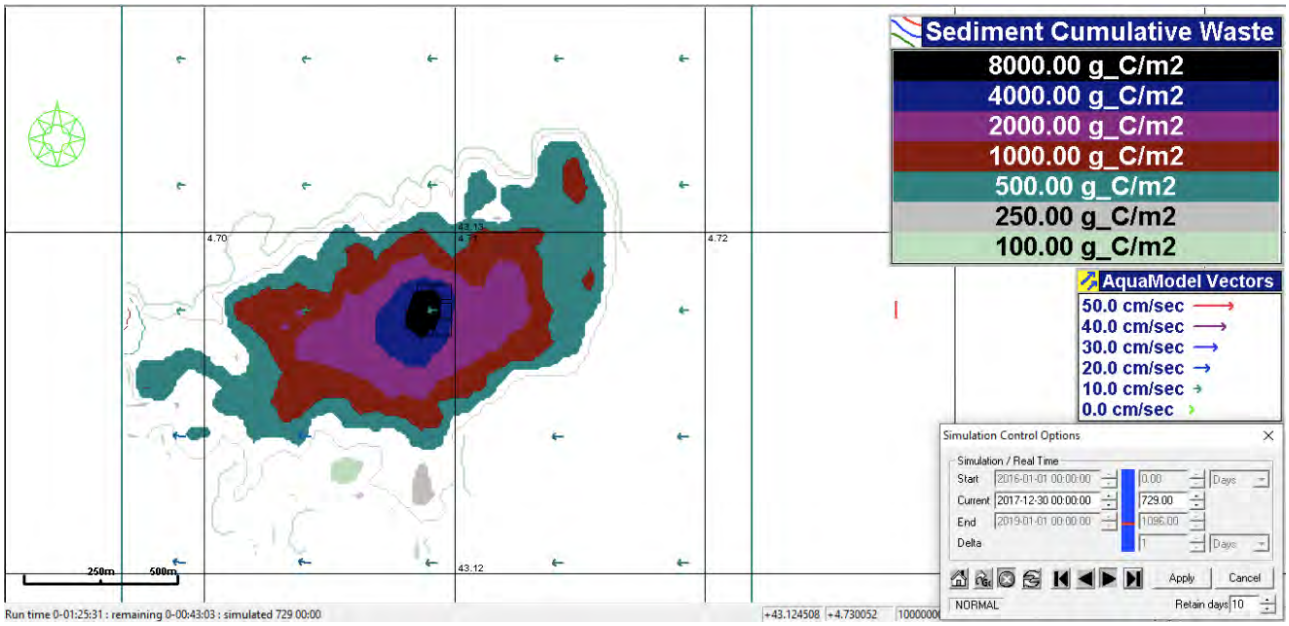


Figure 175: Cumulative wastes; date December, 2nd year

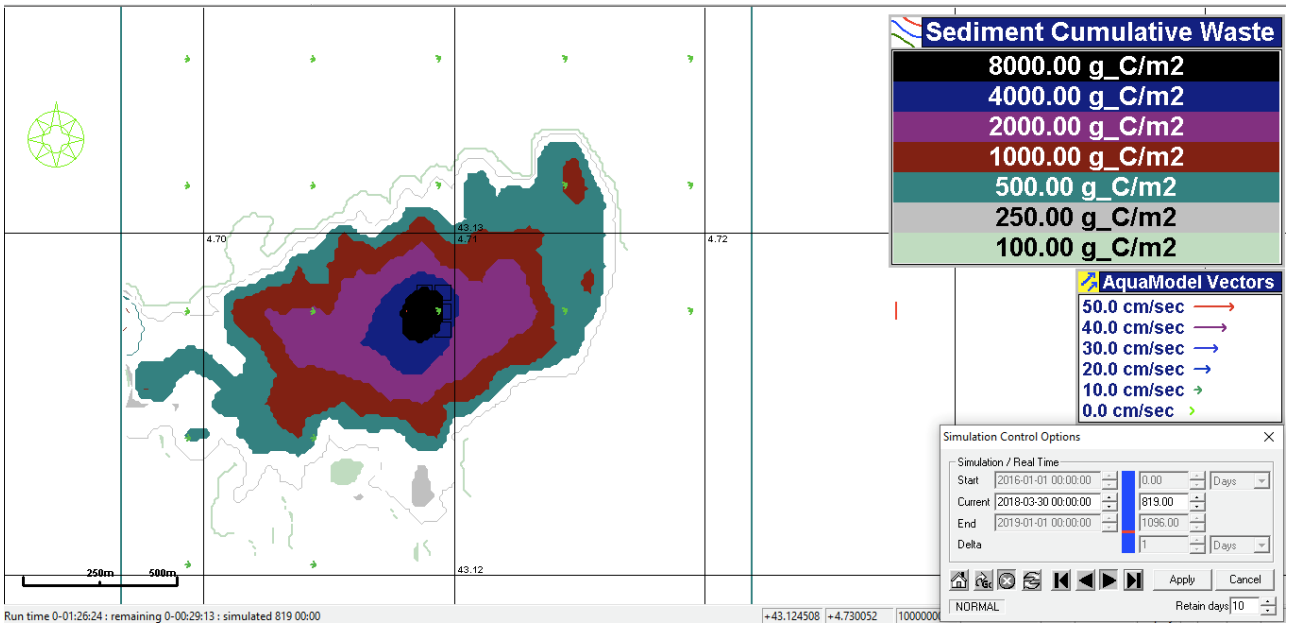


Figure 176: Cumulative wastes; date March, 3rd year

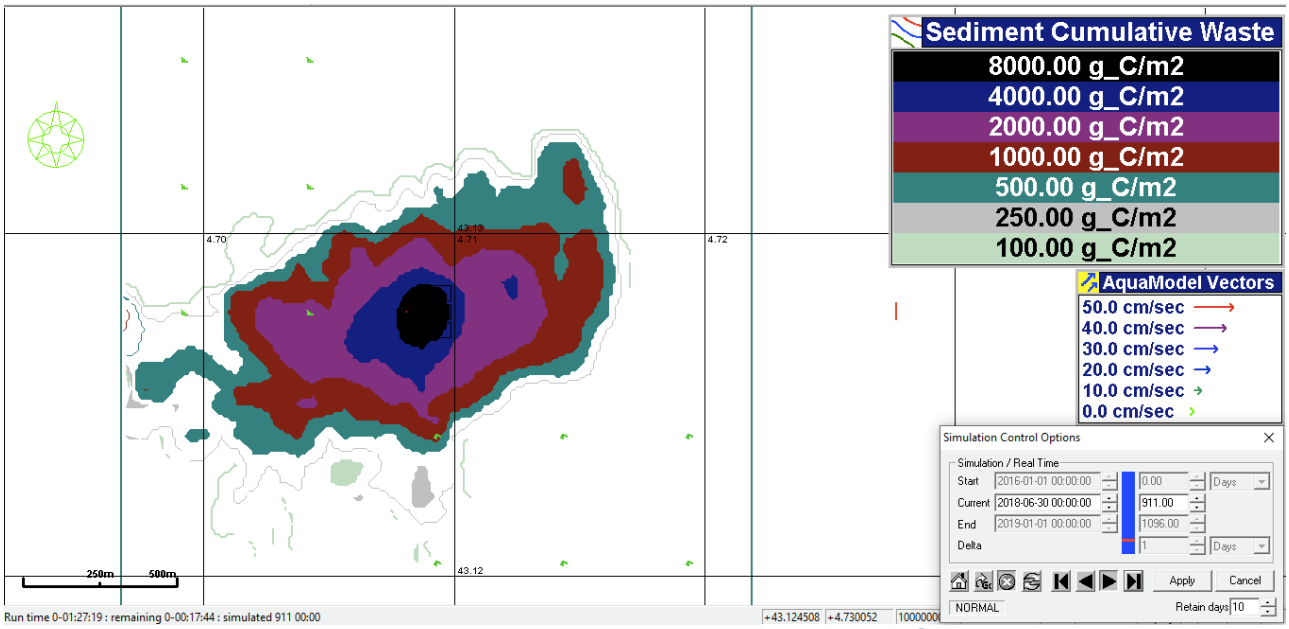


Figure 177: Cumulative wastes; date June, 3rd year

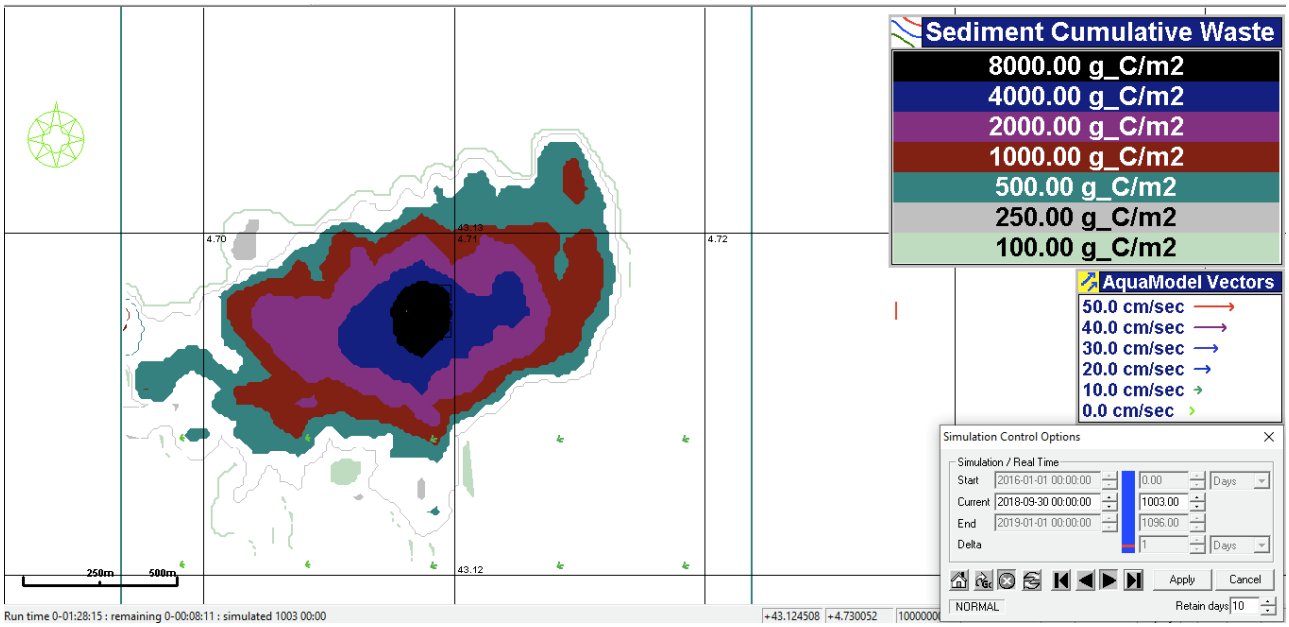


Figure 178: Cumulative wastes; date September, 3rd year

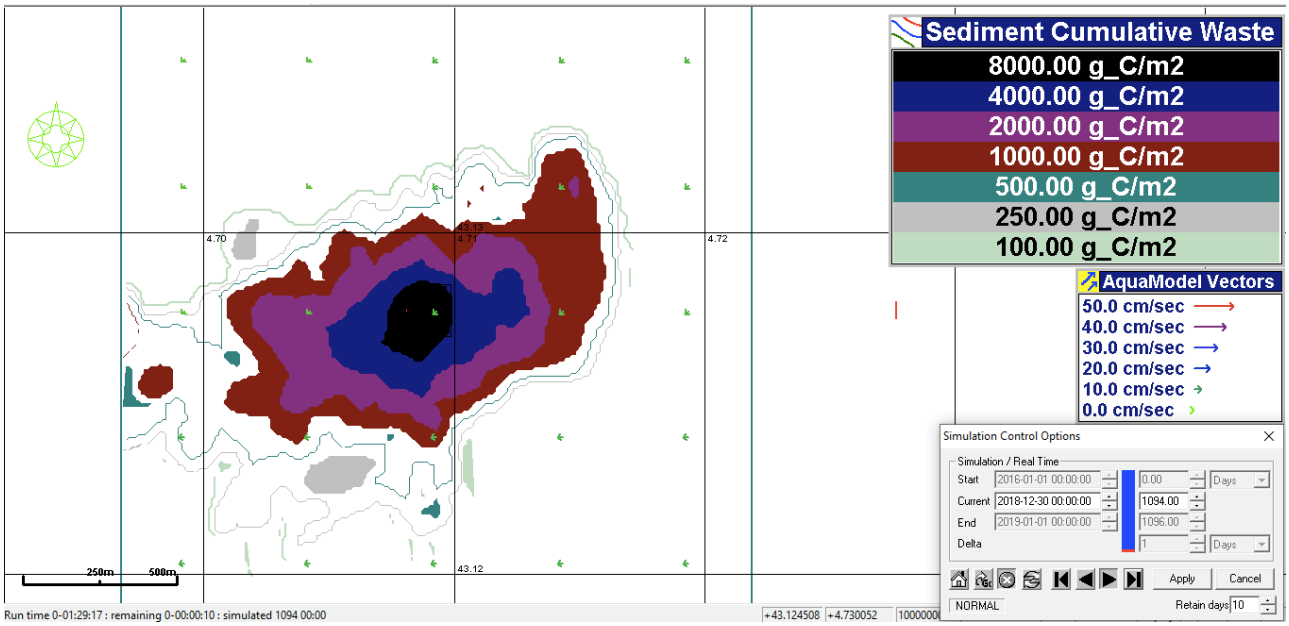


Figure 179: Cumulative wastes; date December, 3rd year

The Fecal wastes

The maps below display the amount of fecal carbon present at any given date in the sediment.

Amounts are dynamically calculated, and is displayed the result of the balance between continuous deposition of fecal carbon and its benthic consumption. Snapshots are displayed at a rate of four pictures per year, at month 3, 6, 9, 12, 15, 18, 21, 24, 27,30, 33, 36. Current vectors are referred at 22,5m of depth, below BGF platform at maximum current exposition of nets. Cages are outlined at the center of map.

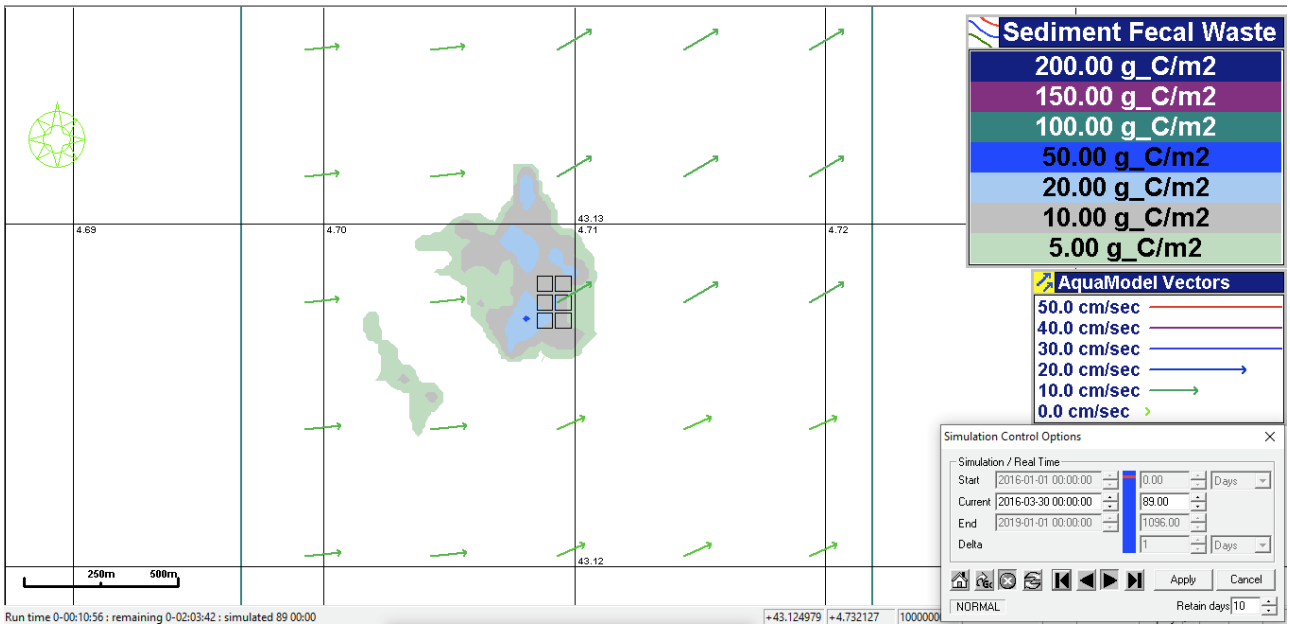


Figure 180: Fecal wastes; date March, 1st year

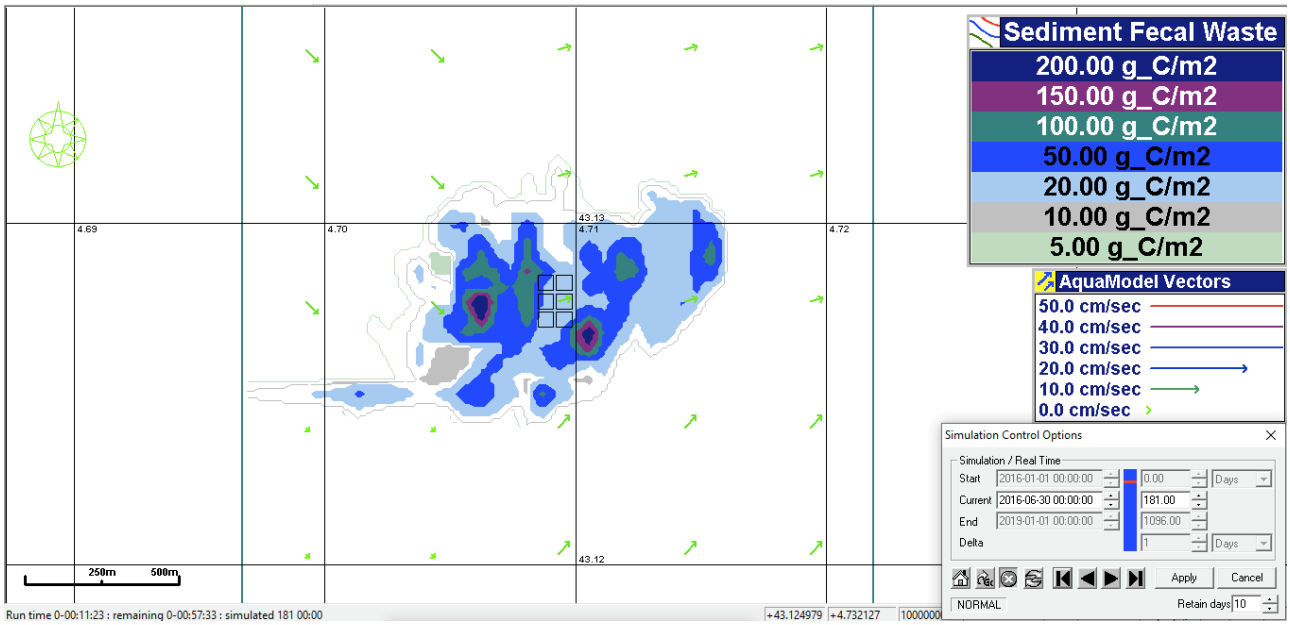


Figure 181: Fecal wastes; date June, 1st year

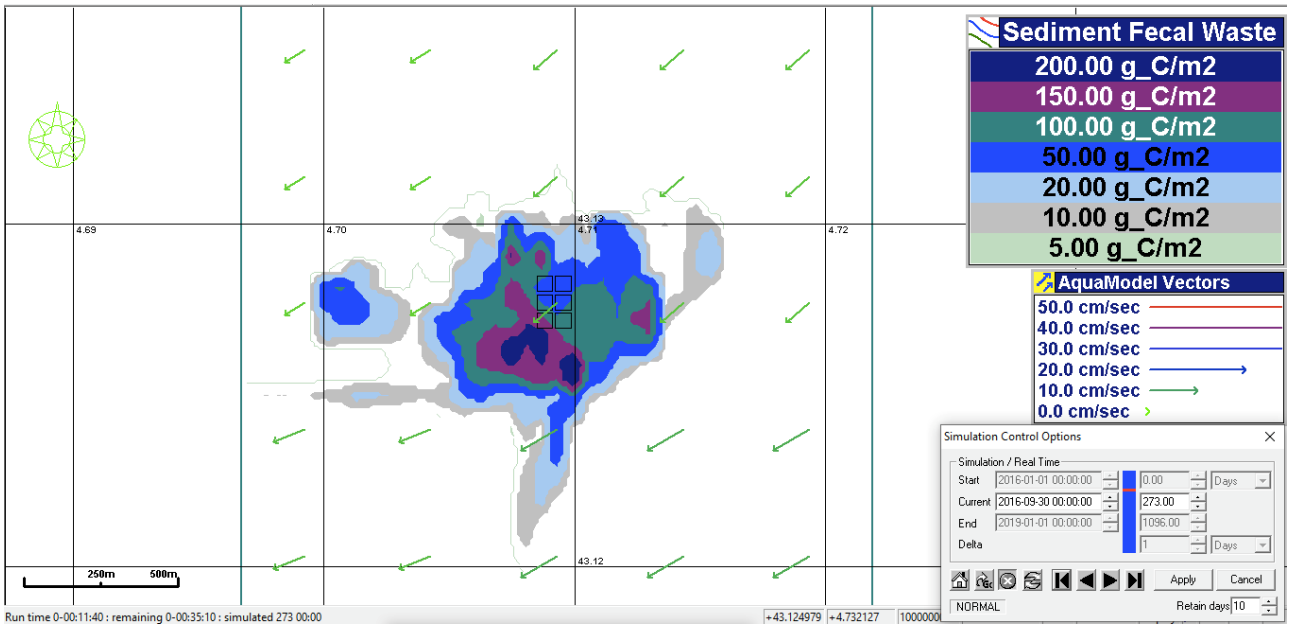


Figure 182: Fecal wastes; date September, 1st year

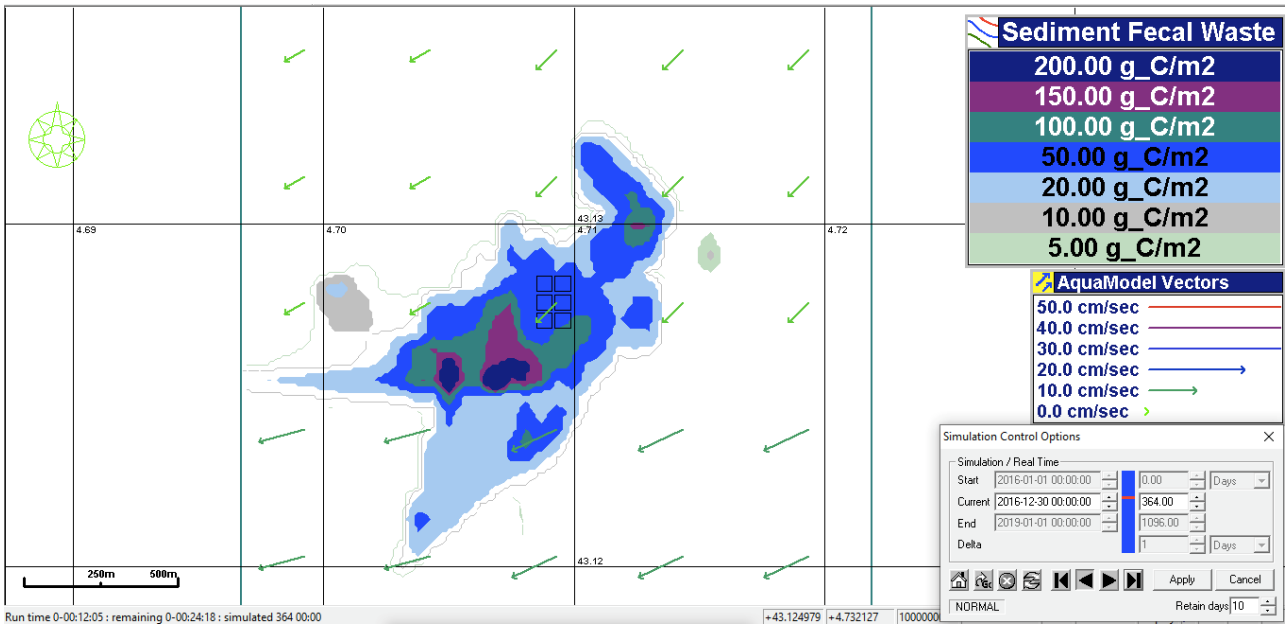


Figure 183: Fecal wastes; date December, 1st year

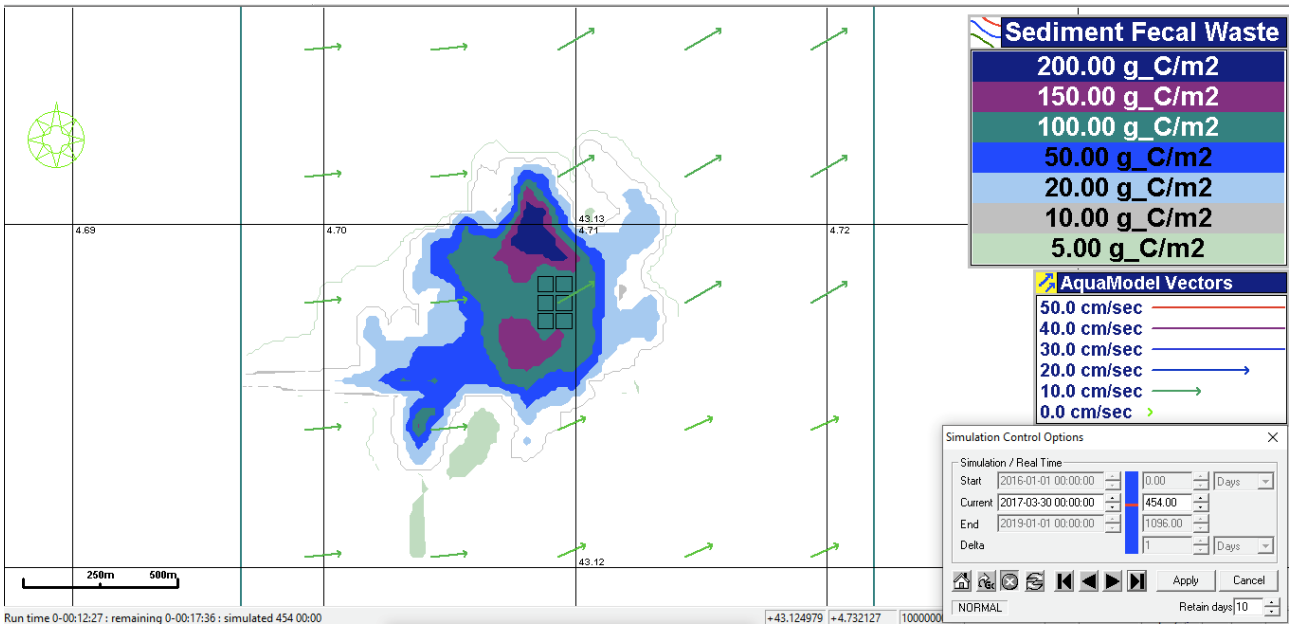


Figure 184: Fecal wastes; date March, 2nd year

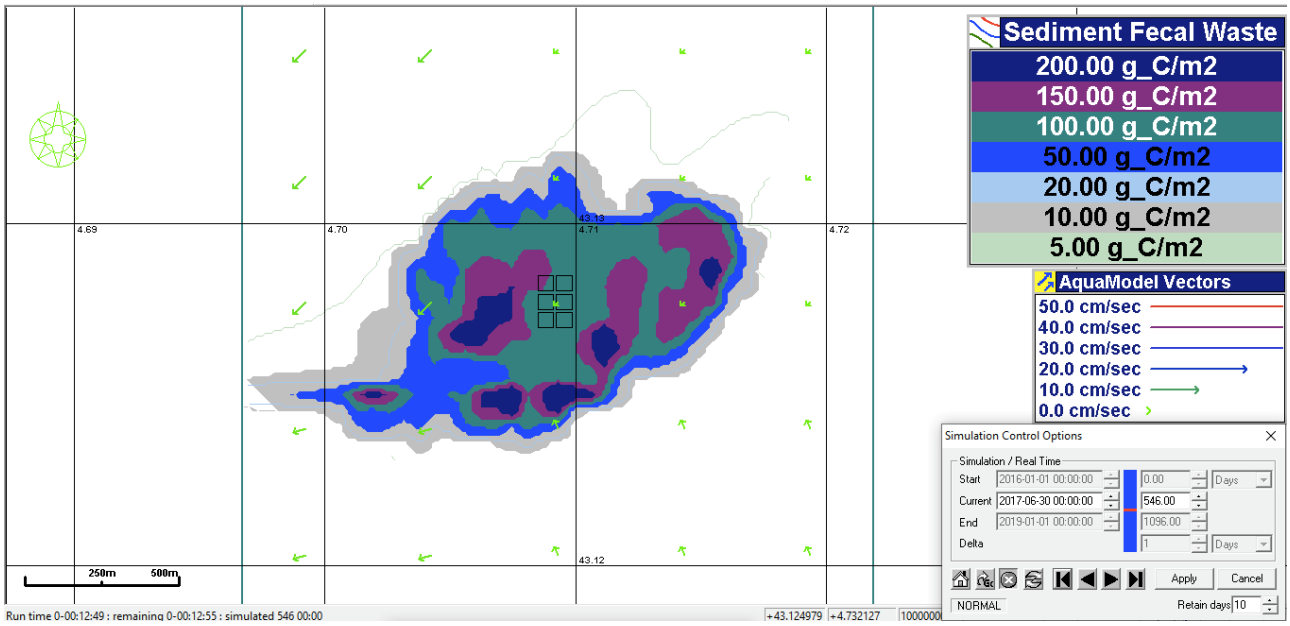


Figure 185: Fecal wastes; date June, 2nd year

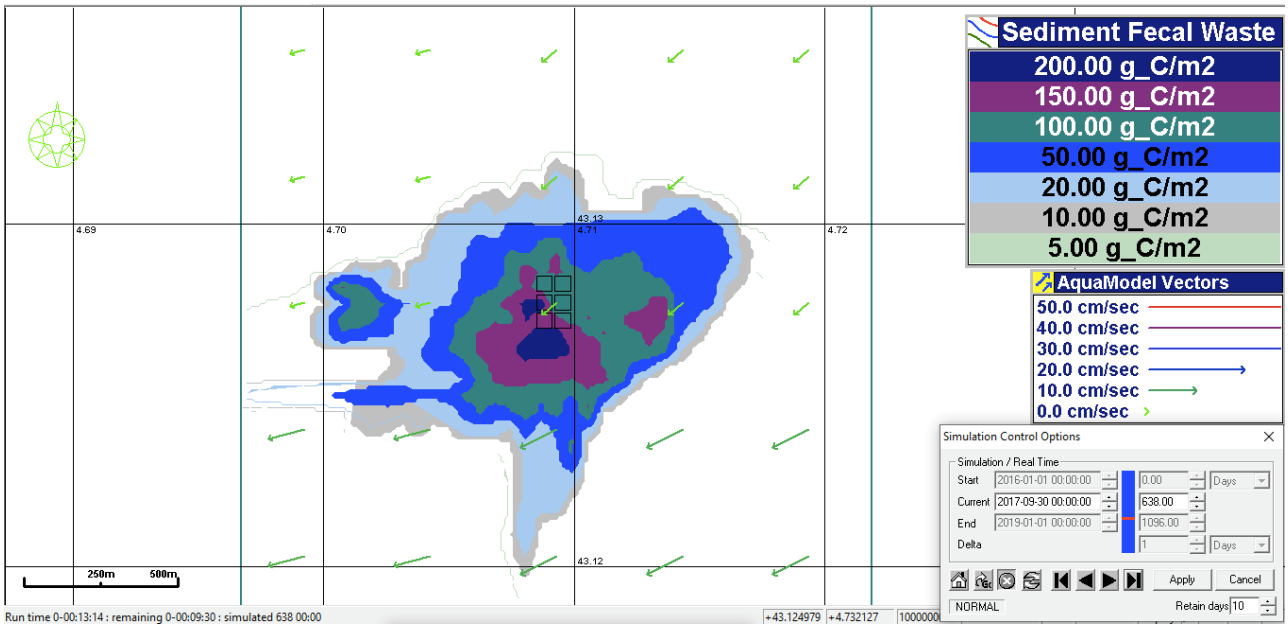


Figure 186: Fecal wastes; date September, 2nd year

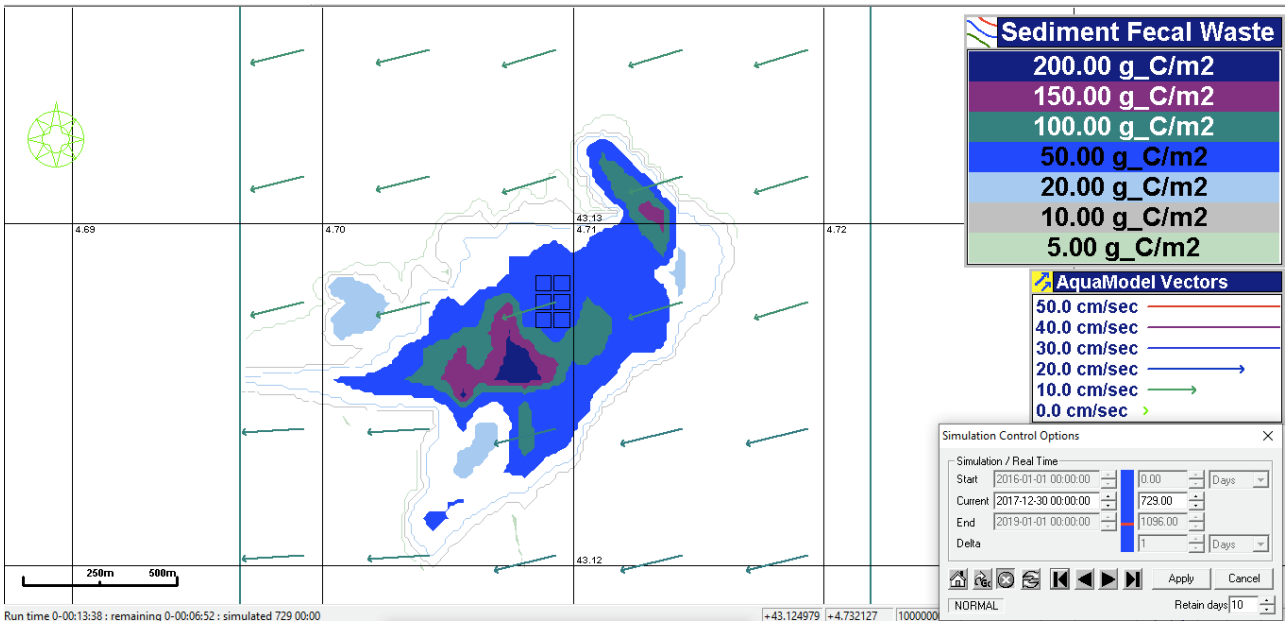


Figure 187: Fecal wastes; date December, 2nd year

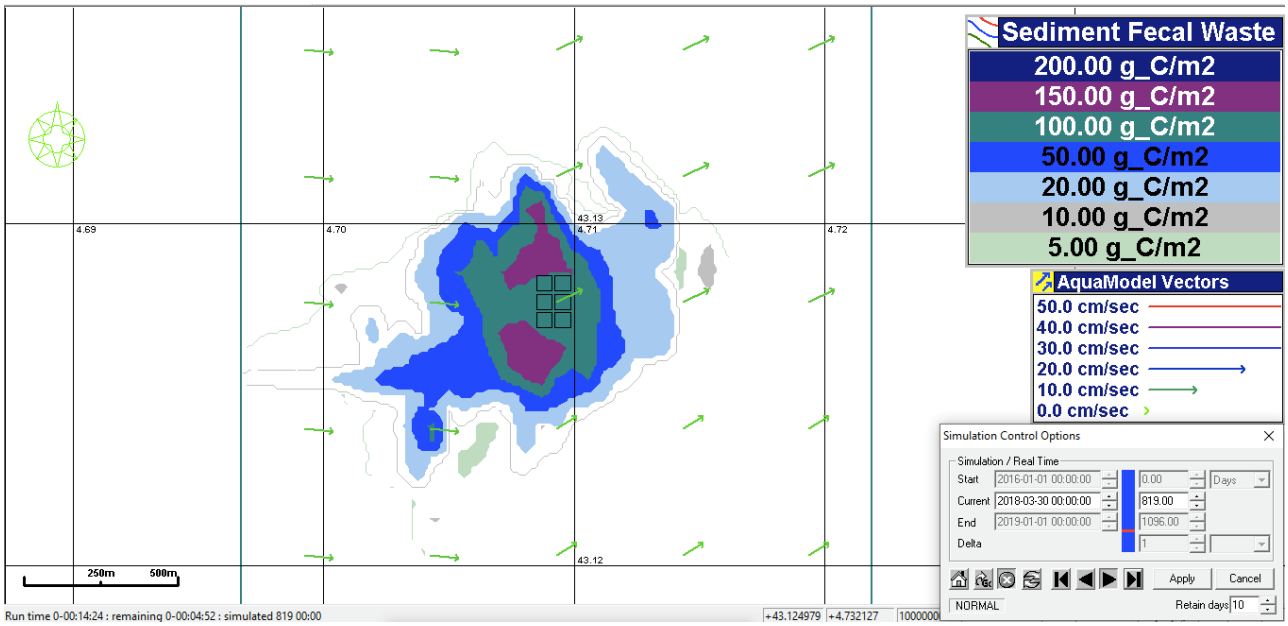


Figure 188: Fecal wastes; date March, 3rd year

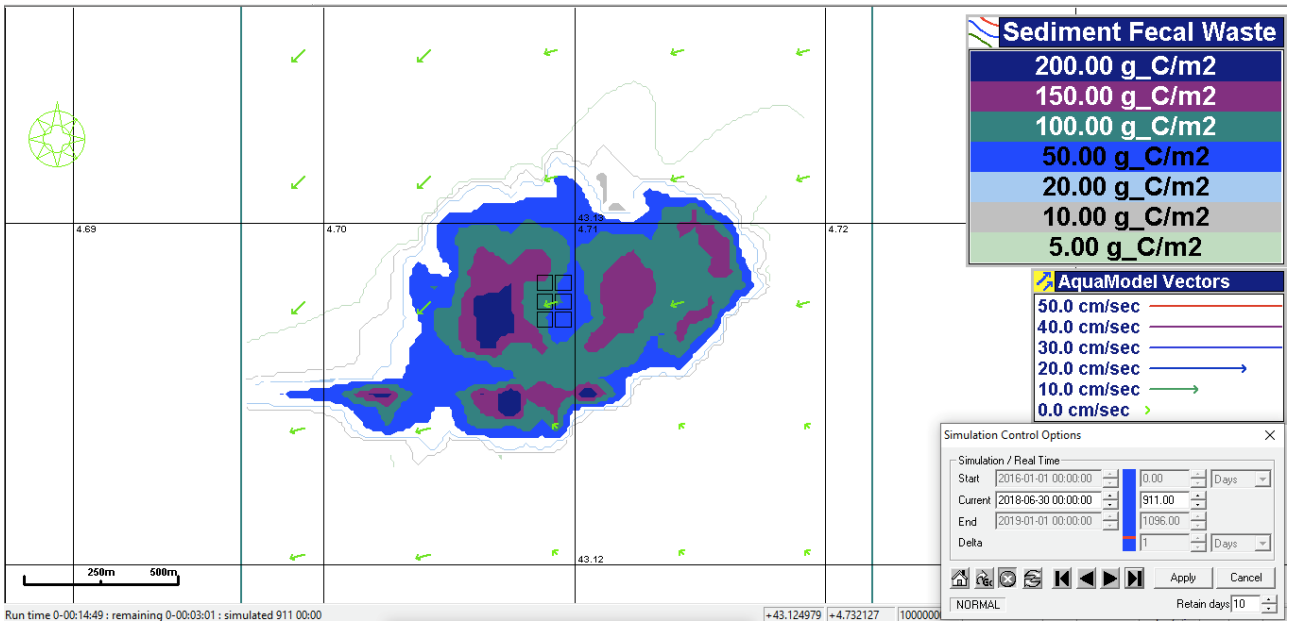


Figure 189: Fecal wastes; date June, 3rd year

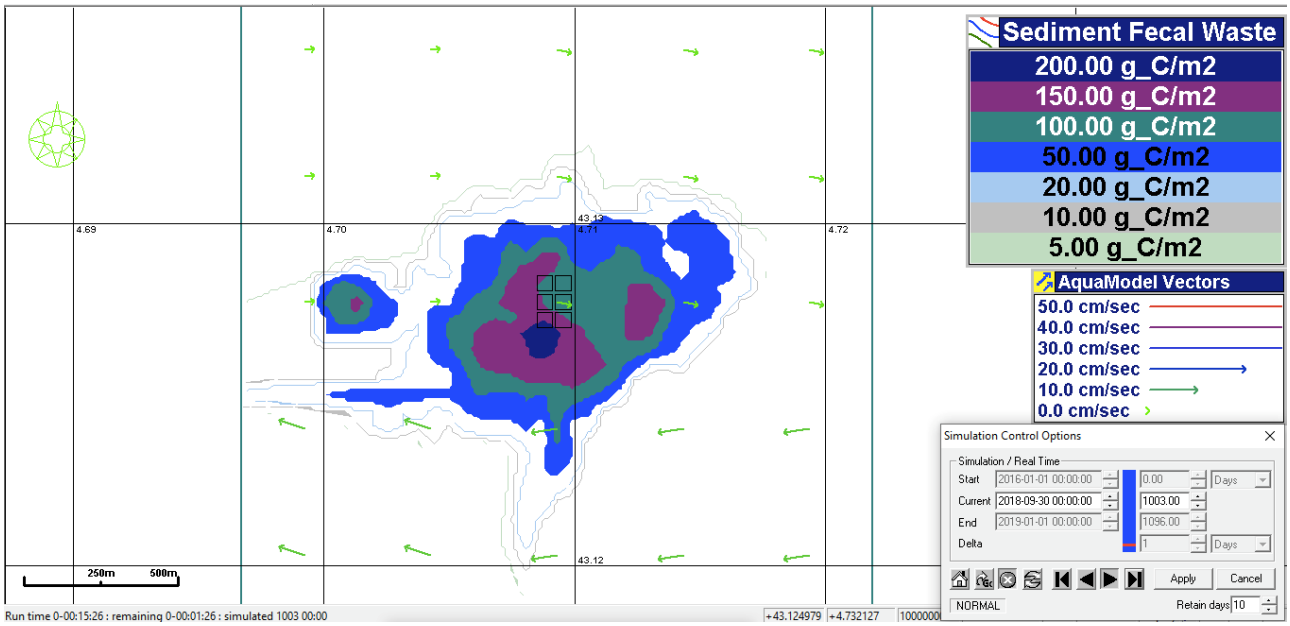


Figure 190: Fecal wastes; date September, 3rd year

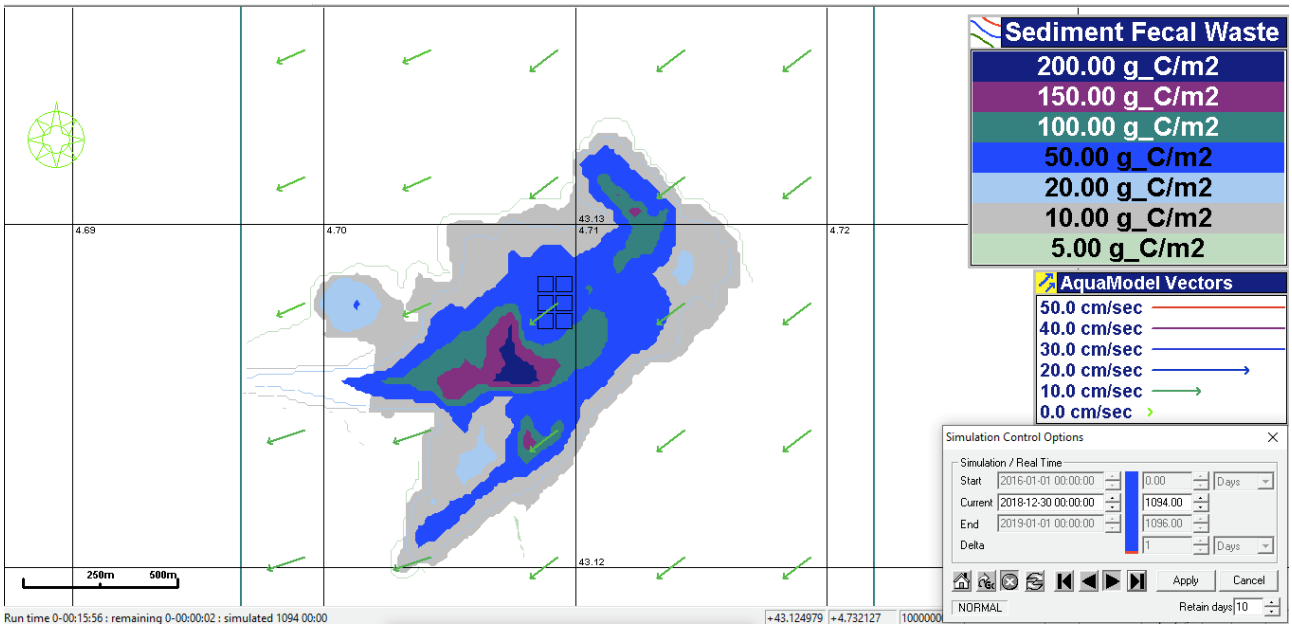


Figure 191: Fecal wastes; date December, 3rd year

The consolidated wastes

The following maps report the percentage of carbon into the sediment that has entered a depositional state and remain into the sediment, likely to undertake benthic decomposition.

This map has to be intended as dynamically calculated, and is displayed the result of the balance between continuous continuous consolidation of total carbon and its benthic removal. Snapshots are displayed at a rate of four/year, at month 6, 9, 12, 15, 18, 21, 24, 27,30, 33, 36, starting from the first date when consolidation appears. Current vectors are referred at 22,5m of depth, below BGF platform at maximum current exposition of nets. Cages are outlined at the center of map.

Figure 192: Consolidated wastes; date June, 1st year

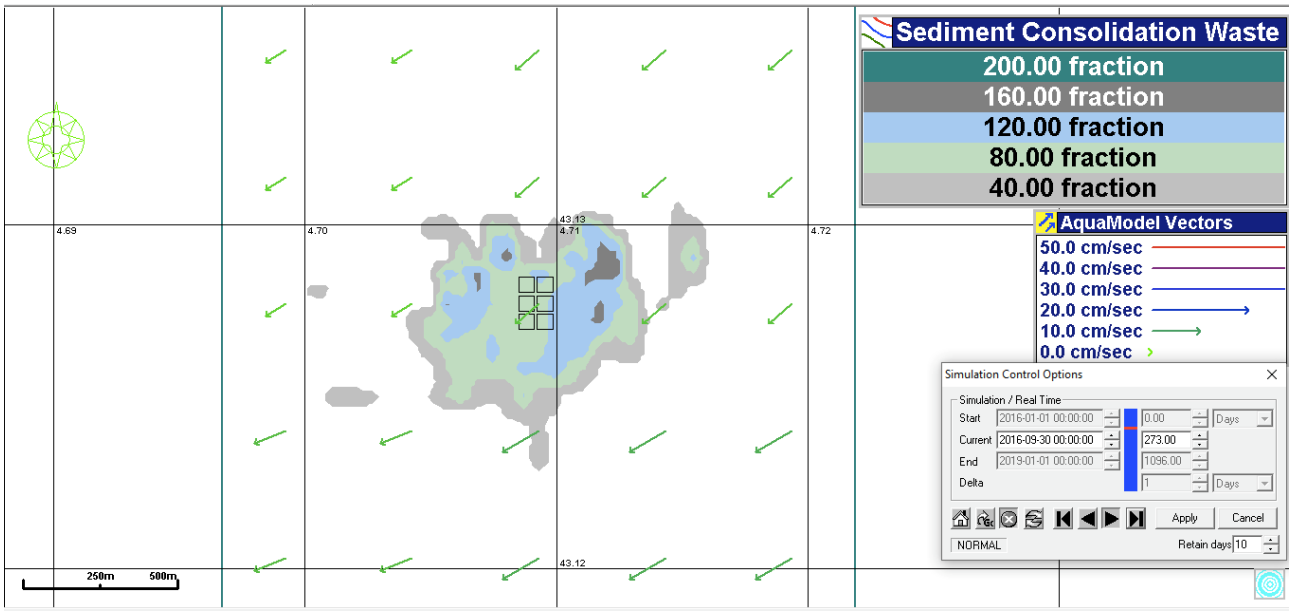


Figure 193: Consolidated wastes; date September, 1st year

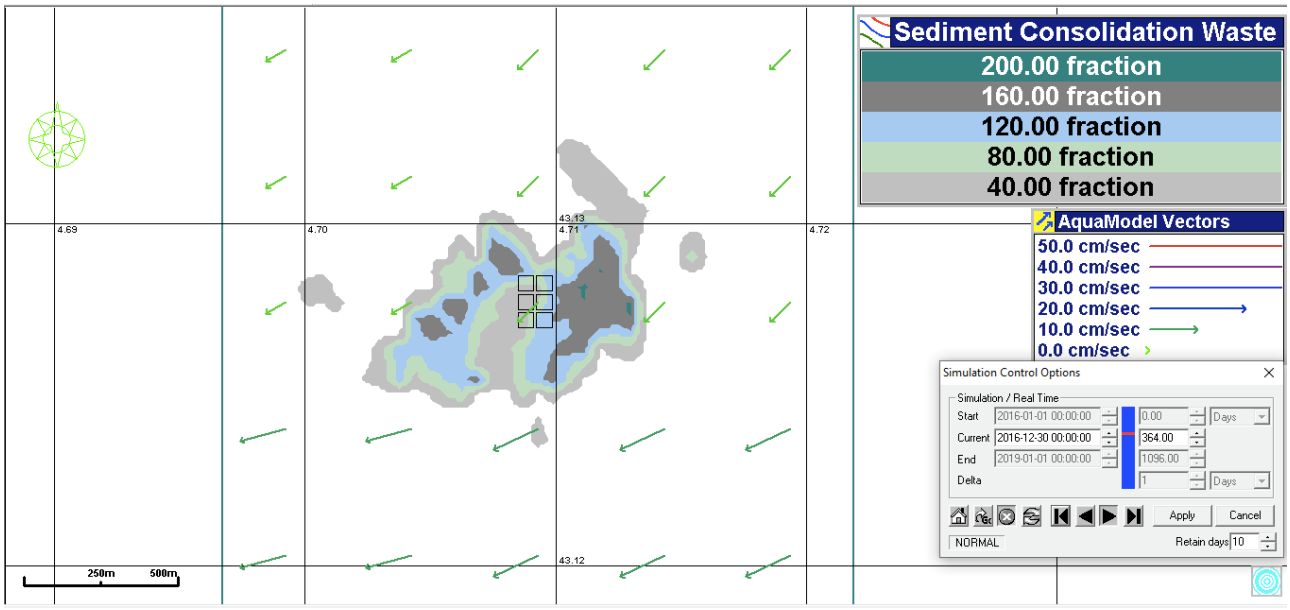


Figure 194: Consolidated wastes; date December, 1st year

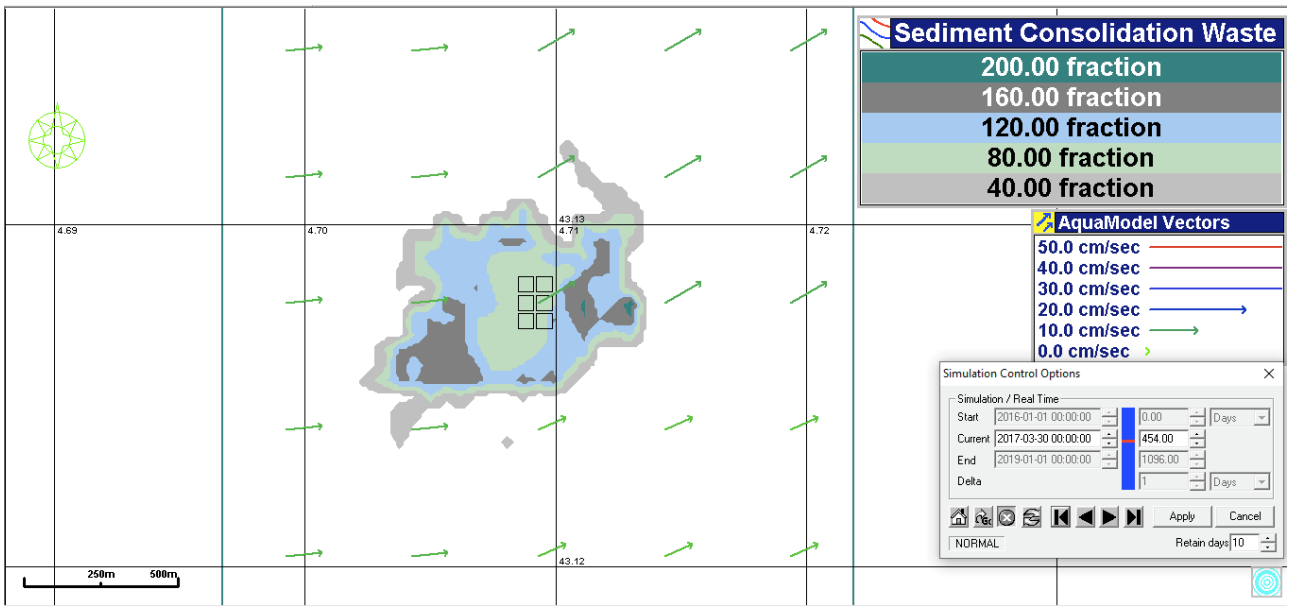


Figure 195: Consolidated wastes; date March, 2nd year

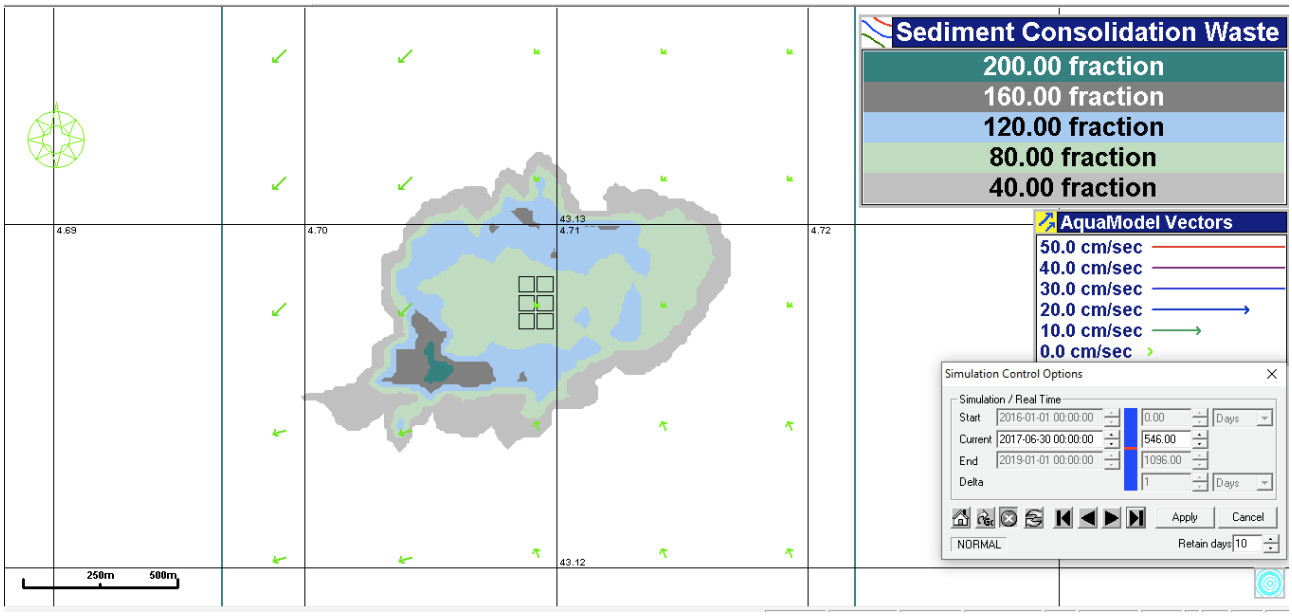


Figure 196: Consolidated wastes; date June, 2nd year

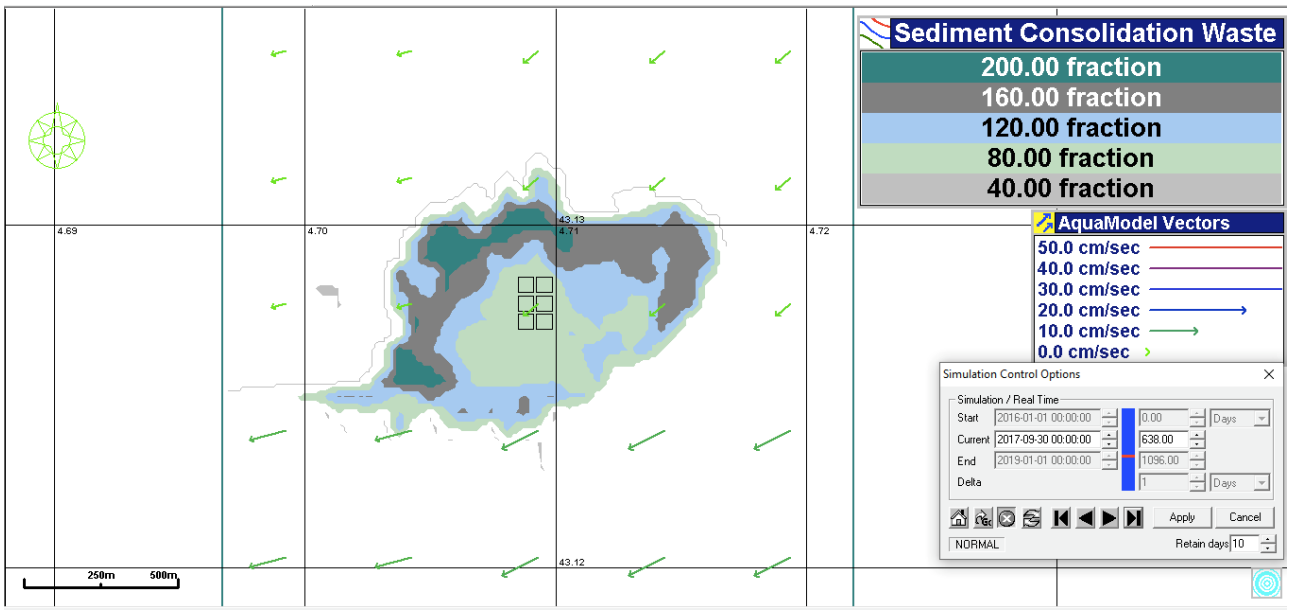


Figure 197: Consolidated wastes; date September, 2nd year

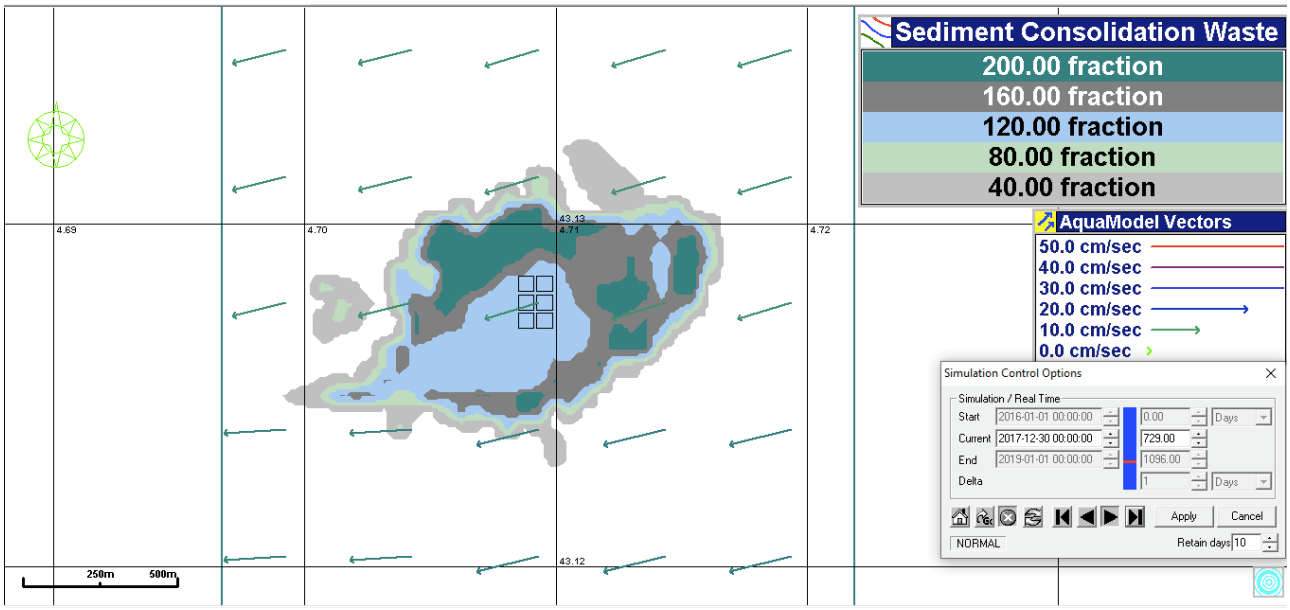


Figure 198: Consolidated wastes; date December, 2nd year

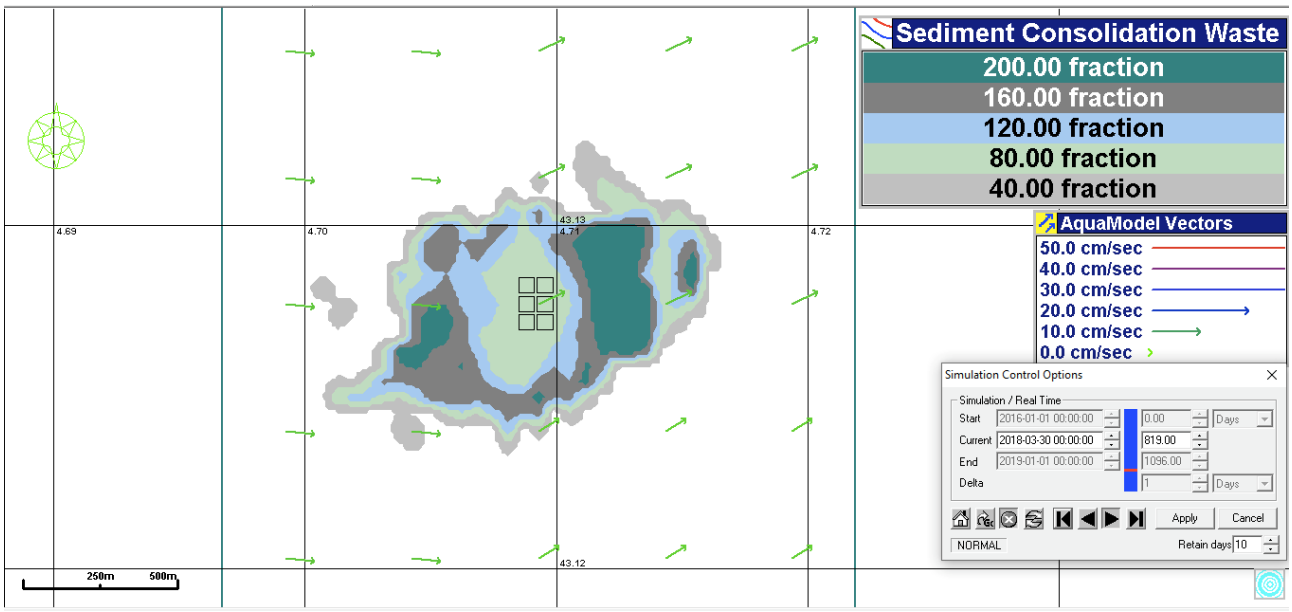


Figure 199: Consolidated wastes; date March, 3rd year

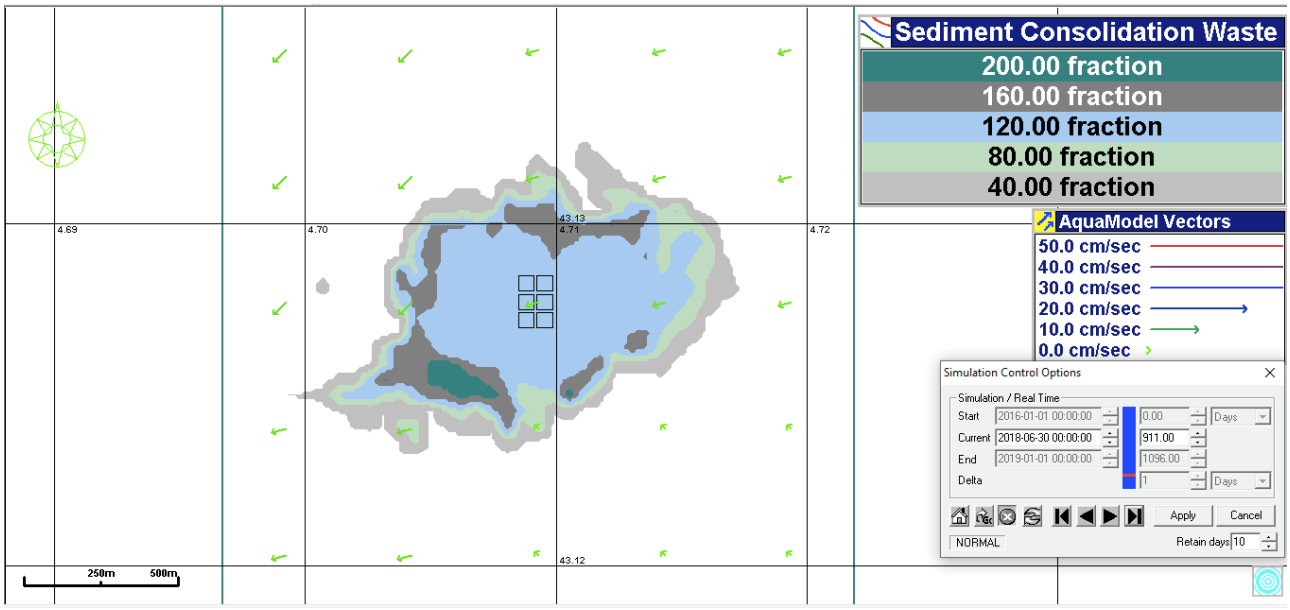


Figure 200: Consolidated wastes; date June, 3rd year

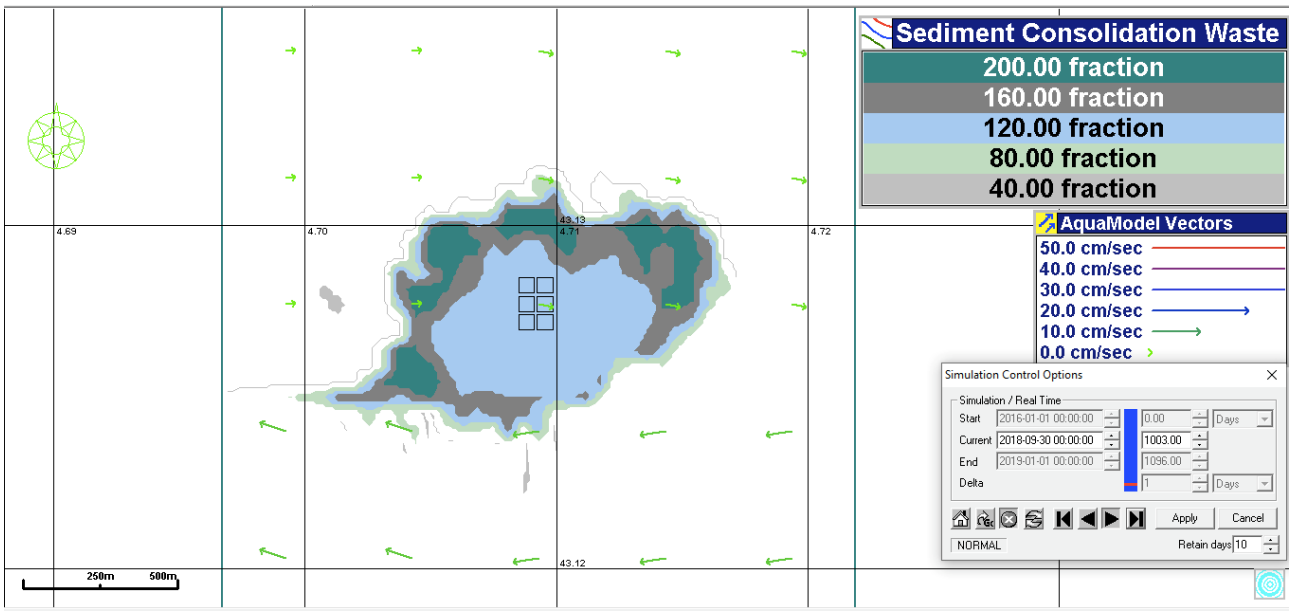


Figure 201: Consolidated wastes; date September, 3rd year

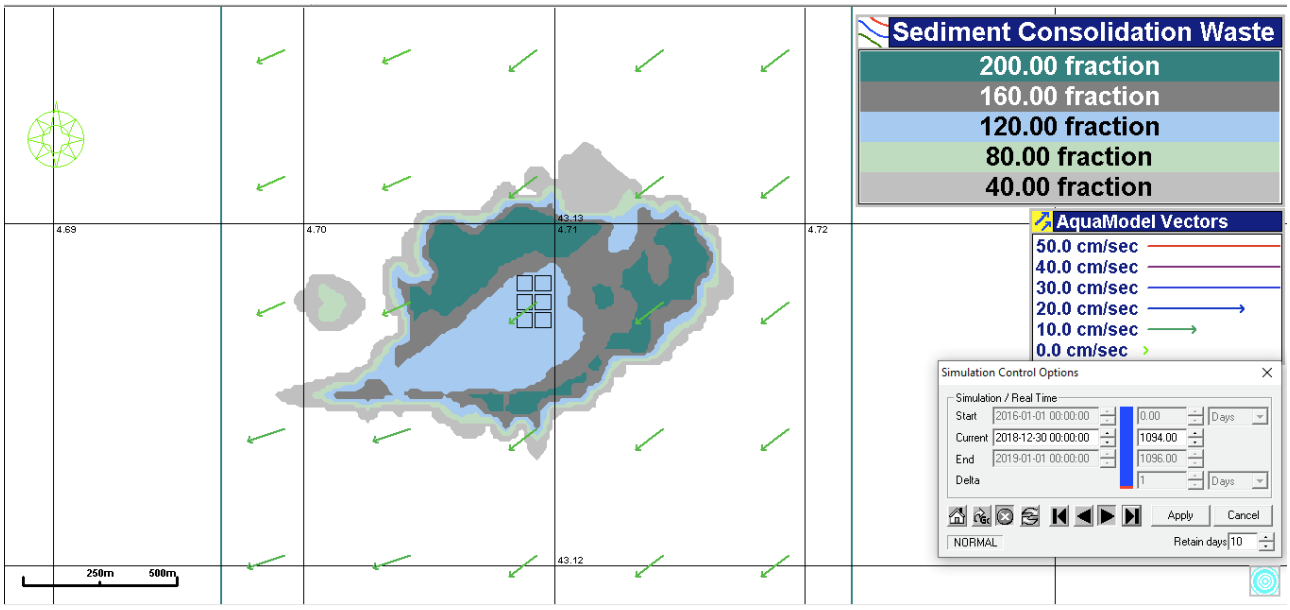


Figure 202: Consolidated wastes; date December, 3rd year

The anaerobic carbon

The following maps report the mass of total carbon into the sediment that has entered into an anaerobic process and is likely to undertake benthic decomposition in absence of oxygen.

This map has to be intended as dynamically calculated, and is displayed the result of the balance between continuous deposition of total carbon and its benthic removal. Snapshots are displayed at a rate of four/year, at month 6, 9, 12, 15, 18, 21, 24, 27,30, 33, 36, starting from the first date when consolidation appears. Current vectors are referred at 22,5m of depth, below BGF platform at maximum current exposition of nets. Cages are outlined at the center of map.

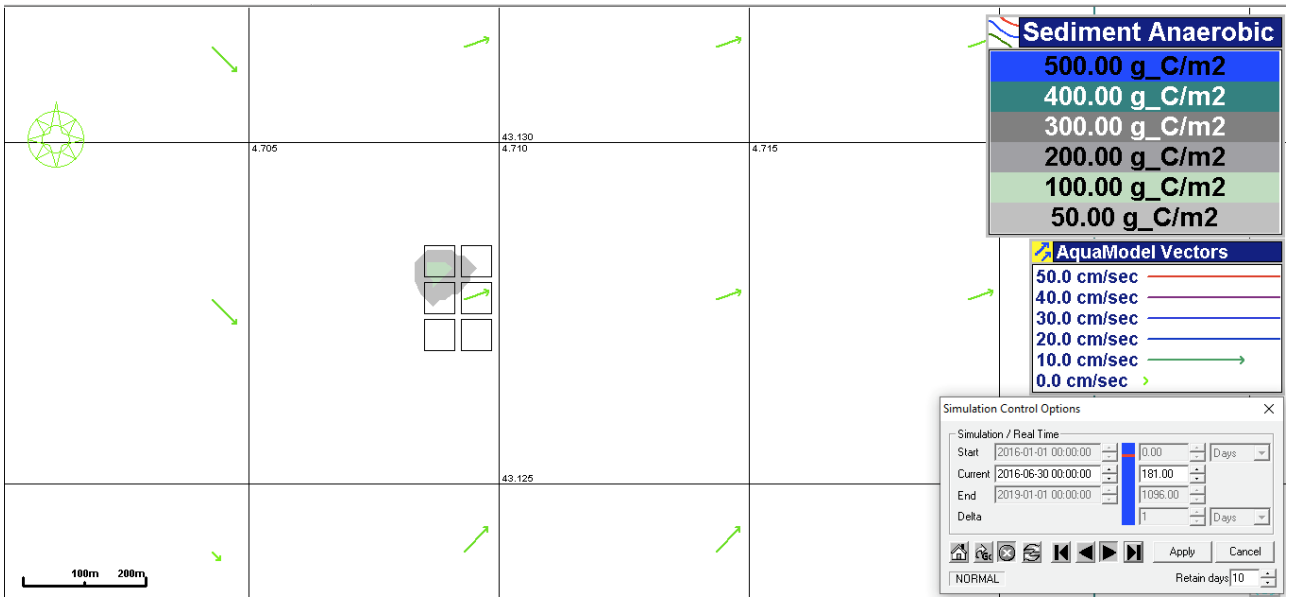


Figure 203: Anaerobic carbon; date June, 1st year

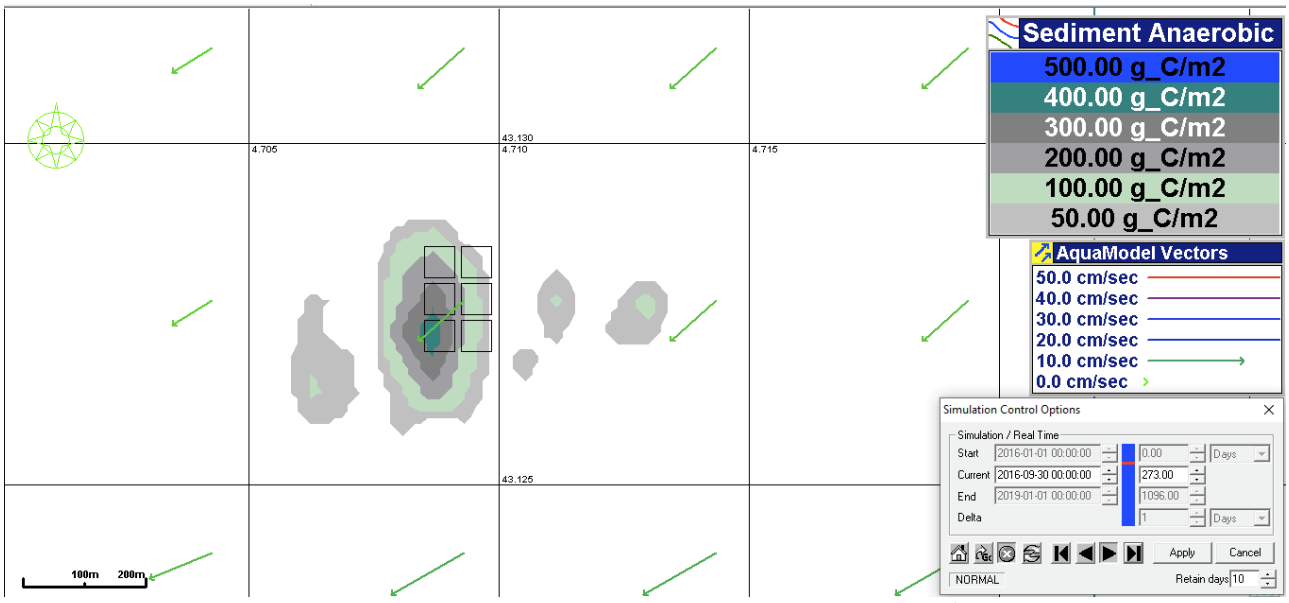


Figure 204: Anaerobic carbon; date September, 1st year

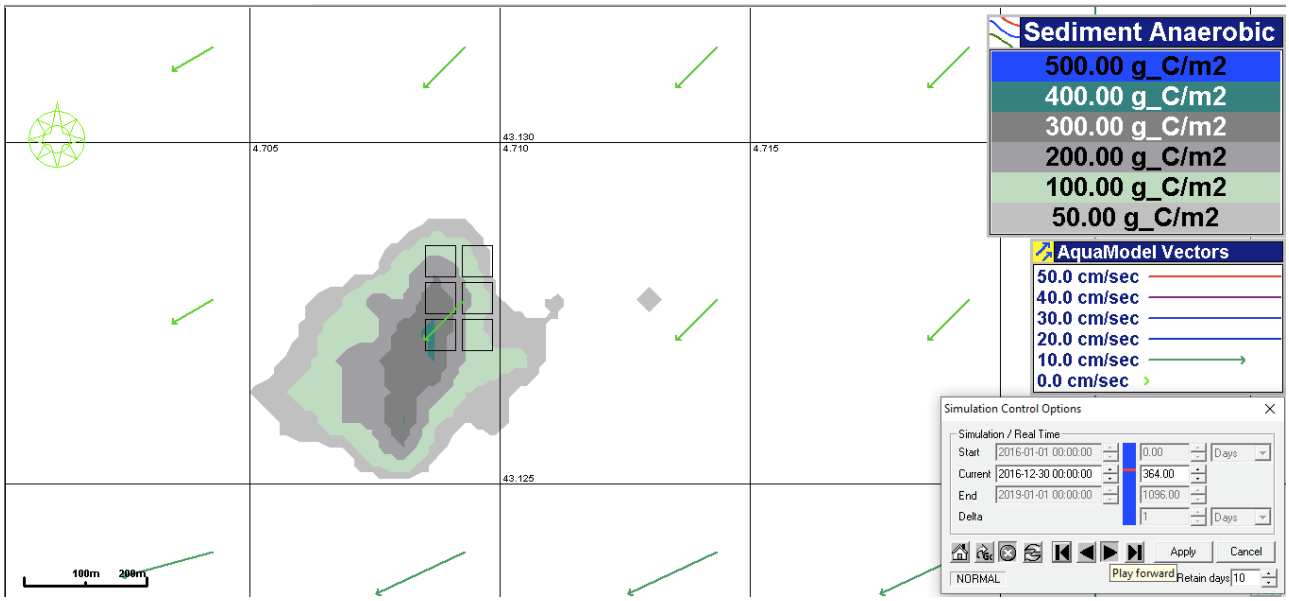


Figure 205: Anaerobic carbon; date December, 1st year

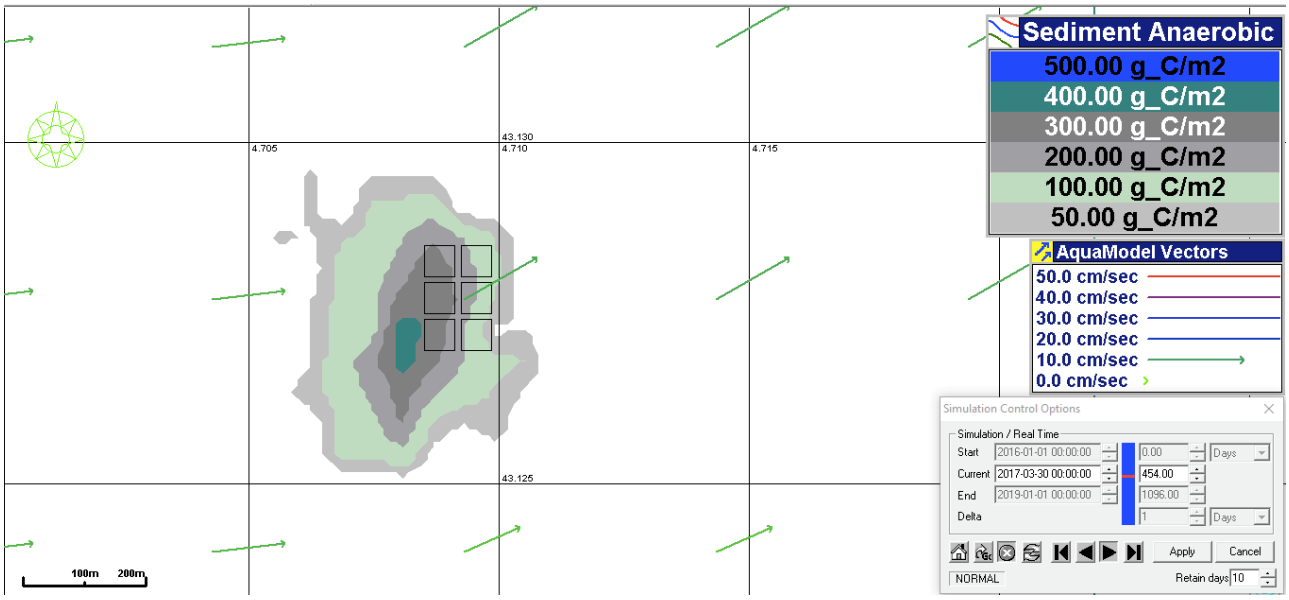


Figure 206: Anaerobic carbon; date March, 2nd year

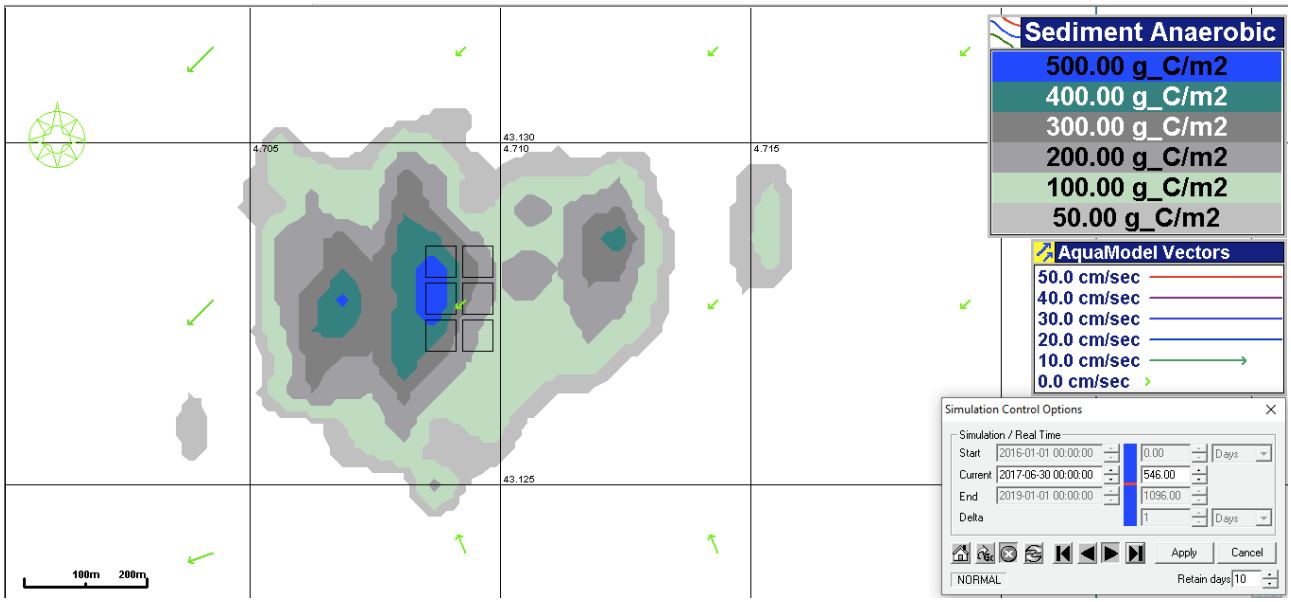


Figure 207: Anaerobic carbon; date June, 2nd year

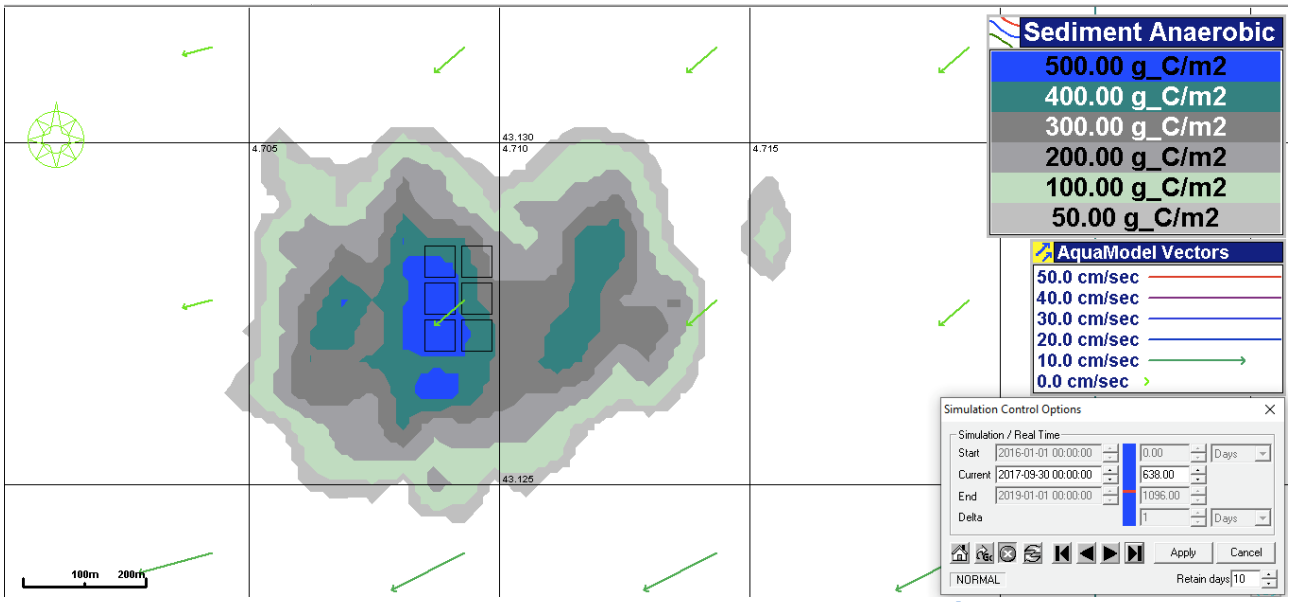


Figure 208: Anaerobic carbon; date September, 2nd year

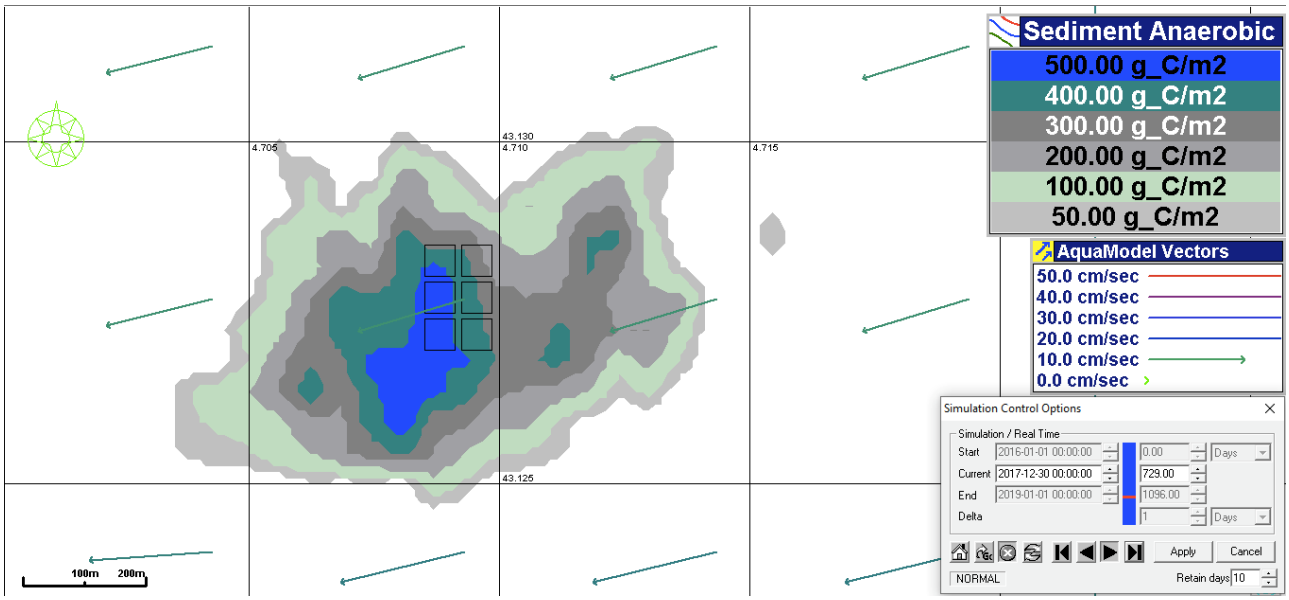


Figure 209: Anaerobic carbon; date December, 2nd year

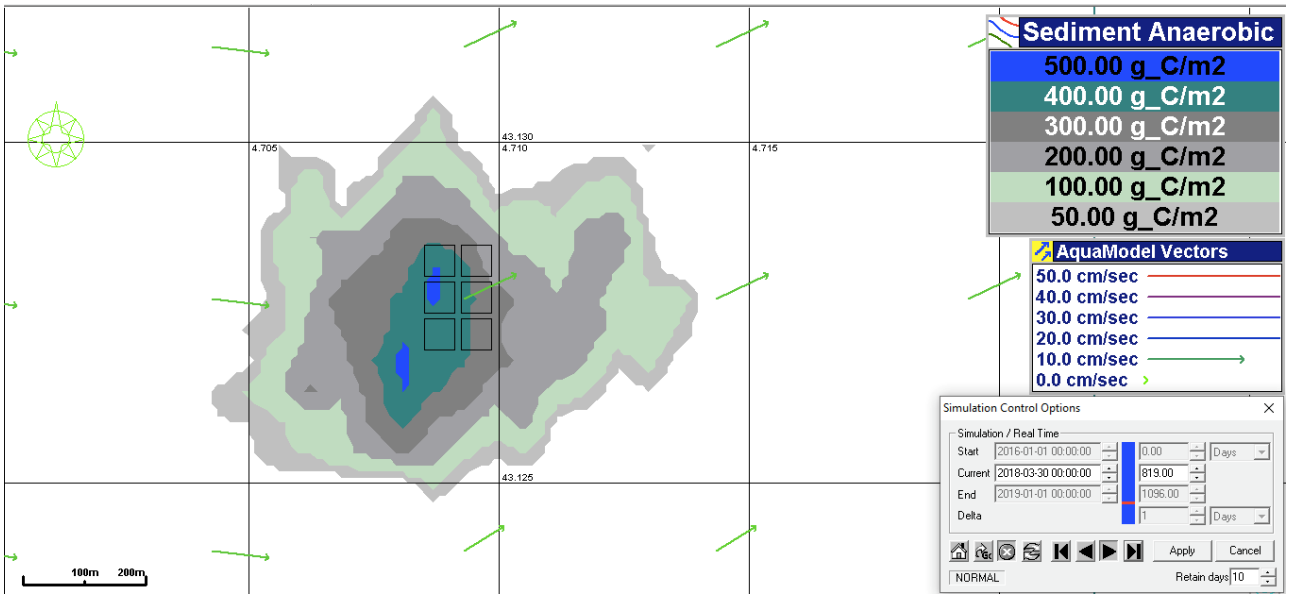


Figure 210: Anaerobic carbon; date March, 3rd year

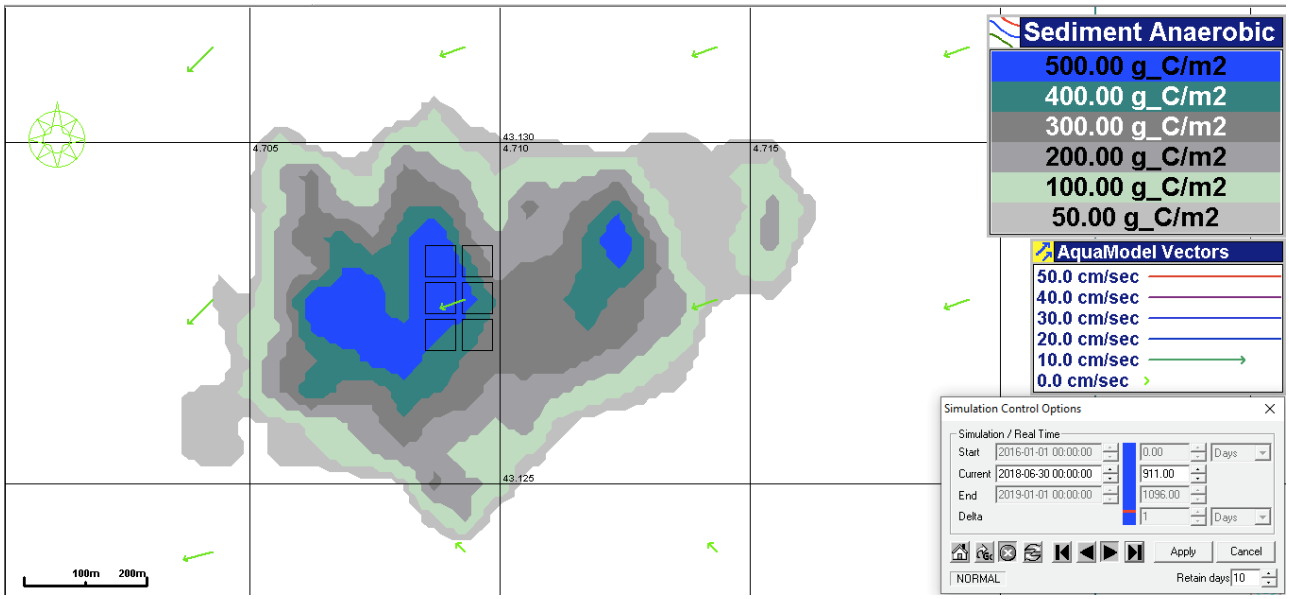


Figure 211: Anaerobic carbon; date June, 3rd year

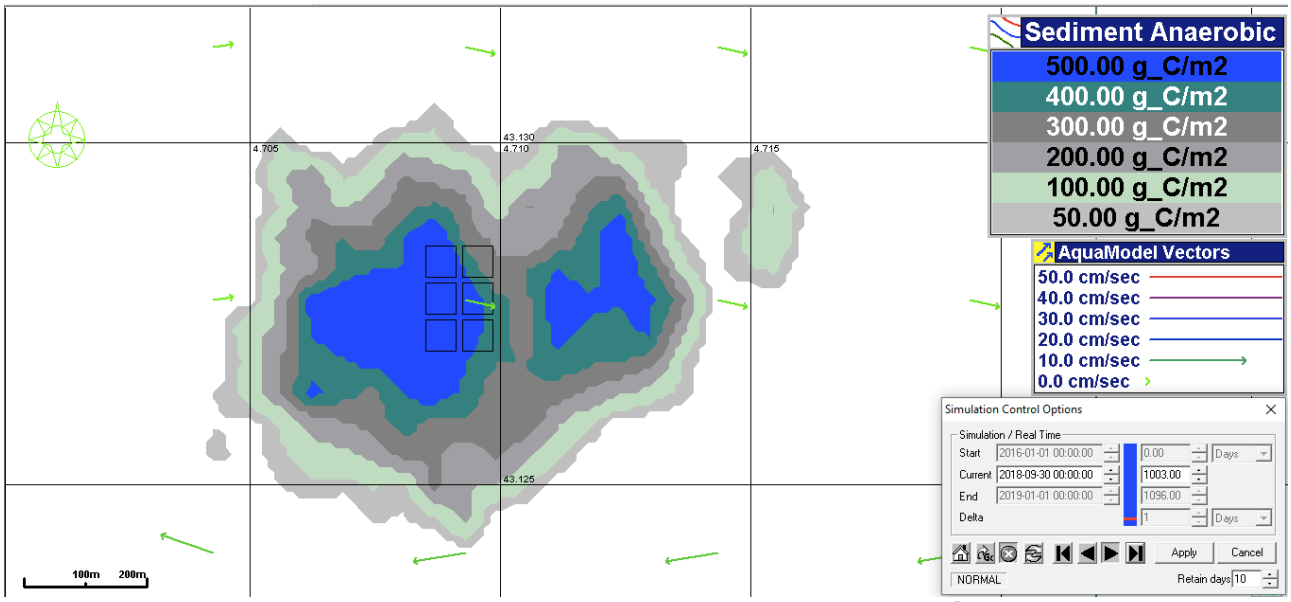


Figure 212: Anaerobic carbon; date September, 3rd year

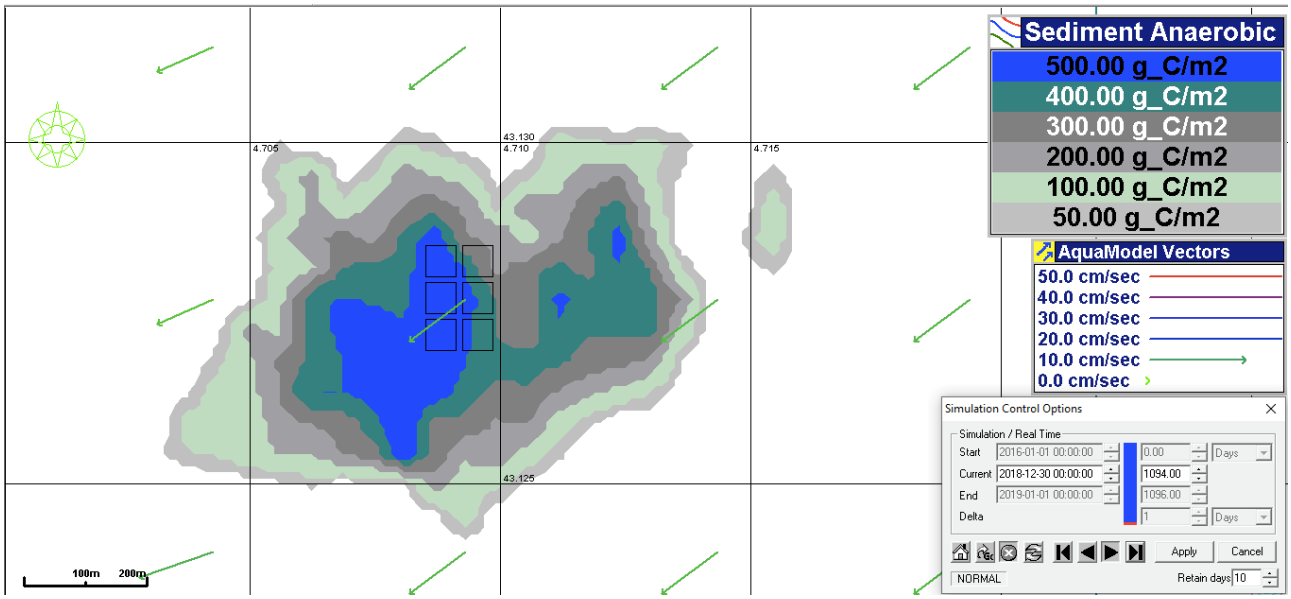


Figure 213: Anaerobic carbon; date December, 3rd year

The TOC Total Organic Carbon

The following maps report the fraction of total organic carbon present into the sediment. This map has to be intended as the overall organic carbon presence, resulting from a balance between depositional and benthic respiration processes. In other words, these maps represent the final results of depositional minus respiration processes, and diplay the carbon standing stock, thus summarizing the modification of benthic features due to aquaculture activities.

Snapshots are displayed at a rate of four/year, at month 6, 9, 12, 15, 18, 21, 24, 27,30, 33, 36, starting from the first date when TOC appears. Current vectors are referred at 22,5m of depth, below BGF platform at maximum current exposition of nets. Cages are outlined at the center of map.

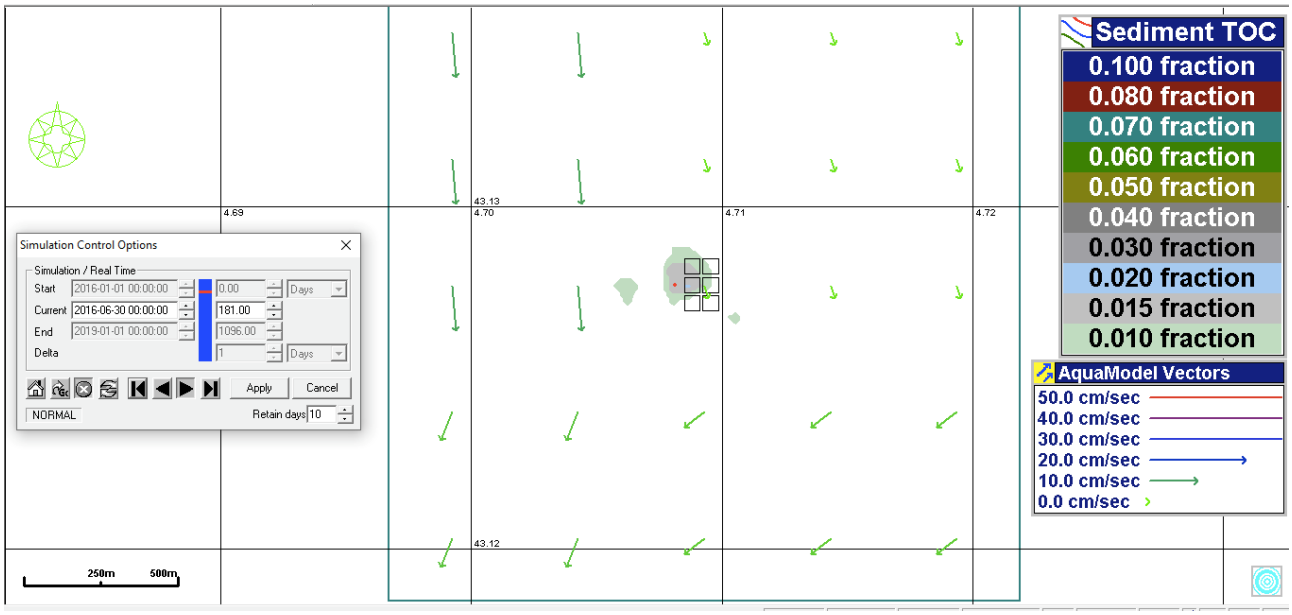


Figure 214: Total Organic Carbon; date June, 1st year

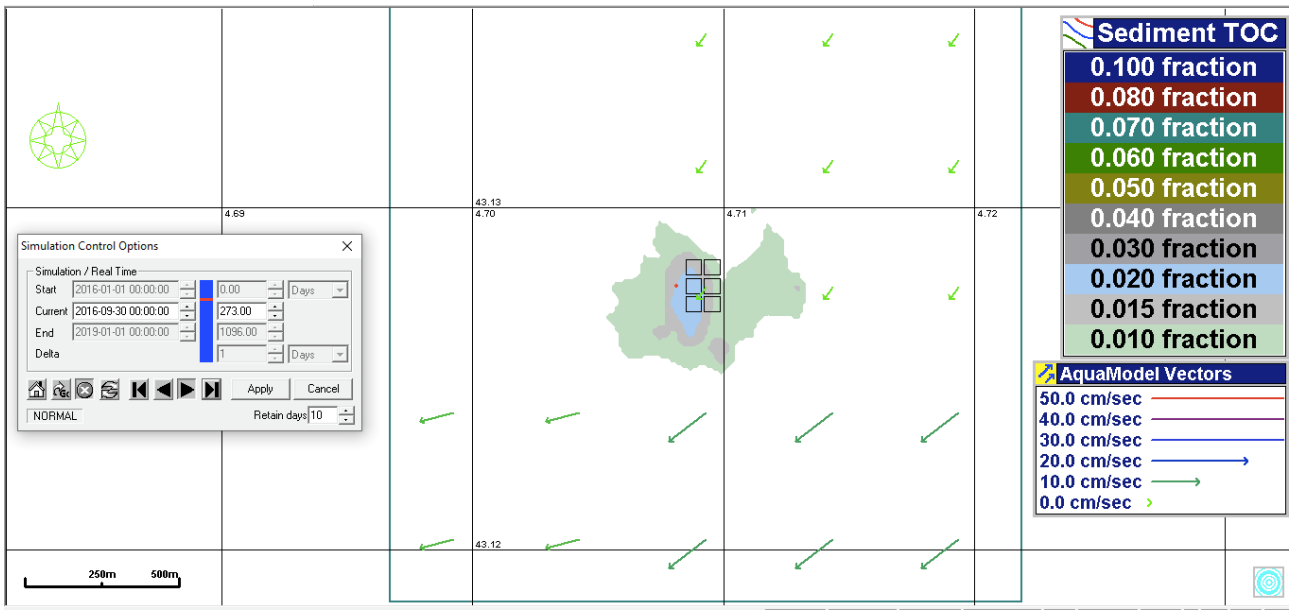


Figure 215: Total Organic Carbon; date September, 1st year

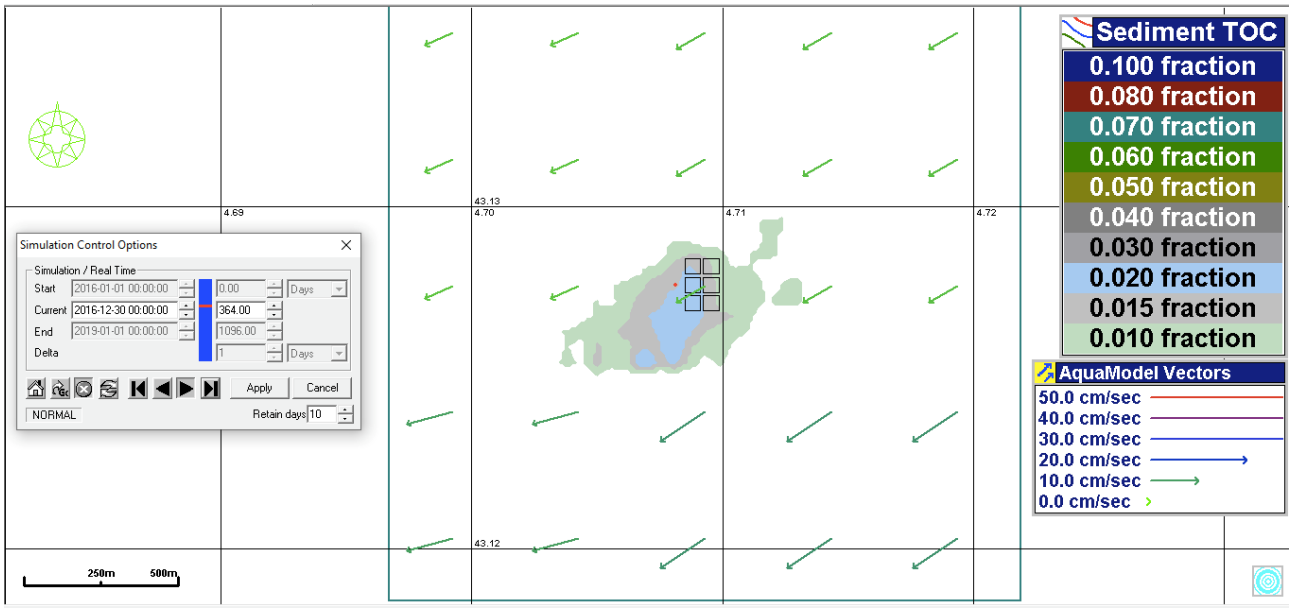


Figure 216: Total Organic Carbon; date December, 1st year

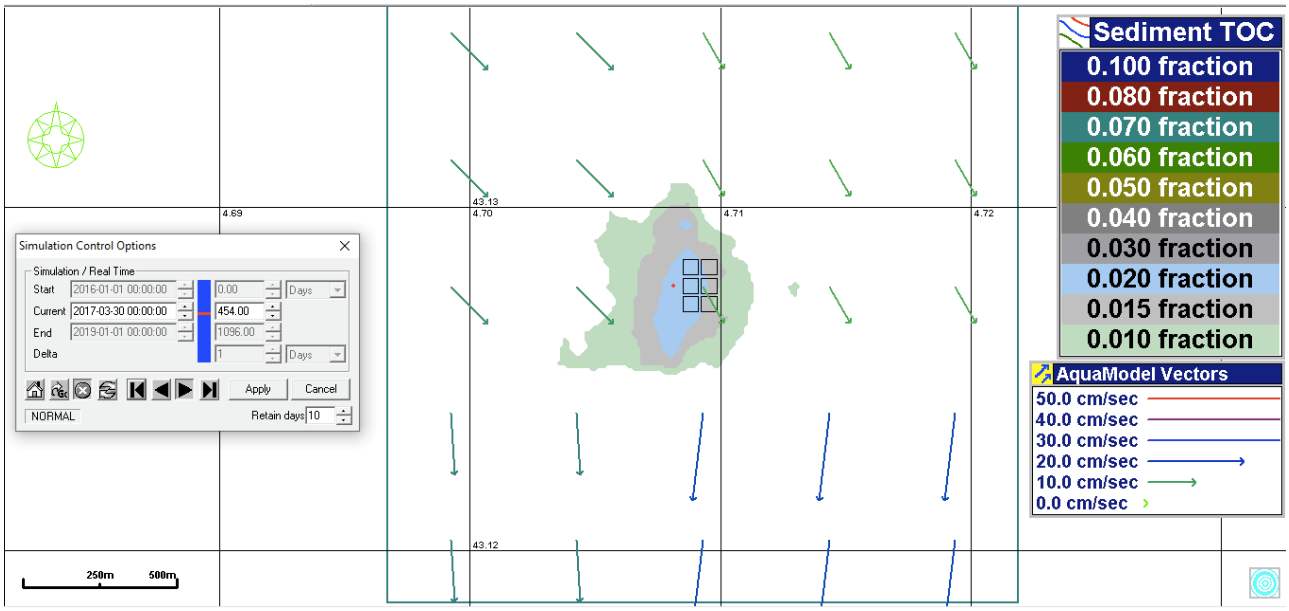


Figure 217: Total Organic Carbon; date March, 2nd year

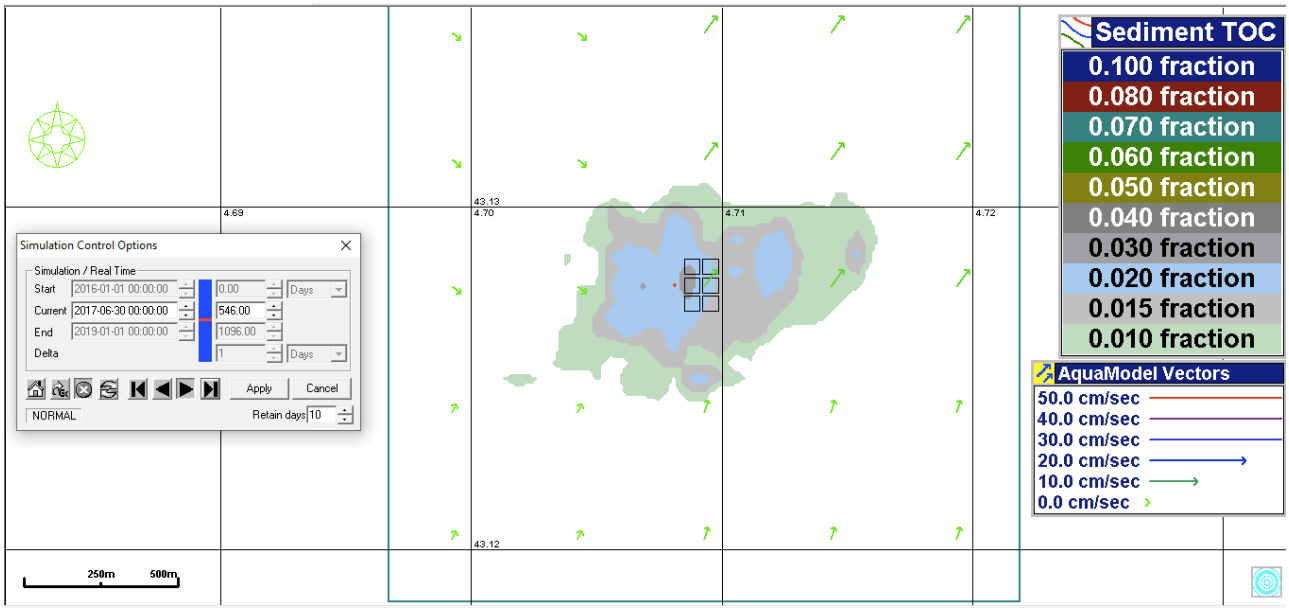


Figure 218: Total Organic Carbon; date June, 2nd year

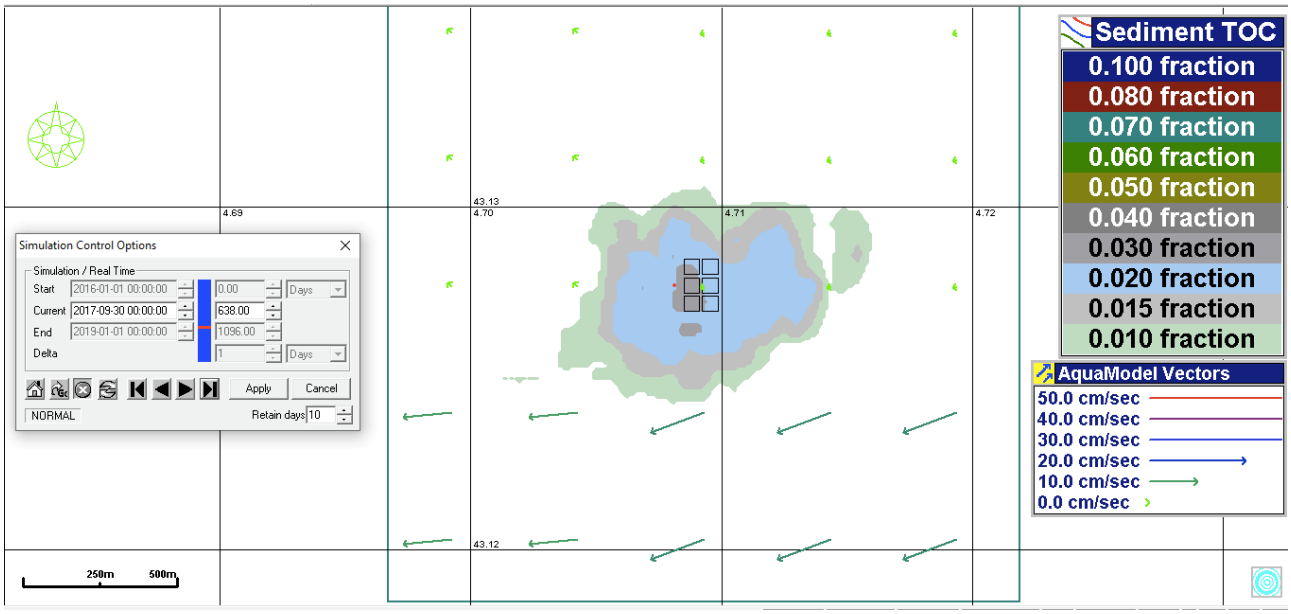


Figure 219: Total Organic Carbon; date September, 2nd year

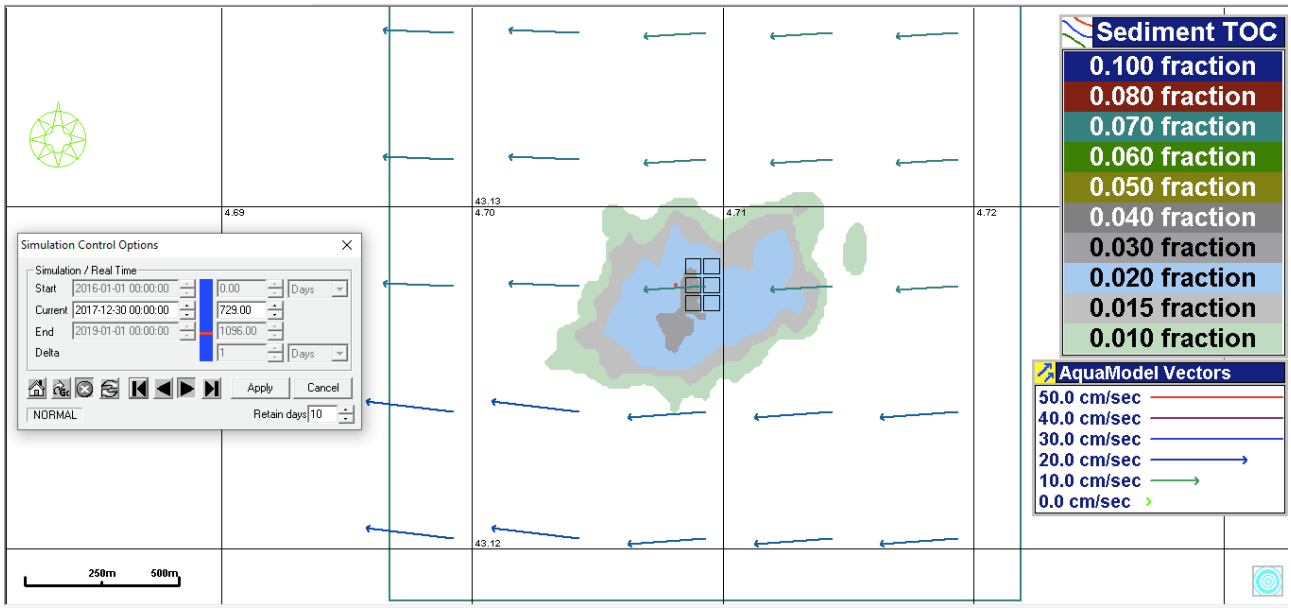


Figure 220: Total Organic Carbon; date December, 2nd year

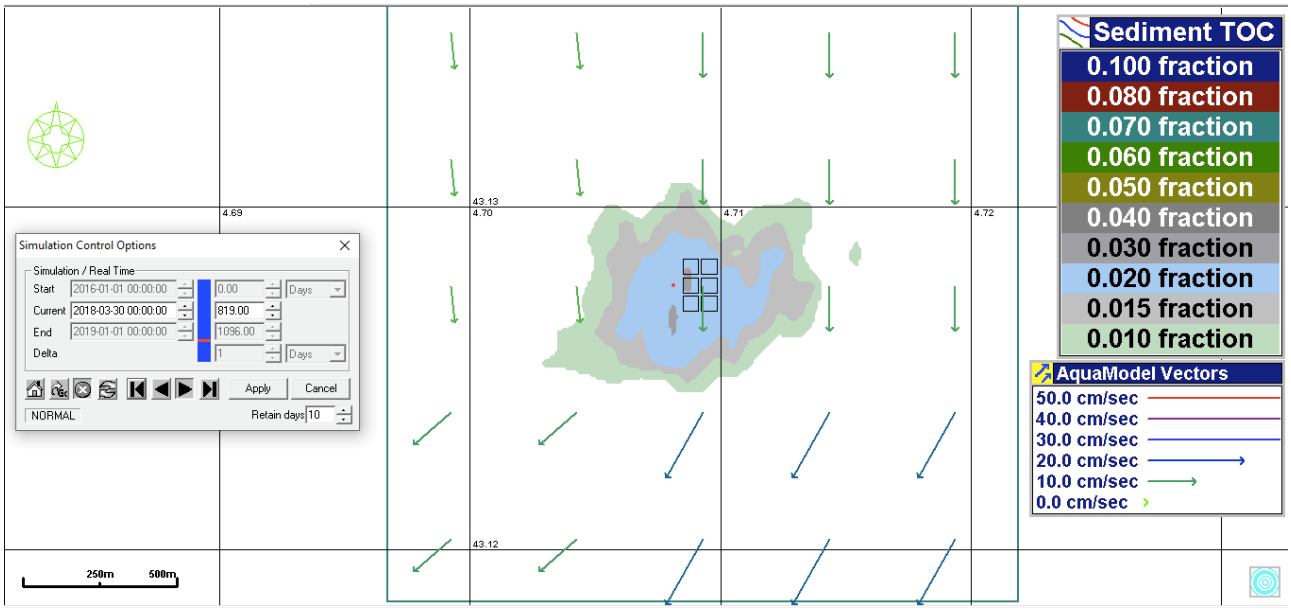


Figure 221: Total Organic Carbon; date March, 3rd year

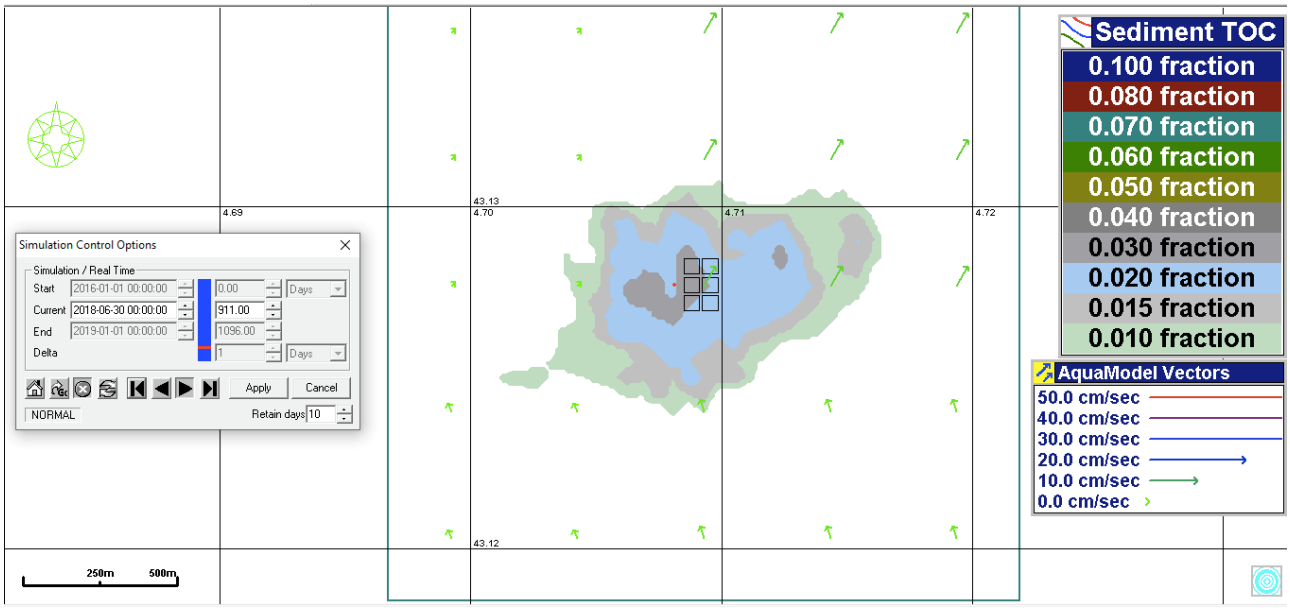


Figure 222: Total Organic Carbon; date June, 3rd year

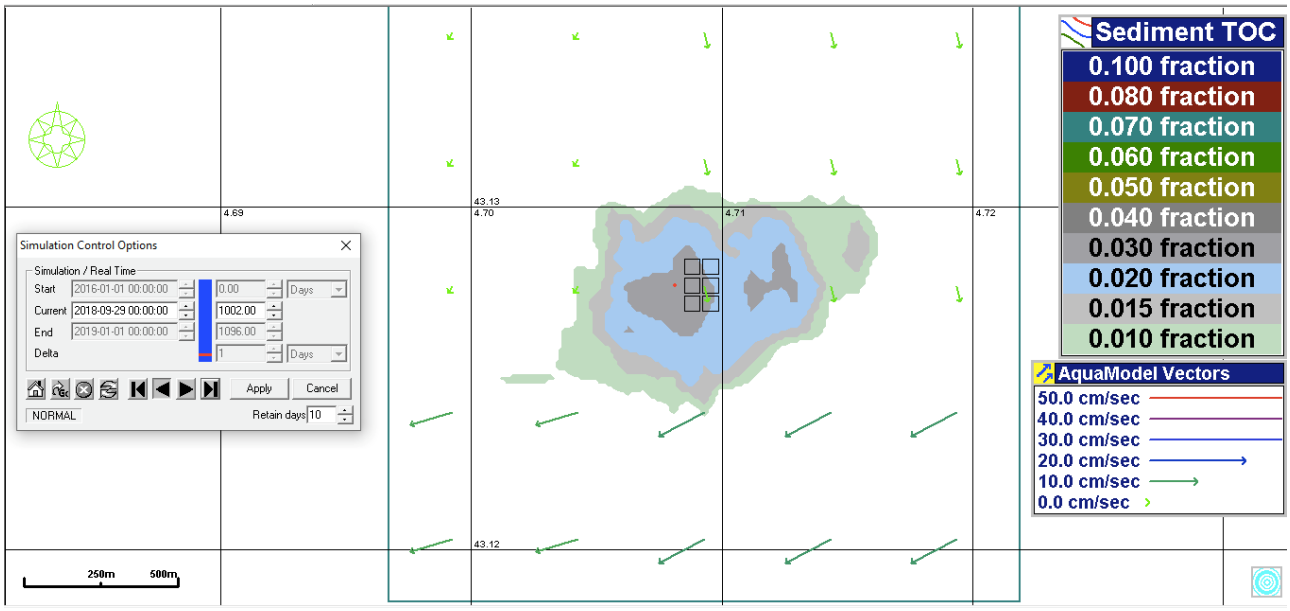


Figure 223: Total Organic Carbon; date September, 3rd year

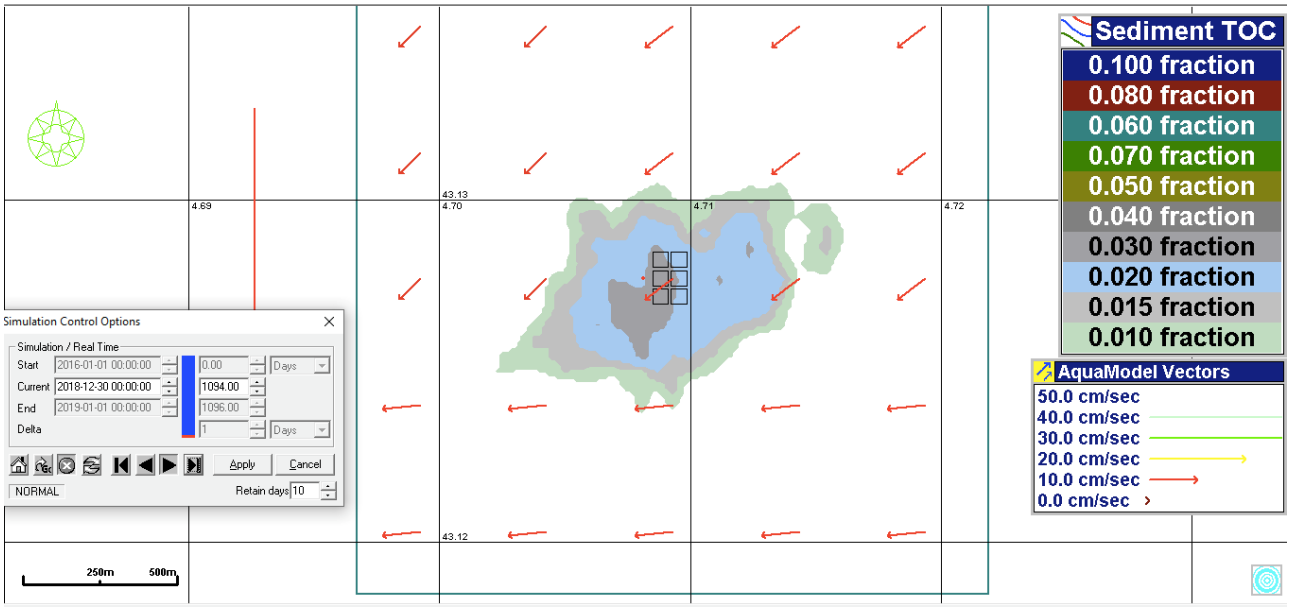


Figure 224: Total Organic Carbon; date December, 3rd year

Benthos sensitivity

Plains of fine mud in the circalittoral belt may be heavily bioturbated by burrowing megafauna; burrows and mounds may form a prominent feature of the sediment surface with conspicuous populations of sea pens, typically *Virgularia mirabilis* and *Pennatula phosphorea*. These soft mud habitats occur extensively throughout the more sheltered basins or at the river mouths, at depth over 20 m. The burrowing Crustacea present typically include *Nephrops norvegicus*, which is frequently recorded from surface observations although grab sampling may fail to sample this species. The urchin Brissopsis lyrifera and the brittlestar Amphiura chiajei can also characterize mud in circalittoral waters. Where intense benthic dredge fishing activity occurs, populations of *Brissopsis lyrifera* may be depressed. Infaunal species in this community include the polychaetes *Nephtys hystricis, Pectinaria belgica, Glycera* spp. and *Lagis koreni* and the bivalves *Myrtea spinifera* and *Nucula sulcata*.

The characterizing and other species in this biotope occupy space in the habitat but their presence is most likely primarily determined by the occurrence of a suitable substratum rather by interspecific interactions. Sea pens and burrowing megafauna are functionally and ecologically dissimilar and are not necessarily associated with each other but occur in the same muddy sediment habitats. It is possible that sea pens might be adversely affected by high levels of megafaunal bioturbation, perhaps by preventing the survival of newly settled colonies. *Brissopsis lyrifera* and *Amphiura chiajei* are functionally dissimilar and are not necessarily associated with each other but for their occurrence in the same muddy sediments.

No single species can be considered a keystone species whose activity is essential to the structure of the community. In addition to sea pens and burrowing megafauna, the biotope often supports a rich fauna of smaller less conspicuous species, such as polychaetes, nematodes and bivalves, living within the sediment.

The species living in deep mud biotopes are generally cryptic in nature. Predation is probably low because many species will be sheltered to some extent from visual surface predators such as fish. Evidence of predation on Virgularia mirabilis by fish seems limited and the species was found in the stomach of haddock. Many specimens of Virgularia mirabilis lack the uppermost part of the colony, which has been attributed to nibbling by fish. The sea slug Armina loveni is a specialist predator of Virgularia mirabilis. However, the arm tips of *Amphiura chiajei* are an important food source for demersal fish and *Nephrops norvegicus* providing significant energy transfer to higher trophic levels. *Nephrops norvegicus* is eaten by a variety of bottom-feeding fish, including cod, haddock, skate and lesser-spotted catshark (dog fish). *Nephrops norvegicus* is carnivorous, feeding on brittle stars, polychaetes and other crustaceans such as Calocaris macandreae.

Bioturbation is particularly important in controlling chemical, physical and biological processes in marine sediments, especially when the influences of physical disturbances such as wave action or strong currents are minimized (Widdicombe & Austen, 1999). The turnover rate of sediment by *Brissopsis lyrifera* was estimated to be 8.0 cm^2 per hour, thus it is likely that *Brissopsis lyrifera* plays an important role in the enhancement of species heterogeneity in an otherwise largely homogenous environment. *Brissopsis lyrifera* is reported to increase meiobenthic species abundance and diversity and have a density dependent effect upon the community structure of meiobenthic nematode communities. The presence of *Brissopsis lyrifera* also significantly influenced nutrient fluxes of nitrogen and phosphorus at the sediment-water interface, owing to its burrowing activity promoting oxygenation of the substrata. The burrowing and feeding activities of *Brissopsis lyrifera* and *Amphiura chiajei* and other macrofauna, are likely to modify the fabric and increase the mean particle size of the upper layers of the substrata by aggregation of fine particles into faecal pellets. Such alteration of the substratum surface can affect rates of particle resuspension.

The biotope has little structural complexity above the sediment surface. Burrows and mounds of burrowing megafauna may form a prominent feature of the sediment surface with conspicuous populations of sea pens. However, dense populations of burrowers create considerable structural complexity, below the surface, relative to sediments lacking these animals. For example, Callianassa subterranea creates complex burrow systems in sandy mud sediments. The burrows consist of a multi-branched network of tunnels connected to several inhalent shafts, each terminating in a funnel shaped opening to the surface. These burrows allow a much larger surface area of sediment to become oxygenated, and thus enhance the survival of a considerable variety of small species (Pearson & Rosenberg, 1978). Burrows also create habitats for other animals such as clams and polychaetes. Burrows are also created by other crustacean species such as Nephrops norvegicus and Calocaris macandreae although these are not as complex as those of Callianassa.

The bioturbatory activities have important consequences for the structural characteristics of the sediment. Bioturbatory activities of deposit feeding genera such as Nucula and Pectinaria will also actively increase the rate of oxygen diffusion through finer sediments (Pearson & Rosenberg, 1978). Many infaunal species are limited to the upper oxygenated layer, however, others penetrate deeper in irrigated burrows or possess long siphons capable of transporting oxygenated water into the sediment, which may result in an oxygenated layer around their burrows.

The redistribution of organic matter within the sediment by effective bioturbating species, such as the shallower burrowing Nephrops norvegicus, will influence depth distribution and community structure as well. However, the activities of the larger burrowers can either enhance or reduce the overall abundance of sediment macrofauna, depending on the species involved. Megafaunal activity creates a mosaic of disturbance patches, which may be important to the maintenance of biodiversity in the sediment community (Hughes, 1998b).

The burrowing and feeding activities of Amphiura spp., if present in high abundance, can modify the fabric and increase the mean particle size of the upper layers of the substrata by aggregation of fine particles into faecal pellets. Such actions create a more open fabric with higher water content which affects the rigidity of the seabed (Rowden et *al*., 1998). Such destabilisation of the seabed can affect rates of particle resuspension.

The arms of *Amphiura spp*. are an important food source for demersal fish and Nephrops norvegicus, providing significant energy transfer to higher trophic levels including to humans. Increased nutrients and eutrophication processes may contribute to an increase in the accumulation of hydrophobic contaminants in Amphiura filiformis and their transfer to higher trophic levels (Gunnarsson & Skold, 1999).

In their investigation of density dependent migration in Amphiura filiformis Rosenberg et *al*. (1997) calculated that in areas of high density of the species (3000 individuals per m^2), the area of sediment at about 3 to 4 cm depth covered by disks of Amphiura spp. could be estimated as 22%. The capacity of such a density of brittle stars to displace sediment can be calculated at $0.18m^2$ per hour. Thus, movement of Amphiura spp. should generate a more or less continuous displacement of sediment and be of great significance to the biogeochemical processes in the sediment.

The hydrodynamic regime determines whether a biotope exists in a particular place by allowing deposition of fine sediment. The hydrography also affects the water characteristics in terms of salinity, temperature and dissolved oxygen. It is also widely accepted that food availability (Rosenberg, 1995) and disturbance, such as that created by storms, (Hall, 1994) are also important factors determining the distribution of species in benthic habitats. Seapen and burrowing megafaunal communities appear to persist over long periods at the same location. Species such as the sea pen Virgularia mirabilis, the brittle star Amphiura spp. appear to be long-lived and are unlikely to show any significant seasonal changes in abundance or biomass. The numbers of some of the other species in the biotope may show peak abundances at certain times of the year due to the seasonality of breeding and larval recruitment.

There are daily patterns of activity in some species. Nephrops norvegicus, for example, forages for food at night, returning to their burrows at sunrise. However, in deeper water (> 100m) this activity is reversed suggesting that activity is determined by light intensity. The echiuran Maxmuelleria lankesteri has been observed to feed only at night and so activity may also be related to light intensity. Movement of the sea pen Virgularia mirabilis in and out of the sediment may be influenced by tidal conditions (Hoare & Wilson, 1977).

Productivity in subtidal sediments is often quite low. Macroalgae are absent and so productivity is mostly secondary, derived from detritus and organic material. However, some shallower sites can have an extensive growth of benthic diatoms in the summer. Allochthonous organic material is derived from anthropogenic activity (e.g. sewerage) and natural sources (e.g. plankton, detritus). Autochthonous organic material is formed by benthic microalgae (microphytobenthos e.g. diatoms

and euglenoids) and heterotrophic micro-organism production. Organic material is degraded by micro-organisms and the nutrients are recycled. The high surface area of fine particles provides surface for microflora.

Time for community to reach maturity

There is very little known about community development for this biotope. Almost nothing is known about the life cycle and population dynamics of sea pens, but data from other species suggest that they are likely to be long-lived and slow growing with patchy and intermittent recruitment. The burrowing decapods that characterise the biotope vary in their reproductive strategies and longevity.

Amphiura chiajei is a long-lived species. Particular cohorts (resultant of a dense and successful larval settlement) may dominate an area for over 10 years and is unlikely to show any significant regular seasonal change in abundance or biomass. However, populations of *Amphiura chiajei* seem to be periodically affected by winter cold, at least in communities of British islands.

Many of the other species in the biotope, such as polychaetes and bivalves, are likely to reproduce annually, be shorter lived and reach maturity much more rapidly. Since most key species reproduce regularly but take a while to grow, recruitment will be rapid but it will take several years to reach maturity and so it will probably take at least five years for the overall community to reach maturity.

This community supports a rich infauna of polychaetes, bivalves, burrowing sea urchins, brittlestars, and sea cucumbers, and a mobile epifauna of crabs and starfish. While the infaunal species composition varies between the biotopes, the infaunal and mobile epifaunal community is probably found across a range of circalittoral mud and deep mud habitats.

Therefore, the sensitivity assessment concentrates on the epifaunal, suspension feeding, sea pens, because a significant reduction in their abundance would result in the loss of the main biotope features.

Organic enrichment

Virgularia is not tolerant to high organic loads, but can be present in sediment up to 5% of organic content, while Pennatula phosphorea is inversely correlated to high organic loads.

Burrowing megafauna is abundant in areas with sediment rich in organic matters, and in proximity of organic source a gradient of polychaete deposit feeder is known, declining the suspension feeders.

Nephrops has been fund up to a load of 4% of organic matter in sediment. In general burrowing megafauna and infauna are resistant to organic enrichment.

On the other hand, Bryssopsis lyrifera and A.chiajei are sensitive to organic enrichment
Resistance can be set at medium; low for Bryssopsys/Amphiura, resilience at low/medium and sesitivity is medium.

Deoxigenation

Virgularia mirabilis is able to tolerate some oxygen reduction, but is found absent from sewage related anoxyc areas. *Nephrops* can tolerate mild hypoxic conditions increasing aemocyanin content in blood, and in hypoxic condition specimens are forced out of their burrows.

Infaunal burrower lives in close proximity of hypoxic/anoxic muddy substrata. *Amphiura chiajei* is tolerant to hypoxia, while *A. filiformis* is less tolerant. These brittelstars expose their bodies outside sediment in low oxygen concentration, in the same way than *Bryssopsis lyrifera*, a species not resistent to hypoxia.

Under hypoxia some key species may be lost. Therfore resitance is low, resilience medium and sensitivity is medium.

Resistance is medium, as a small part of population may be lost, Resilience is low and sensitivity is medium.

Penetration/disturbance of sediment

Bryssopsis and Amphiura live close to sediment surface. Sediment smotering can displace or kill infaunal community, resulting in loss of biological organization and species richness. Resistance is low, resilience medium and sensitivity medium.

Deep sediment disturbance can be expected over a total area of **166 728** m^2, calculated from the map of seabed total waste depositions. Although anchors and the near chain part will remain deeply embedded in sediment, allowing benthos to recover after installation, the most lenght of chains will be subjected to occasional movements when heavy storms solicitate the whole mooring system. This will not allow for a benthos recovery, and a substantial percentage of the above estimated area will remain defaunated for the platform entire life.

The sediment deeply smootered by mooring chains will thus be deprived of the superficial or burrowing fauna, due to the mechanical removal action of the chains.

The deposition of fecal materials and uneaten feed on the bottom is spread on a large area, covering approximately **1 618 994** m^2. On this area a shift of the origina VTC community may be expected to more tolerant species to organic enrichment. A smaller area of **867 495** m^2, where the consolidated carbon in sediment indicates the part of the seabed where the sediment features has been modified. The area where the TOC carbon is high after and steady in time can experience a persistence modification of the community, with the disppearing of the speciesless tolerant to enrichment or to secudary oxygen depletion, in favour of a pool of opportunistic/tolerant species, mainly Polichaetes. This area can bestimated in **511675** m^2.

However, the VTC community in one of the most widespread in the mediterranea sea, and the loss of an area of **166 728** m^2, plus a modification over an additional surface of **161 894** m^2, for a total of **0,32** km^2 of affected areas, are not relevant over the whole community surface.

The species living in this community are neither rare nor protected, and with except of Nephrops norvegicus, of any commercial interest. Being very localized in space, recovery from disturbance or organic enrichment can happen by invasion by side population, or by larval settlement during the process of sediment recovery.

While the recolonization after mechanical disturbance can be rather quick, provided that sediment features have not been modified (1-2 years for infauna, some years for megafauna), the recolonization of organically enriched sediments may take longer. For the sediment where the organic carbon has consolidated, say, has been subtracted from benthic consumption, the time to return to original condition is due to the benthic anaerobic respiration, thus rather slow and depending from temperature and sediment irrigation, with a likely estimation of several years (2-10yrs).

Where organic matter has been actively consumed by benthos, in areas where TOC remains low and is subjected to a dynamic cycle, the substitution of less tolerant species has to be expected, and the full recovery of the original community features, after organic loading cessation, can be estimated in short (1-2 years) for infauna, in some years for megafauna to settle and develop new populations.

5.1.6 Impact on pelagic communities

The dispersion of Total Dissolved Nitrogen has been computed on a scale of 2 km, a distance that provide an effective nitrogen dilution due to the intense flow field.

On short scale, the computational unit has been set to describe the spatial dispersion pattern around the farm, on a scale of some km, where the most part of effects are usually evident.

The computational domain has been set as follow:

- The computational cells have been set in number of 41 x 41 x 6 units;
- Each cell has a size of 50 m x 50m x 15 m;

The total size of the computational volume is therefore of:

- 50 m x 41 cells = 2050 m;
- 50 m x 41 cells = 2050 m;
- 5 m x 24 cells = 90 m

The above has determined a computational total volume of 2050 m x 2050 m x 90 m.

Within the given volume, a 3-dimensional computational mode has been used: the velocity vectors have those retrieved from the CMEMS IBI ANALYSIS FORECAST PHYS 005 001 product,

The used flowfield data set is the from 01.01.2016 to 01.01.2019, from January to December. Computational step is at 1 hour, resulting maps are computed at steps of 1 day.

<u>Nitrogen Dispersion</u>

The computation has been performed at time steps of one hour, at the same interval of current data.

In this way, the information on movements due to semidiurnal tide components has been maintained. In the same time, this interval has requested a long computing time and generated as well a redundancy of images, beyond the aim of the present study.

Cages has been schematized as located between -20 and -45 m of depth, to account for dispersion due to the deepest cage part, below platform wall, here considered as a solid barrier to transversal water movement.

In order to describe the annual Nitrogen dispersion pattern, a subset of images, sampled at a rate of one image /month has been extracted and presented.

Along the images, the arrows represent the current vector, calculated at the depth of 22.5 m. Their length is proportional to the current speed, as in the side legend. To represented Nitrogen diffusion as sourcing from the portion of cage below the platform wall, say, from 20 to 45 m, the output point has been set at 22.5 m on maps. Maps are 2050 x 2050 m wide.

Red line crossing image from SE to NW represent the transect line, along which the section with Dissolved Nitrogen concentration from surface to bottom is displayed.

Dissolved Nitrogen concentration is in mgN/m^3, and account for total Nitrogen (NH4+ plus other forms) excreted by fish.

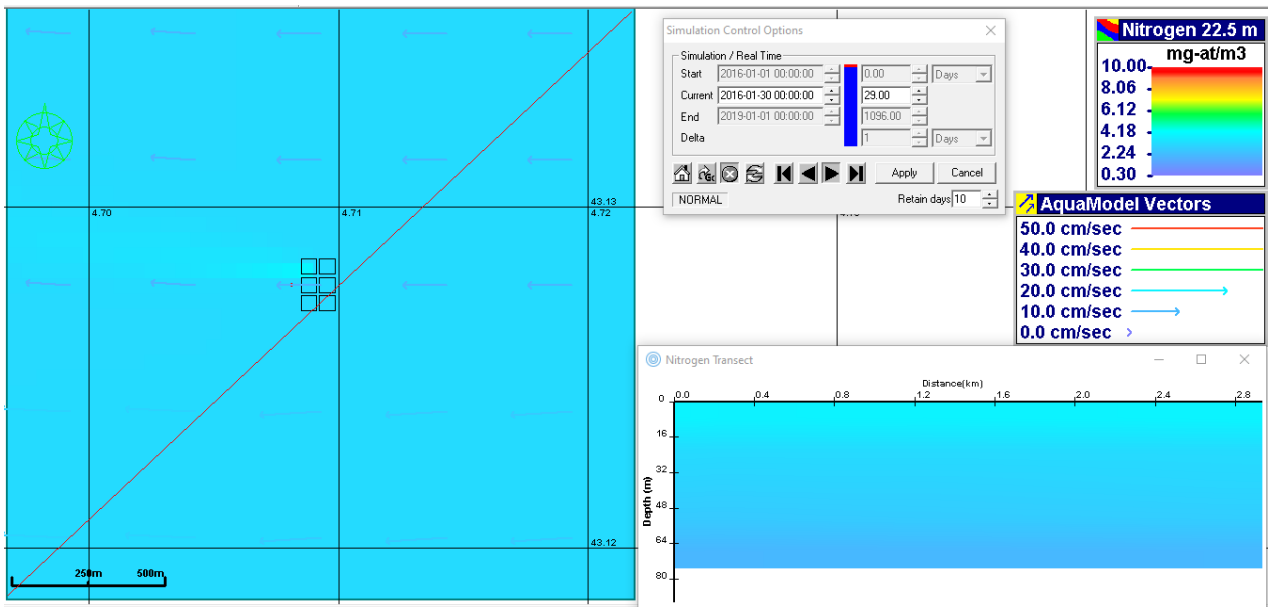


Figure 225: Nitrogen dispersion in January, 1st year

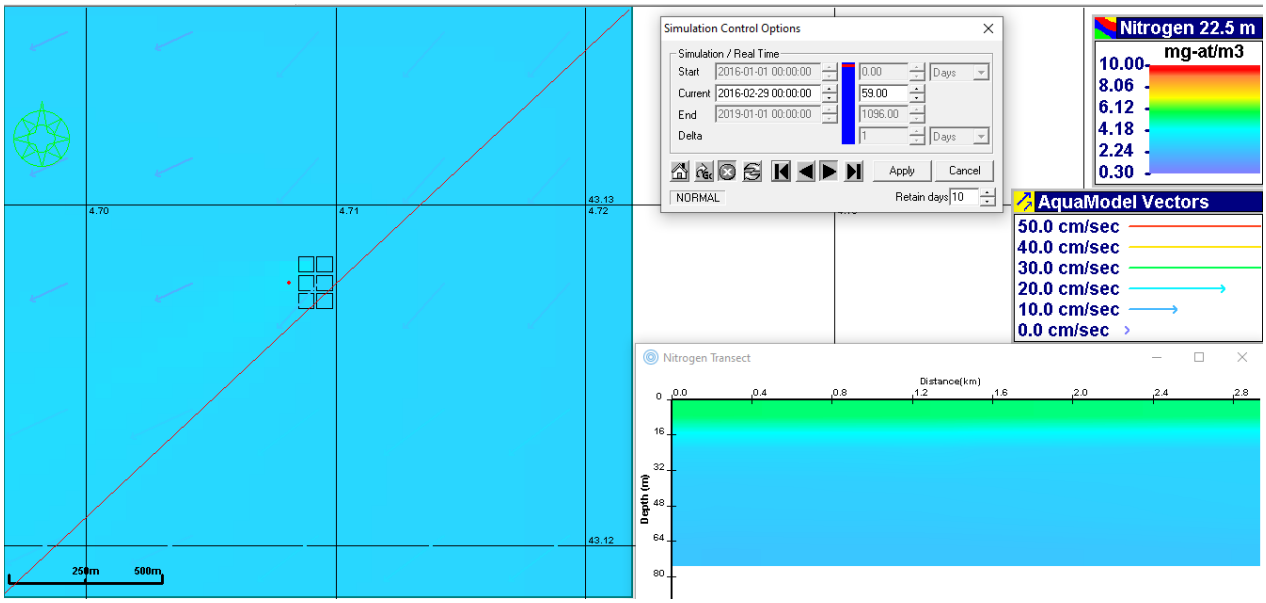


Figure 226: Nitrogen dispersion in February, 1st year

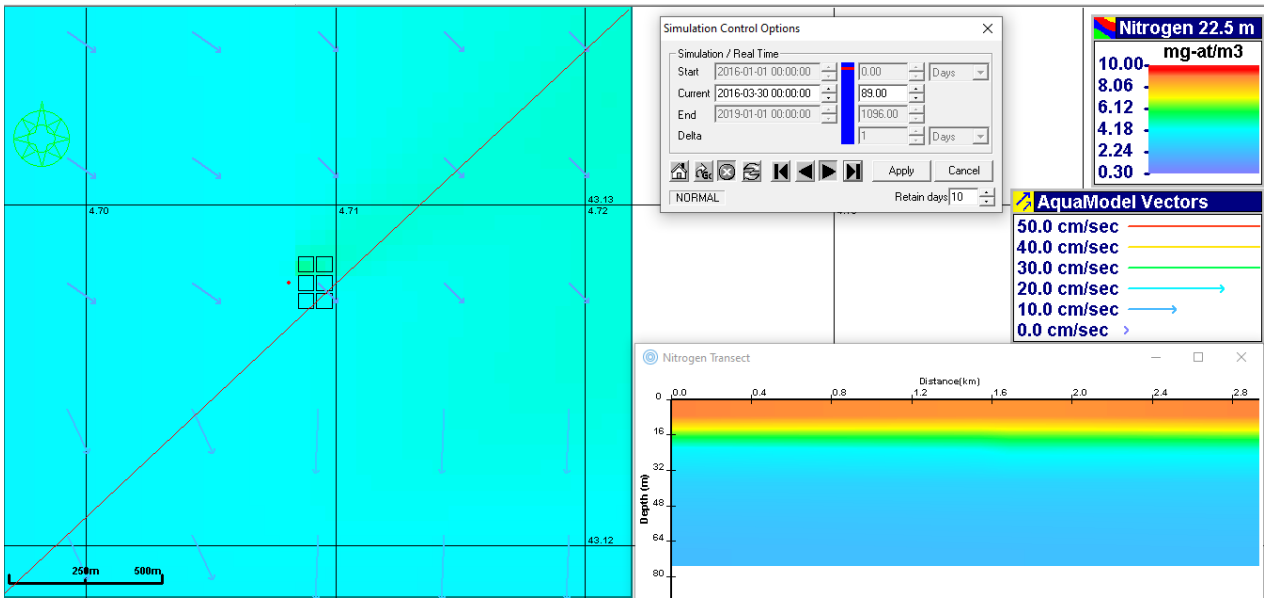


Figure 227: Nitrogen dispersion in March, 1st year

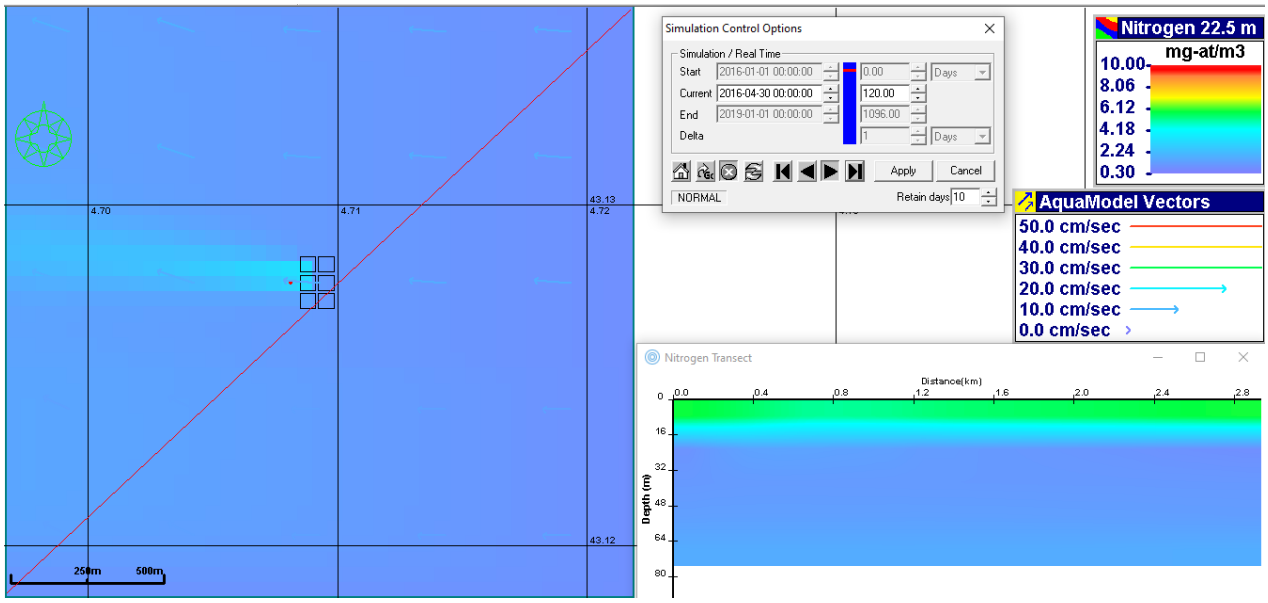


Figure 228: Nitrogen dispersion in April, 1st year

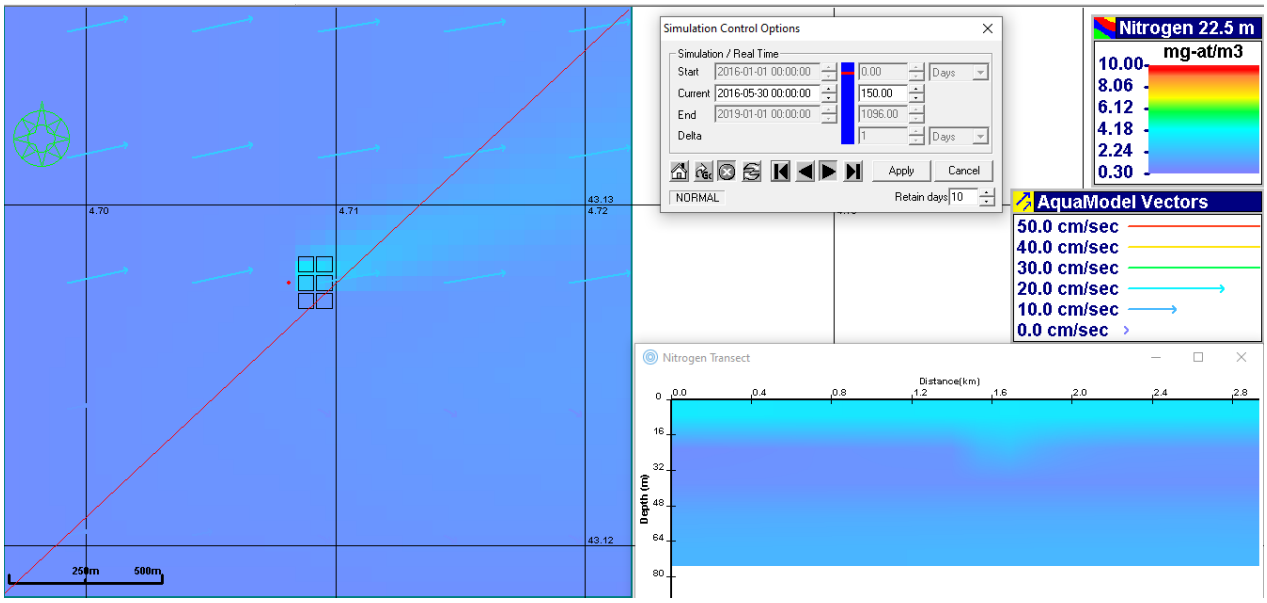


Figure 229: Nitrogen dispersion in May, 1st year

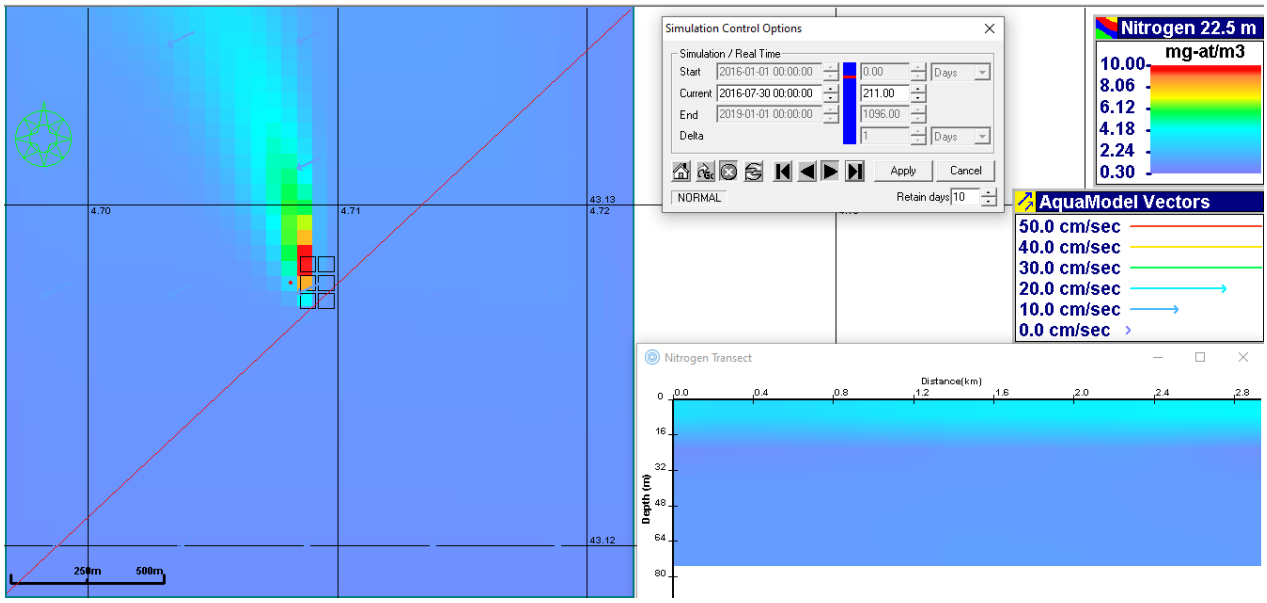


Figure 230: Nitrogen dispersion in June, 1st year

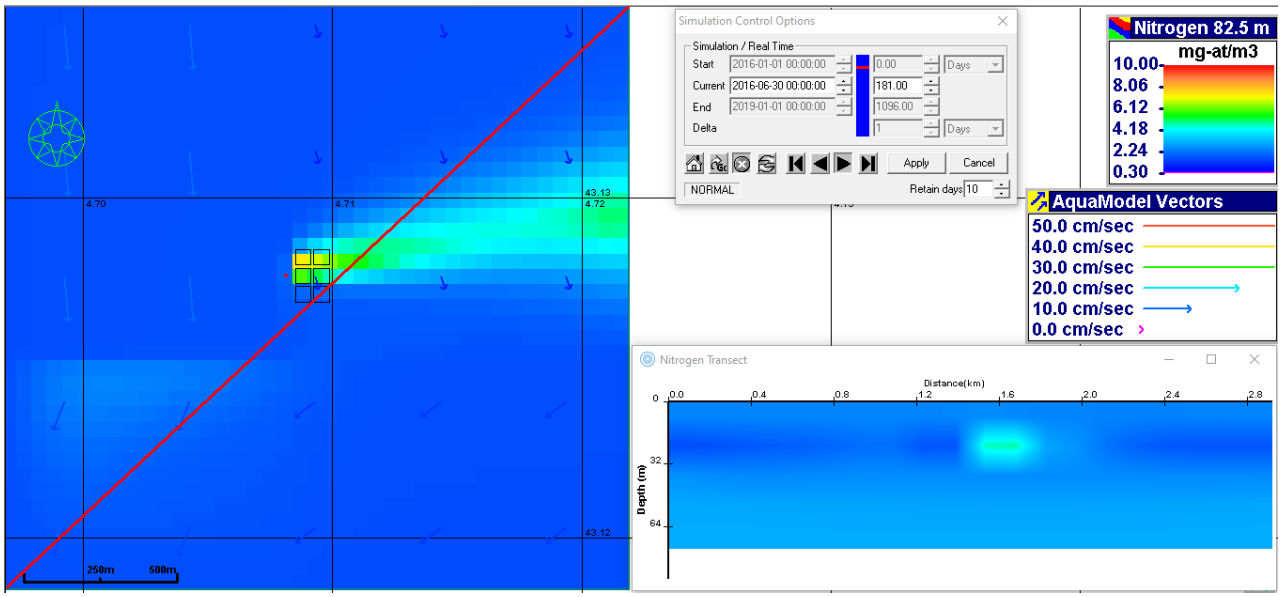


Figure 231: Nitrogen dispersion in July, 1st year

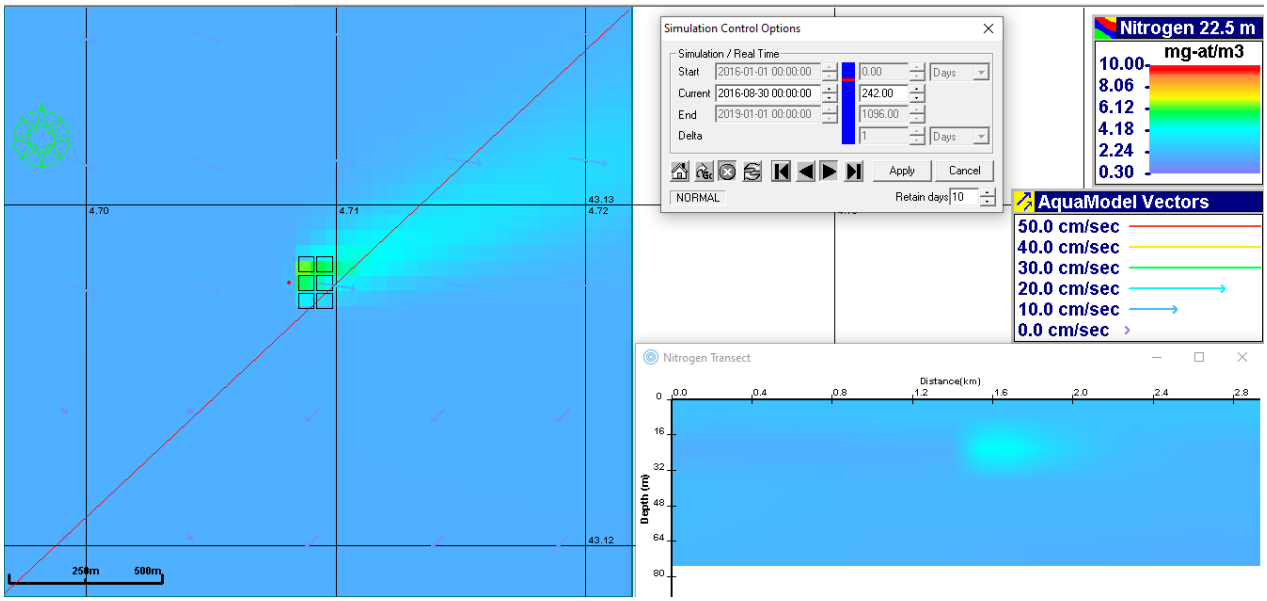


Figure 232: Nitrogen dispersion in August, 1st year

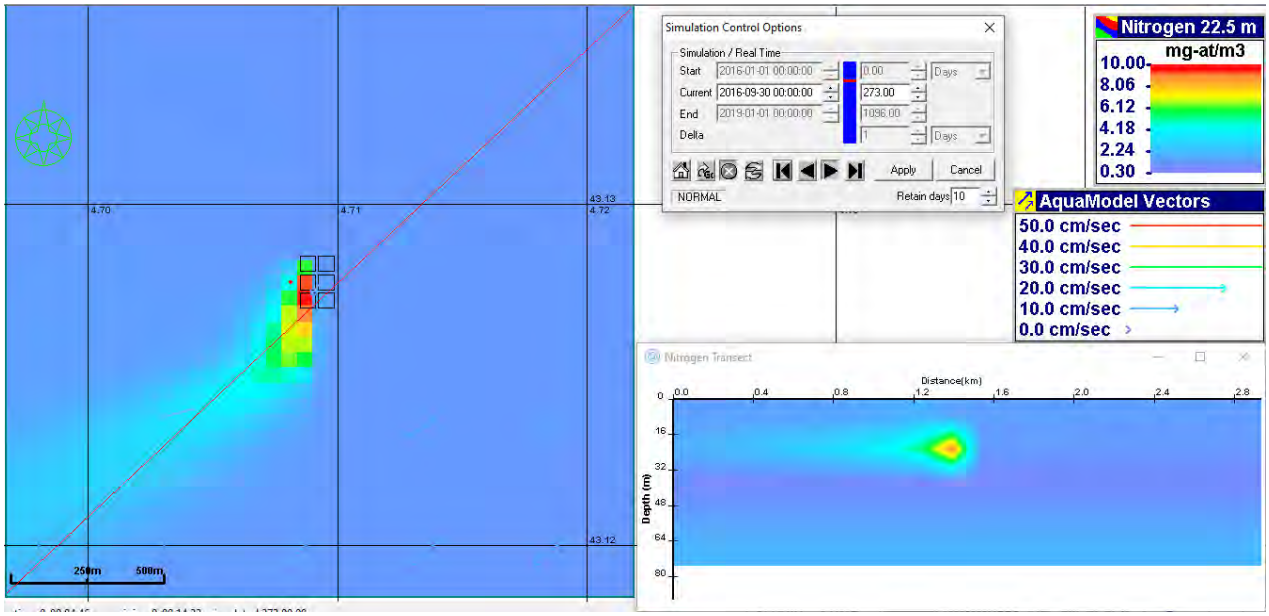


Figure 233: Nitrogen dispersion in September, 1st year

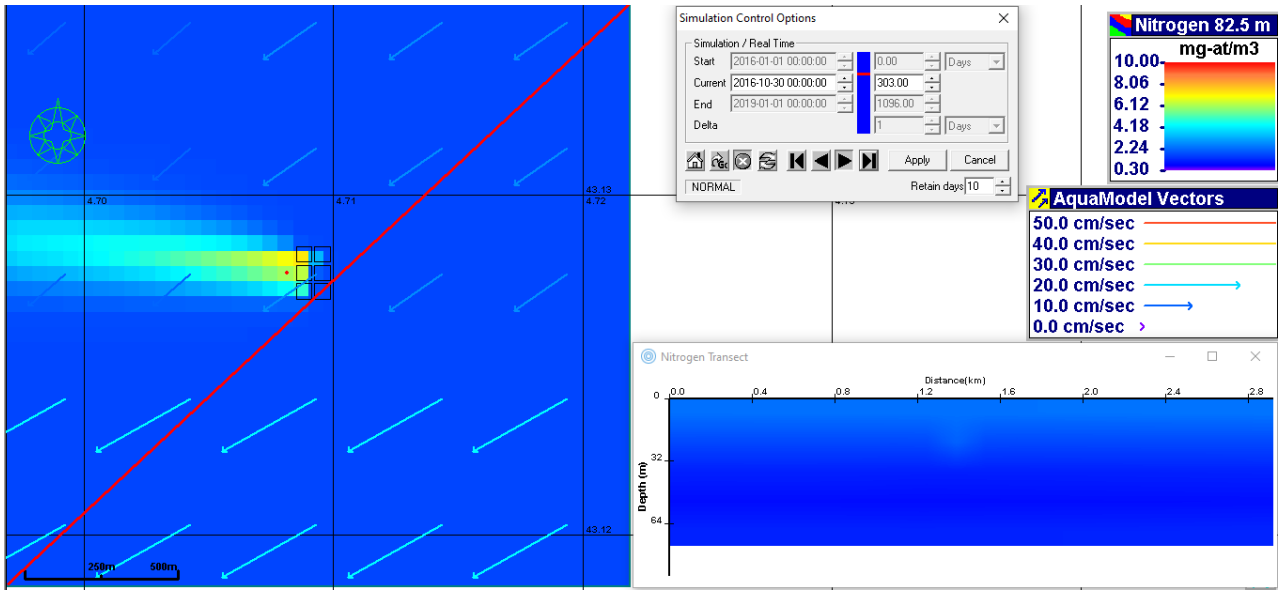


Figure 234: Nitrogen dispersion in October, 1st year

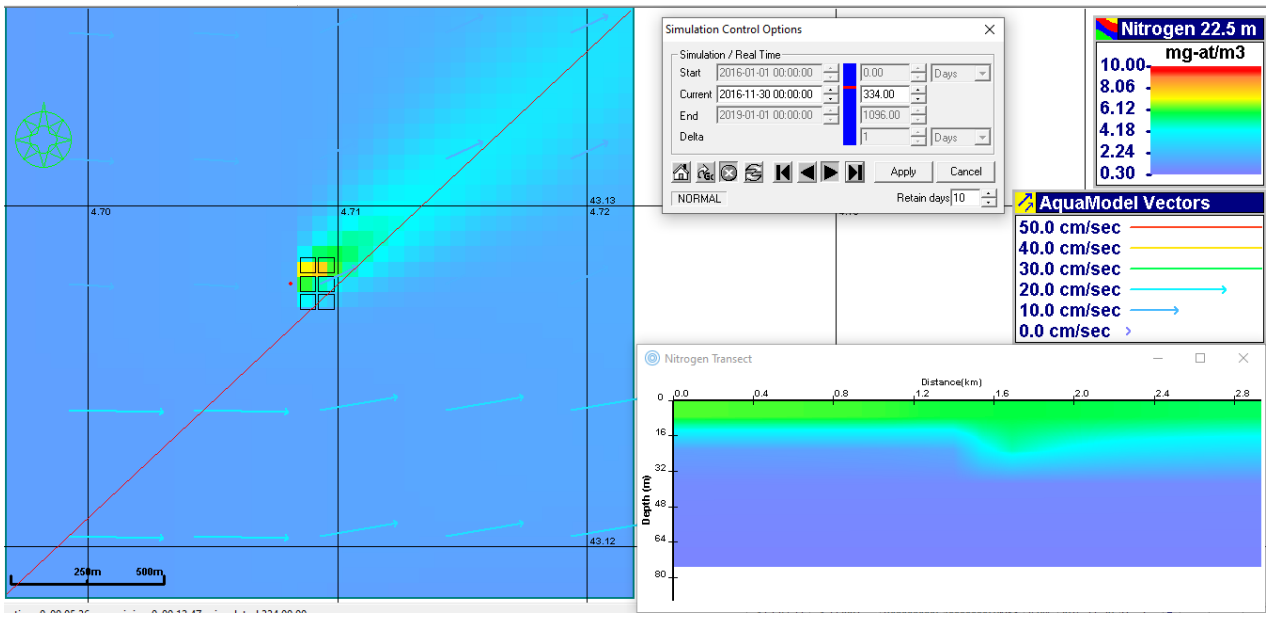


Figure 235: Nitrogen dispersion in November, 1st year

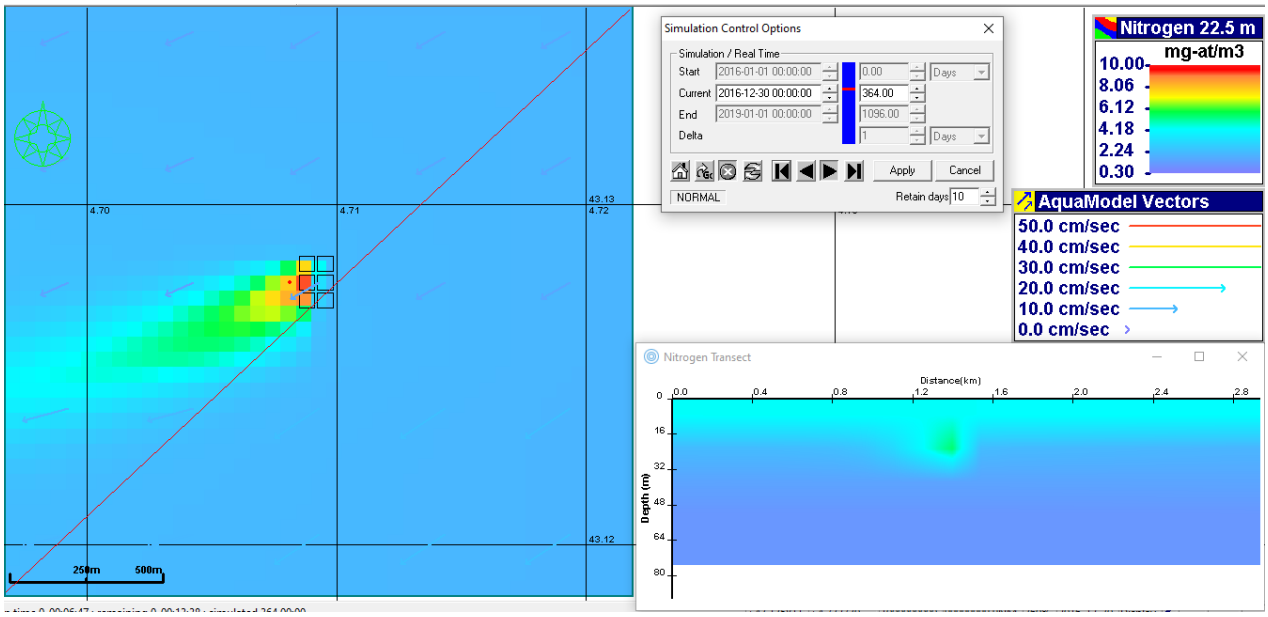


Figure 236: Nitrogen dispersion in December, 1st year

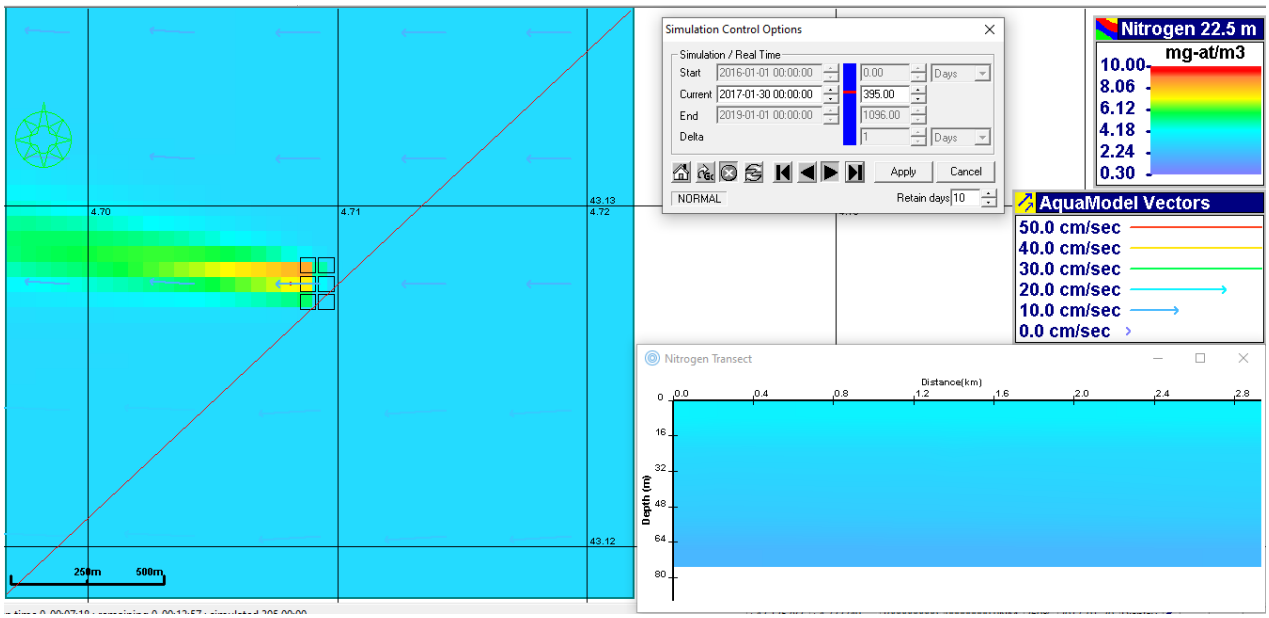


Figure 237: Nitrogen dispersion in January, 2nd year

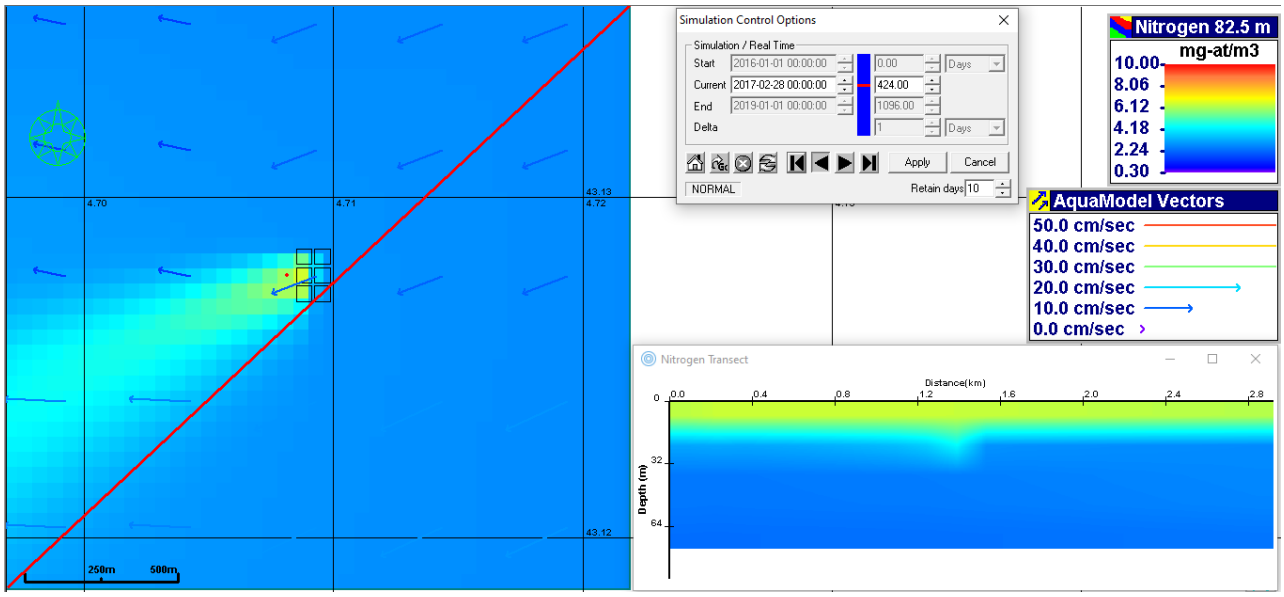


Figure 238: Nitrogen dispersion in February, 2nd year

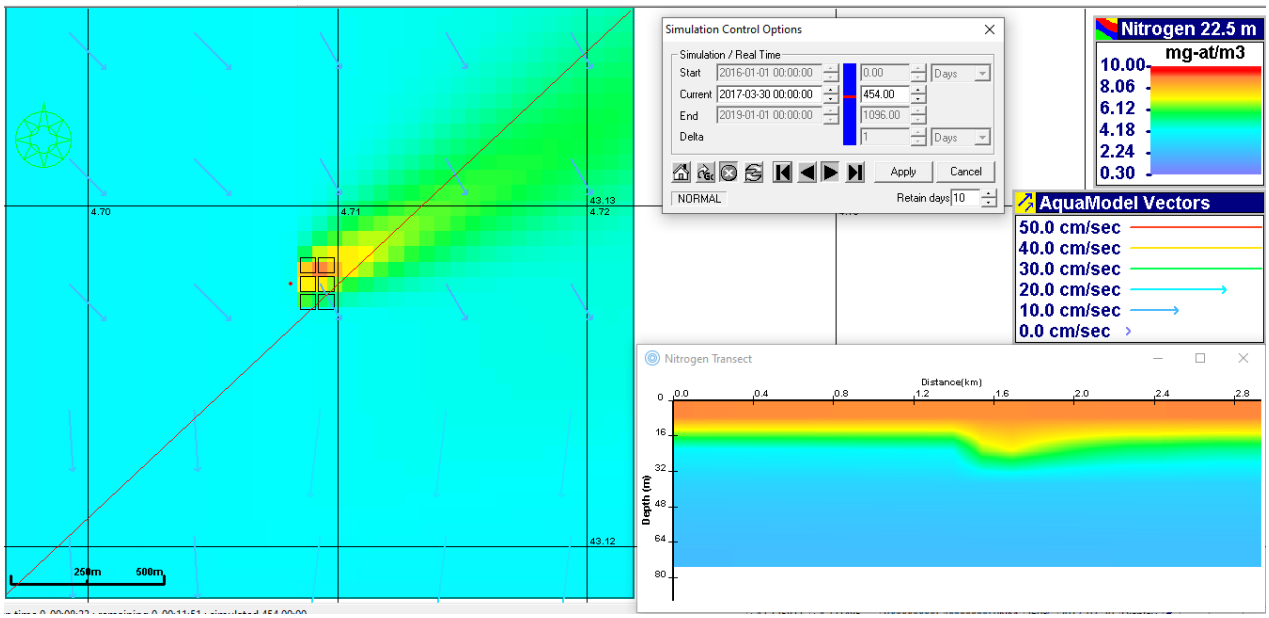


Figure 239: Nitrogen dispersion in March, 2nd year

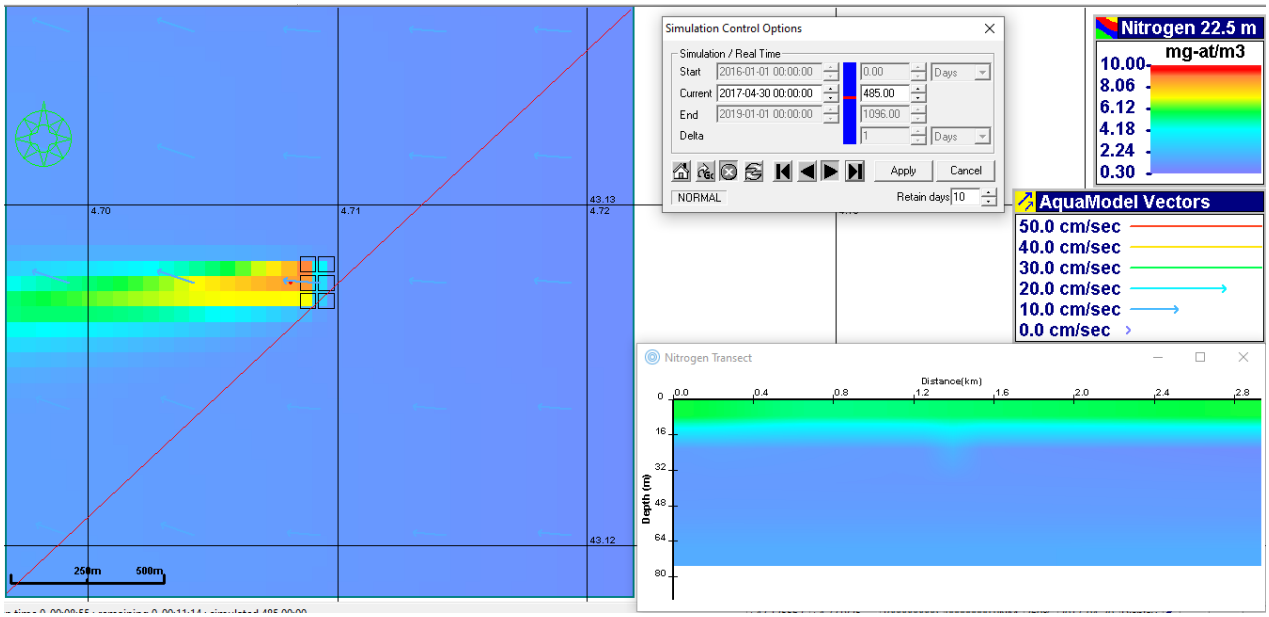


Figure 240: Nitrogen dispersion in April, 2nd year

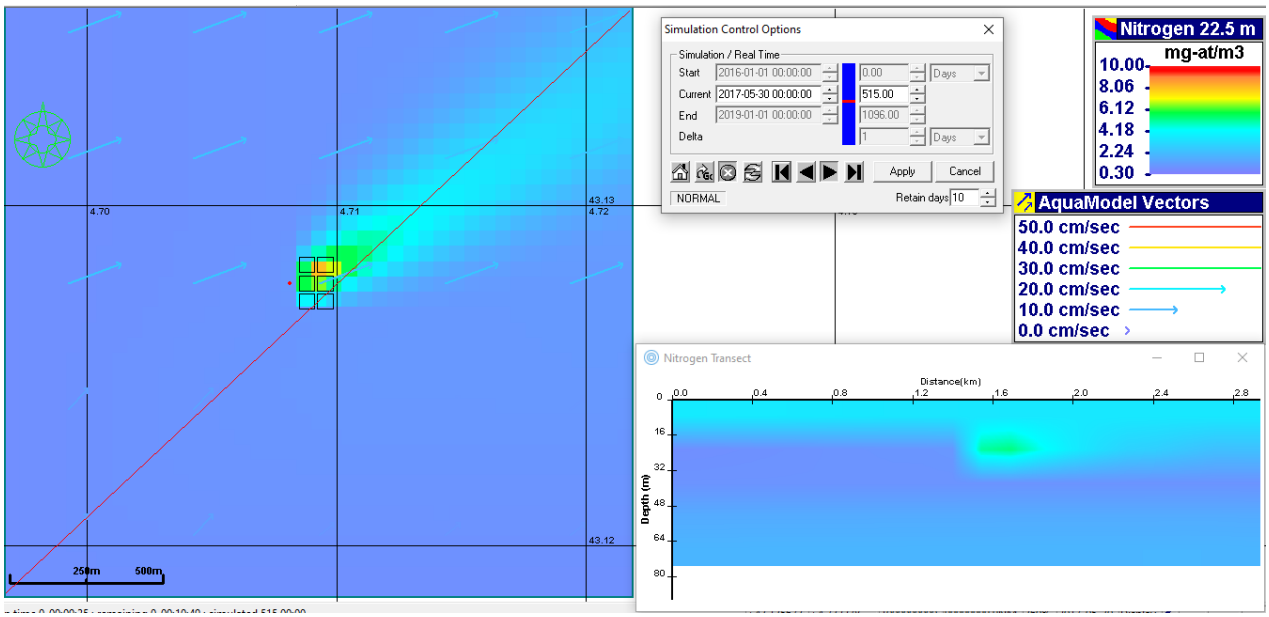


Figure 241: Nitrogen dispersion in May, 2nd year

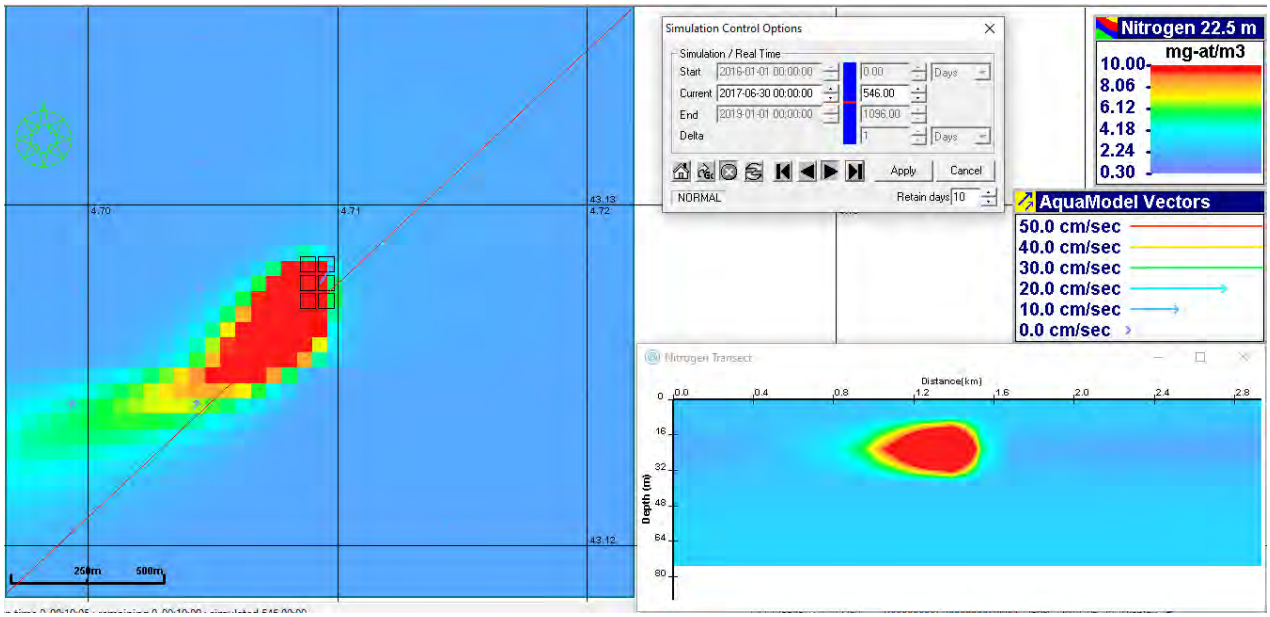


Figure 242: Nitrogen dispersion in June, 2nd year

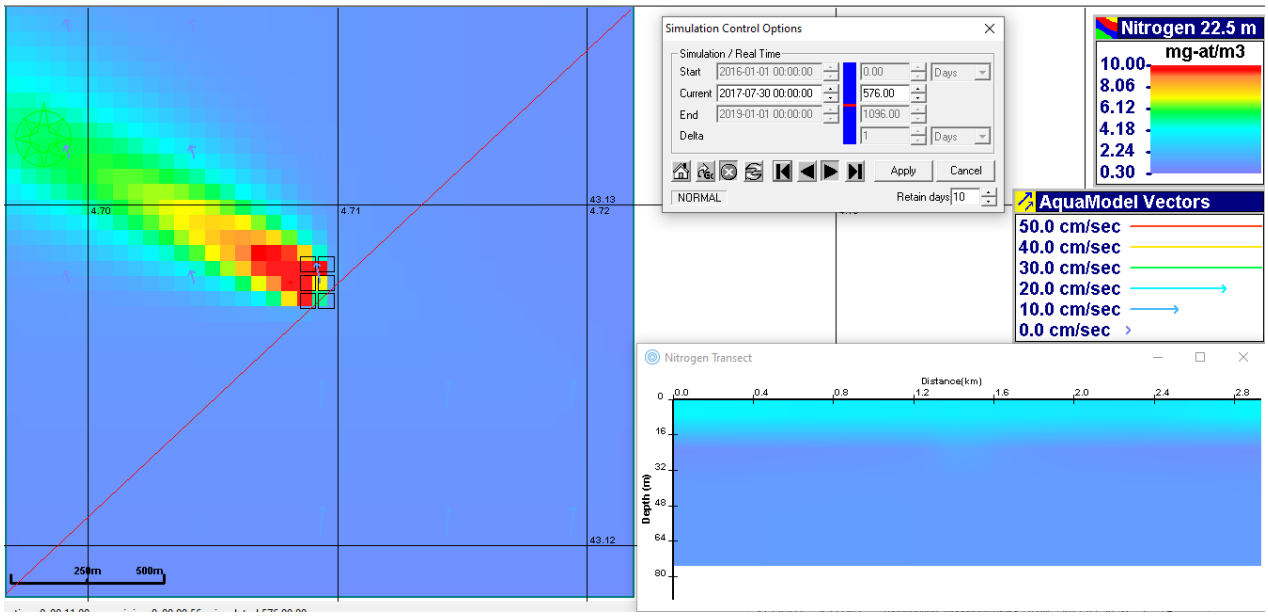


Figure 243: Nitrogen dispersion in July, 2nd year

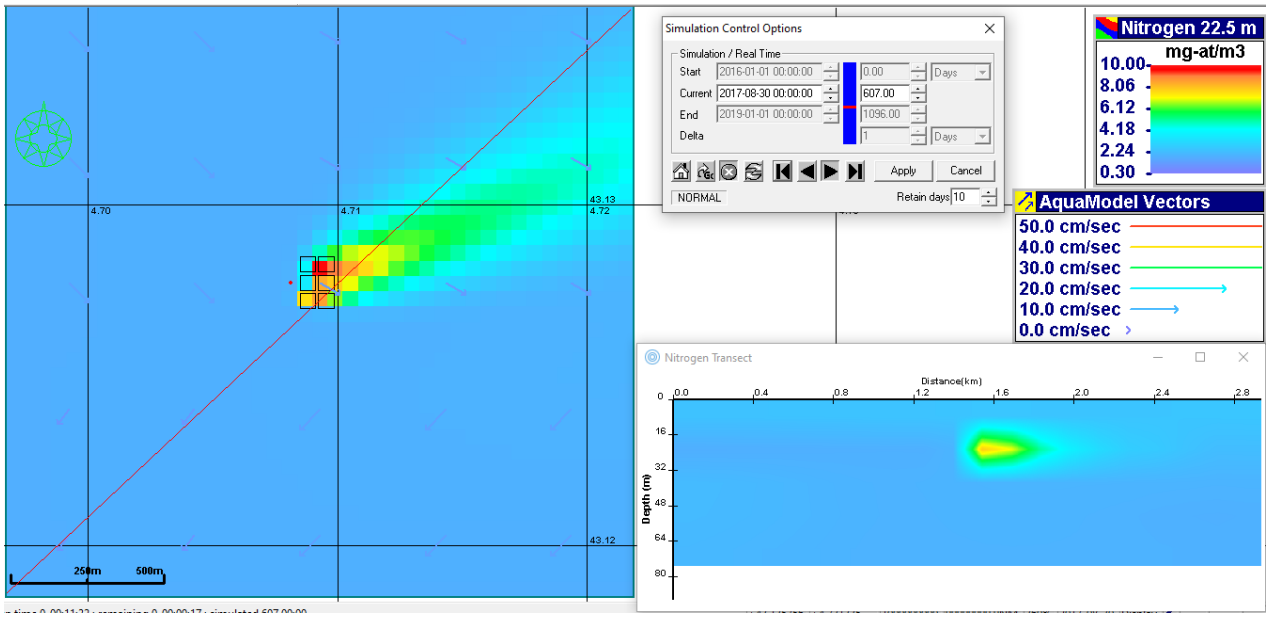


Figure 244: Nitrogen dispersion in August, 2nd year

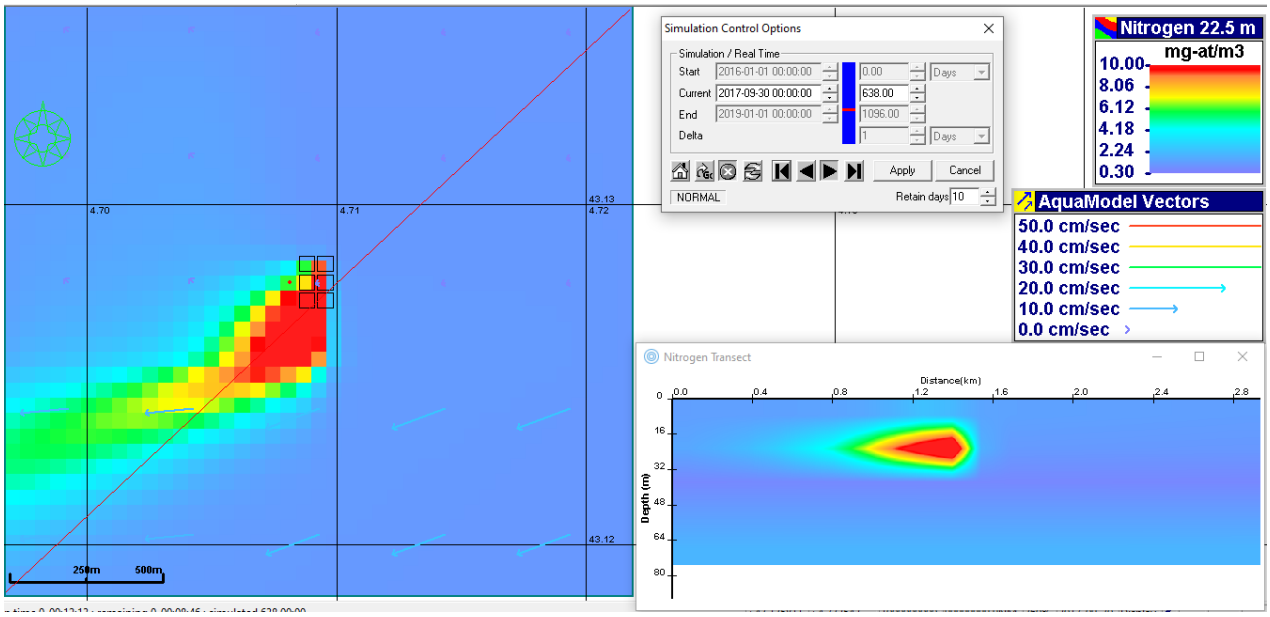


Figure 245: Nitrogen dispersion in September, 2nd year

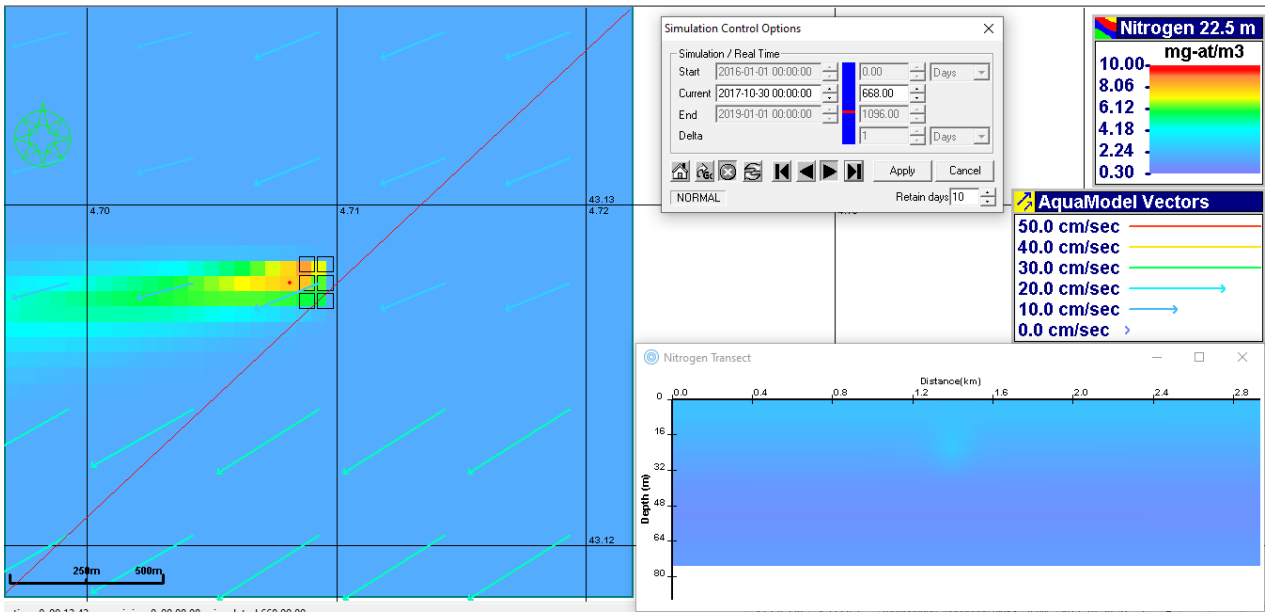


Figure 246: Nitrogen dispersion in October, 2nd year

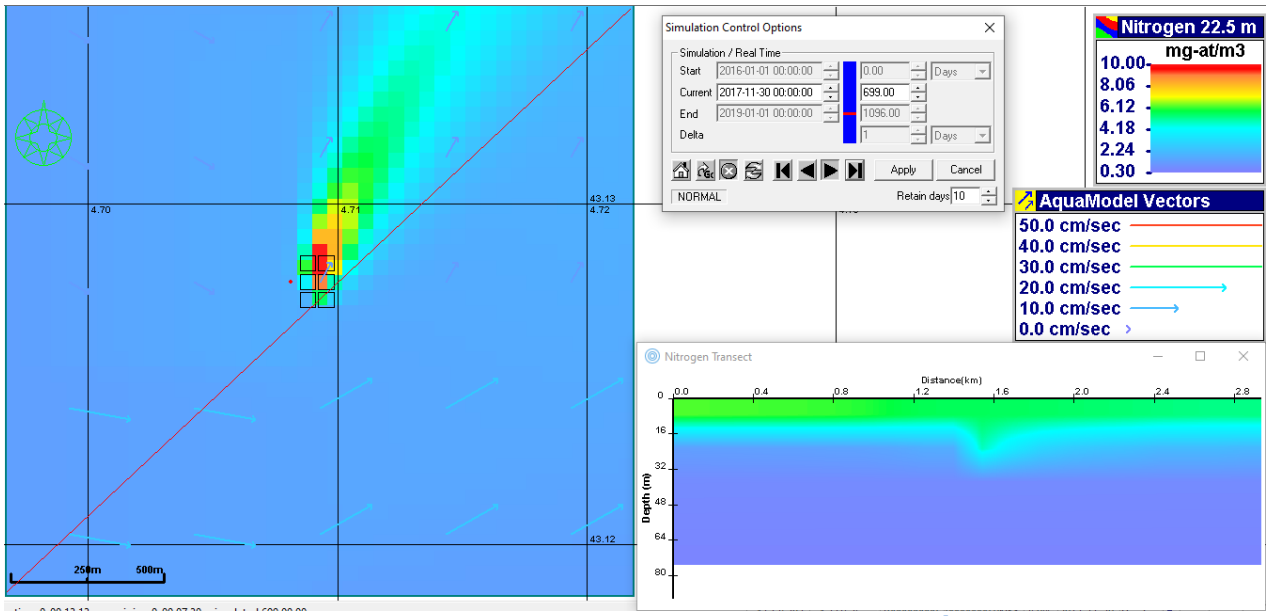


Figure 247: Nitrogen dispersion in November, 2nd year

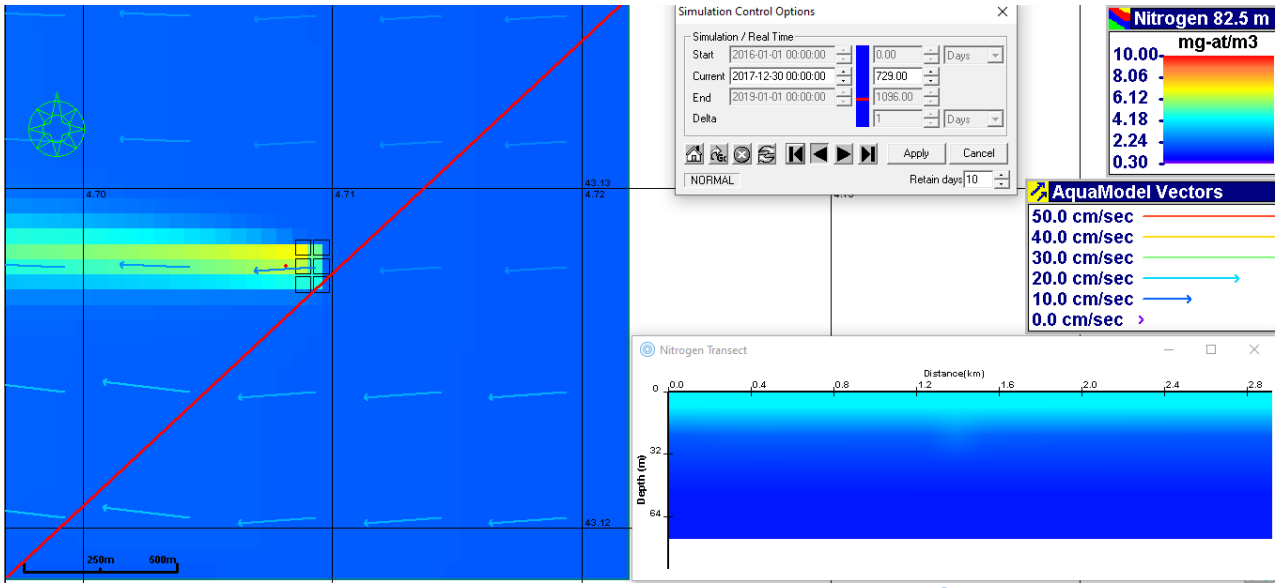


Figure 248: Nitrogen dispersion in December, 2nd year

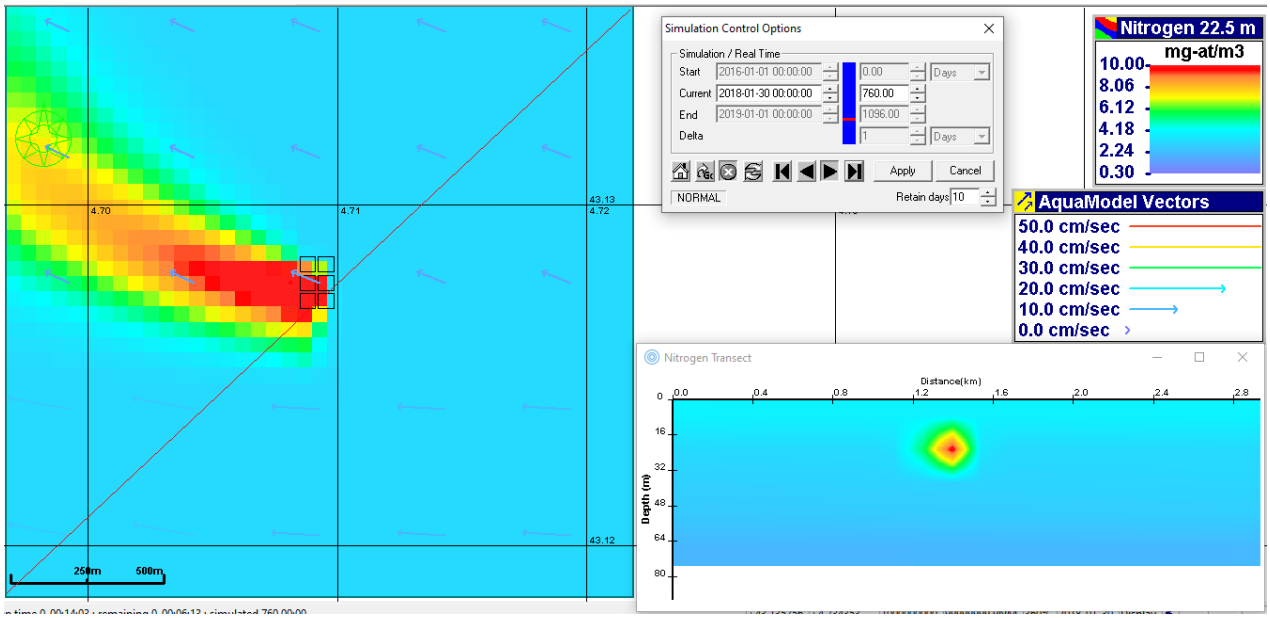


Figure 249: Nitrogen dispersion in January, 3rd year

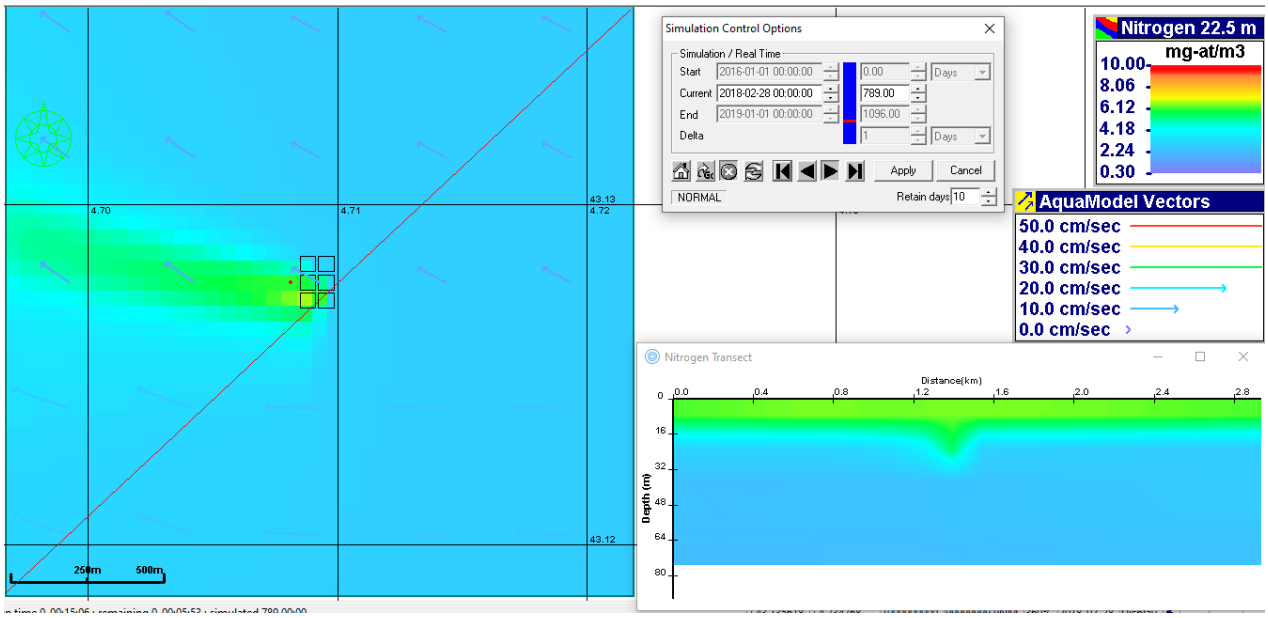


Figure 250: Nitrogen dispersion in February, 3rd year

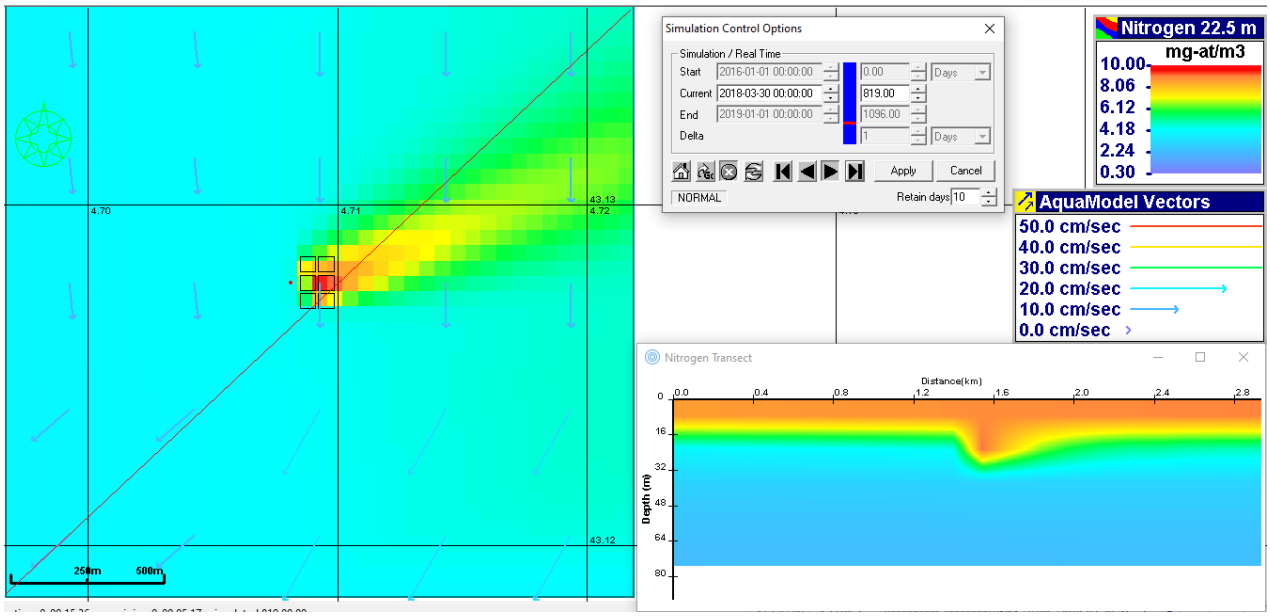


Figure 251: Nitrogen dispersion in March, 3rd year

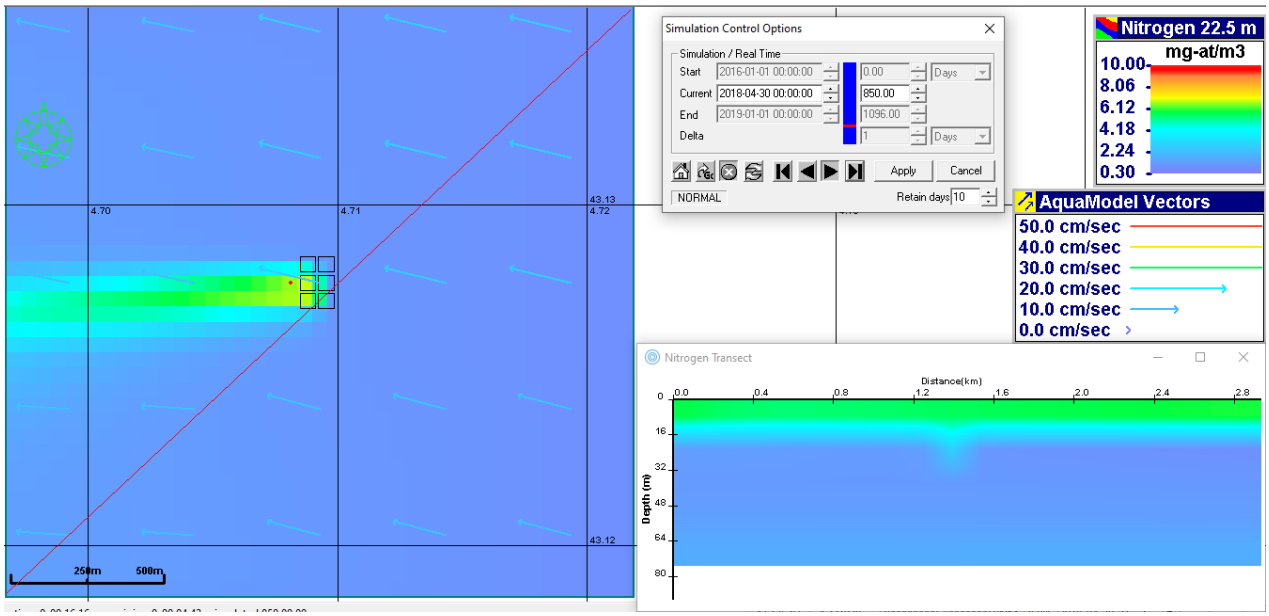


Figure 252: Nitrogen dispersion in April, 3rd year

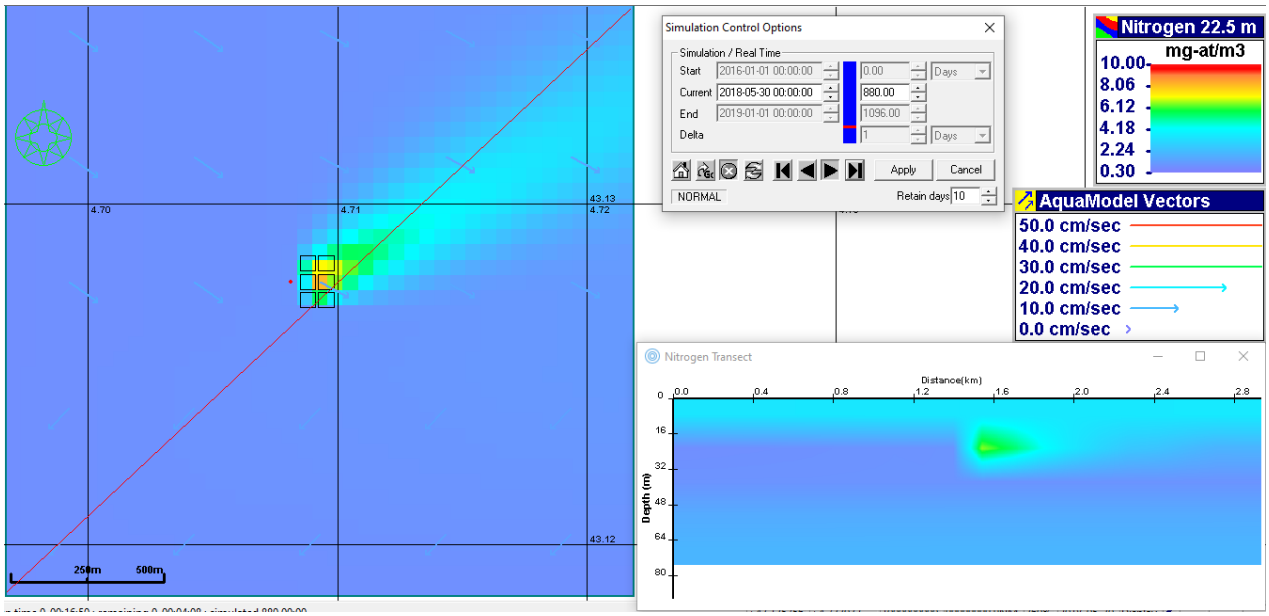


Figure 253: Nitrogen dispersion in May, 3rd year

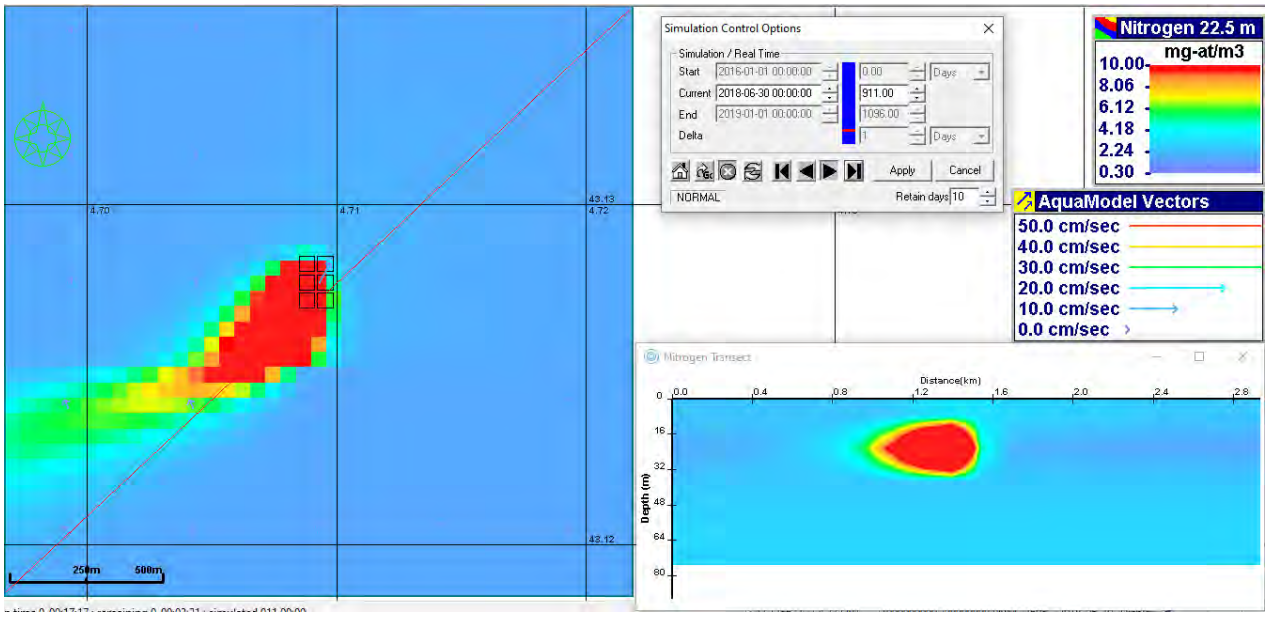


Figure 254: Nitrogen dispersion in June, 3rd year

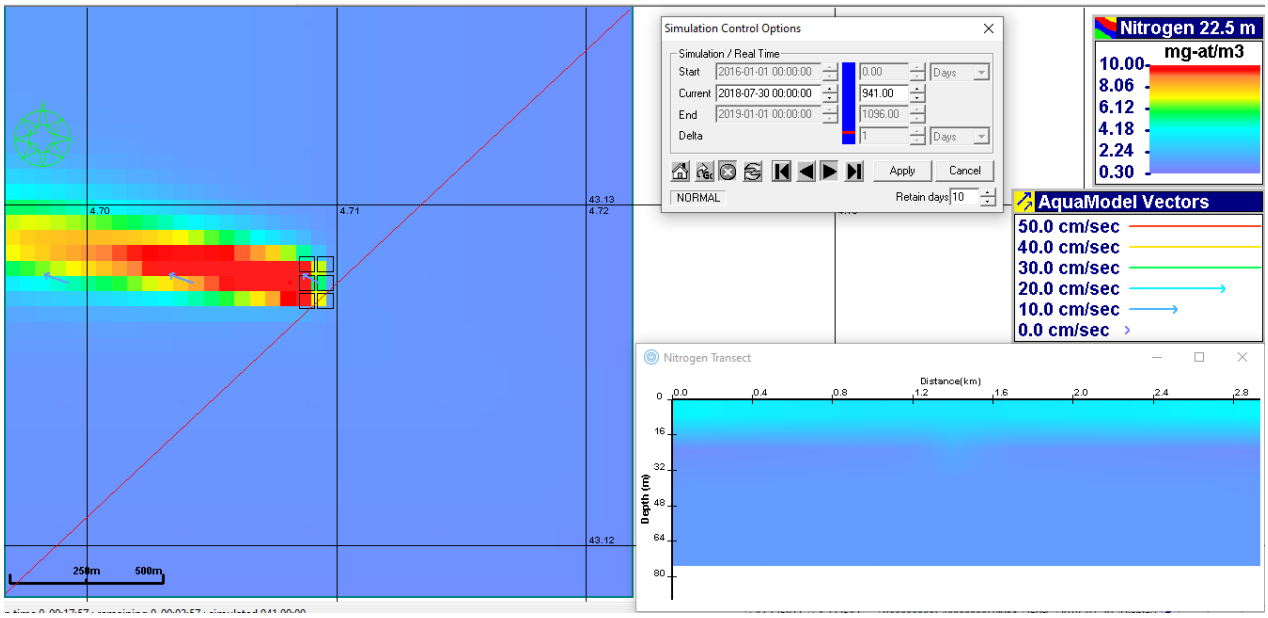


Figure 255: Nitrogen dispersion in July, 3rd year

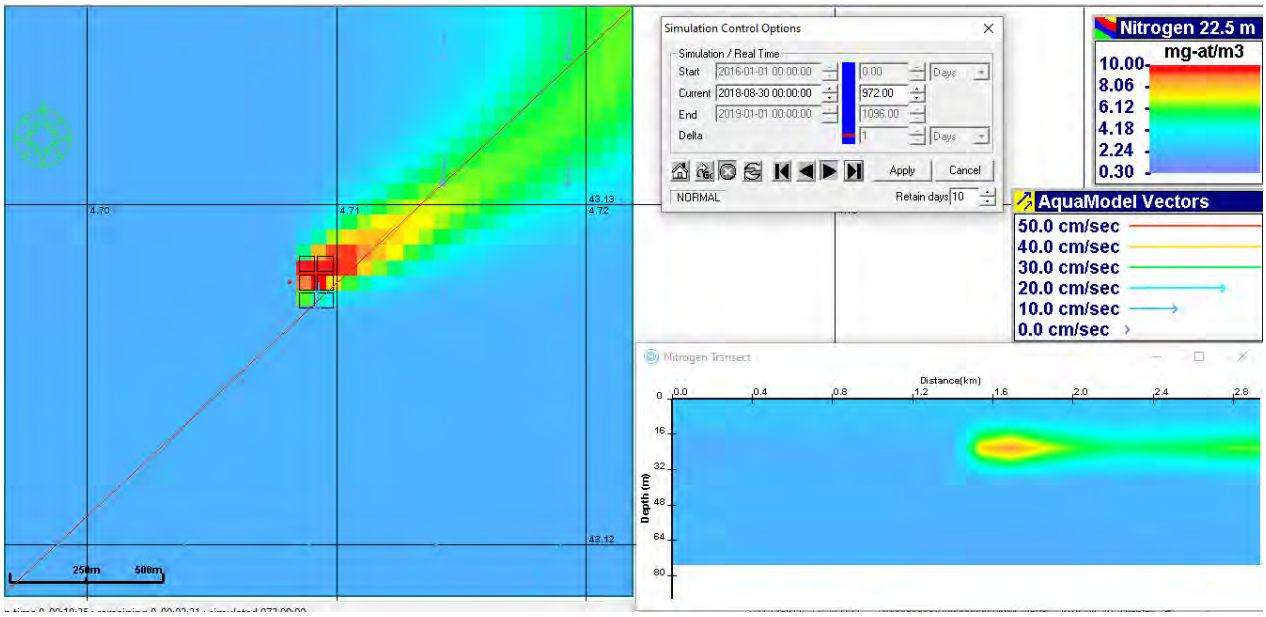


Figure 256: Nitrogen dispersion in August, 3rd year

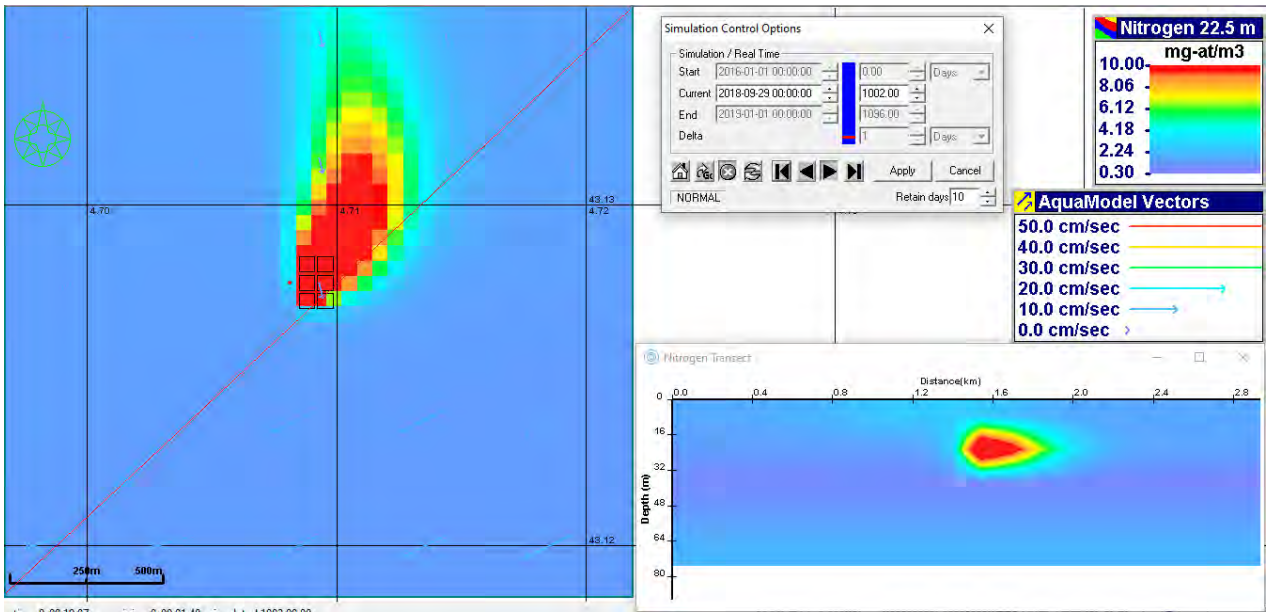


Figure 257: Nitrogen dispersion in September, 3rd year

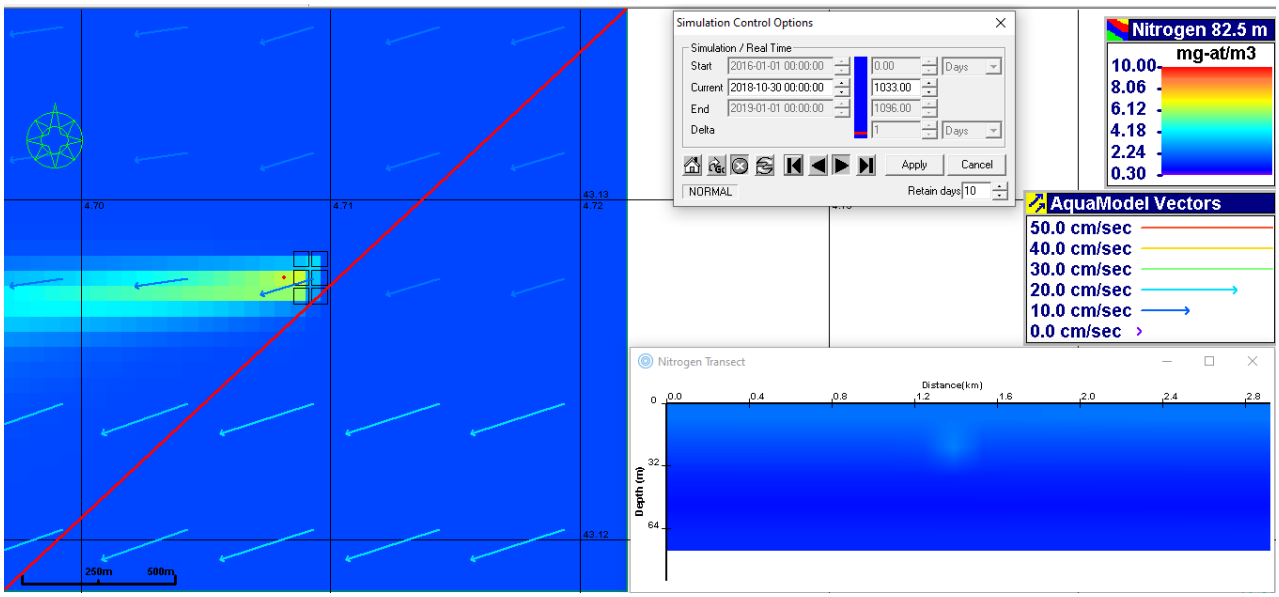


Figure 258: Nitrogen dispersion in October, 3rd year

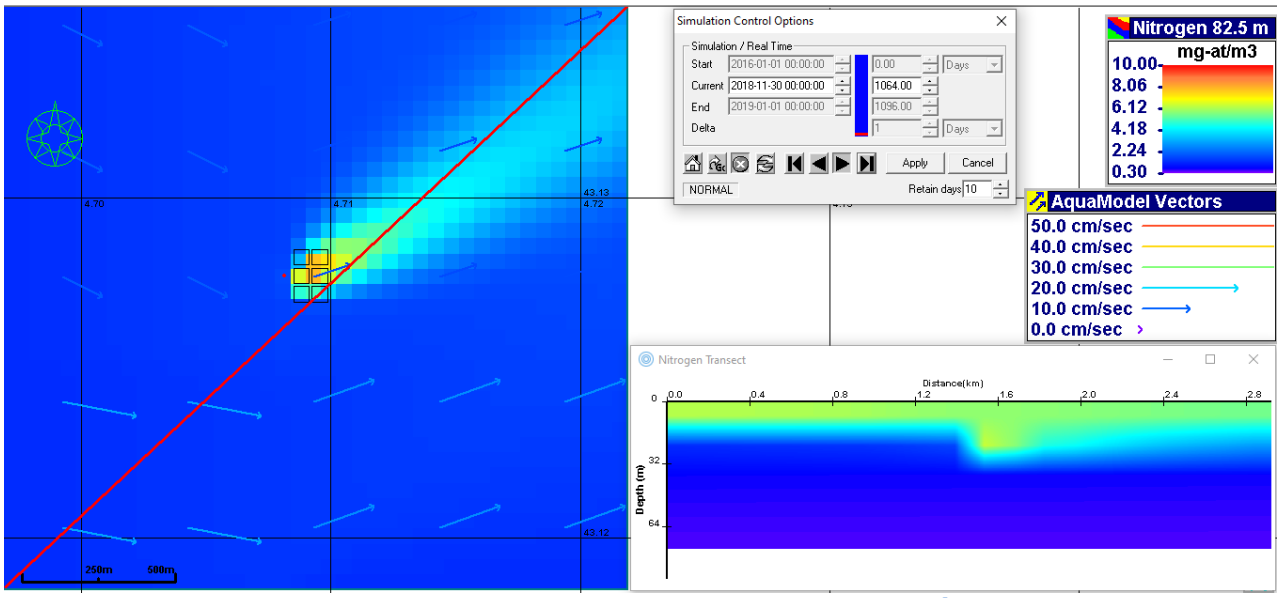


Figure 259: Nitrogen dispersion in November, 3rd year

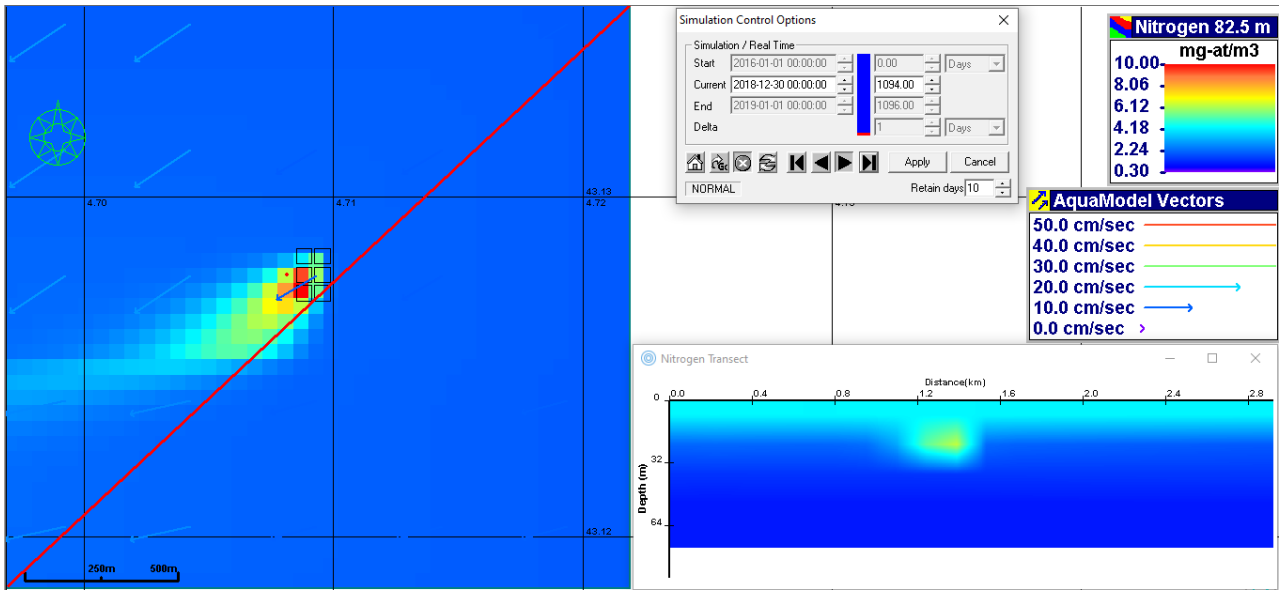


Figure 260: Nitrogen dispersion in December, 3rd year

Considerations

The nitrogen dispersion is quick and only in some case moves beyond the computational limits. This is due the the intense circulation pattern, that bring Nitrogen concentration quickly to the level of surrounding waters, minimizing effects on pelagic communties.

The fast dilution does not allow for a sufficient contact time between planktonic microalgal community and Nitrogen-enriched waters, thus preventing the possiblity of algal blooms. In all the time series considered, the plume of excreted Nitrogen does not exceed the basal Nitrogen level, being waters off Marseille periodically enriched by the Rhone freshwater plume, as can be seen from the evolution in the bottom colors.

Oxygen consuption

As per Nitrogen, the computation has been performed at time steps of one hour, at the same interval of current data. In this way, the information on movements due to semidiurnal tide components has been maintained. In the same time, this interval has requested a long computing time and generated as well a redundancy of images, beyond the aim of the present study.

Cages has been schematized as located between 0 and -35 m of depth, to account for oxygen consumption due the average biomass distribution in cage, and assuming that water flow can freely renew cages inner water volumes, without any barrier due to platform wall. This simulation represents the hypothesys of maximum undisturbed renewal due to natural flow field.

In order to describe the annual oxygen consumption pattern, a subset of images, sampled at a rate of one image /month has been extracted and presented.

Along the images, the arrows represent the current vector at 7.5 m of depth. Their length is proportional to the current speed, as in the side legend. Oxigen concentration pattern is represented in maps as sourcing from the middle of cage, at a depth of 7.5 m.

Maps have an area of 2050 x 2050 m.

Red line crossing image around the minimum concentration represents the transect line, along which the section with Dissolved Oxygen concentration from surface to bottom is displayed. Dissolved Oxygen concentration is in mg/l.

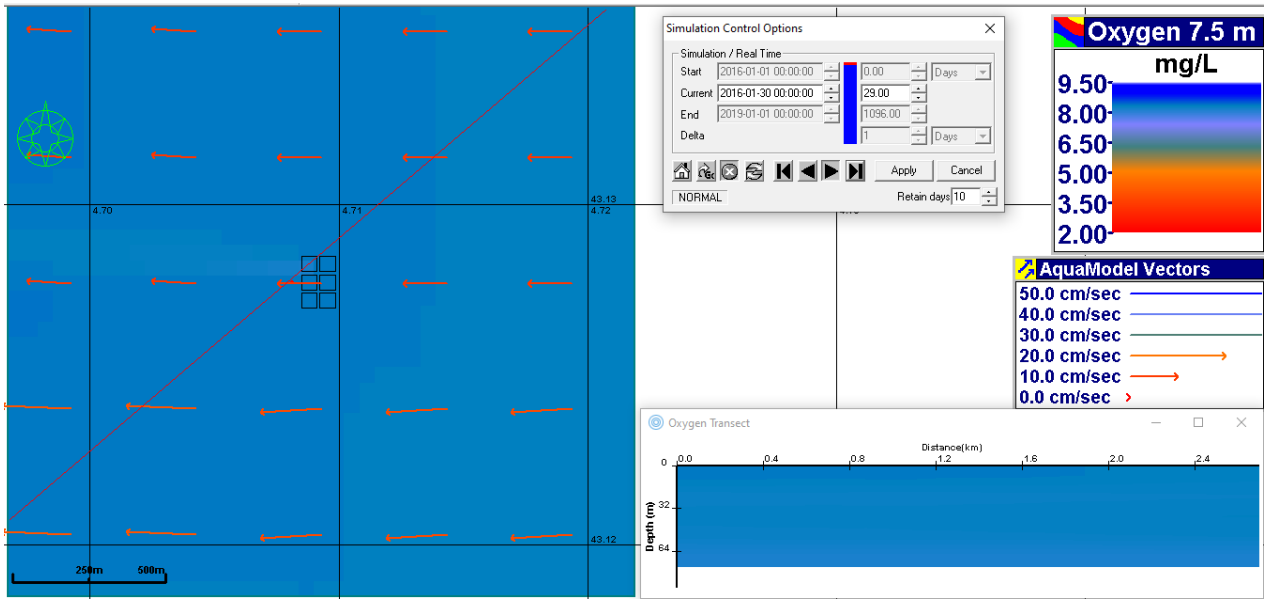


Figure 261: Dispersion of Oxygen deprived waters in January, 1st year

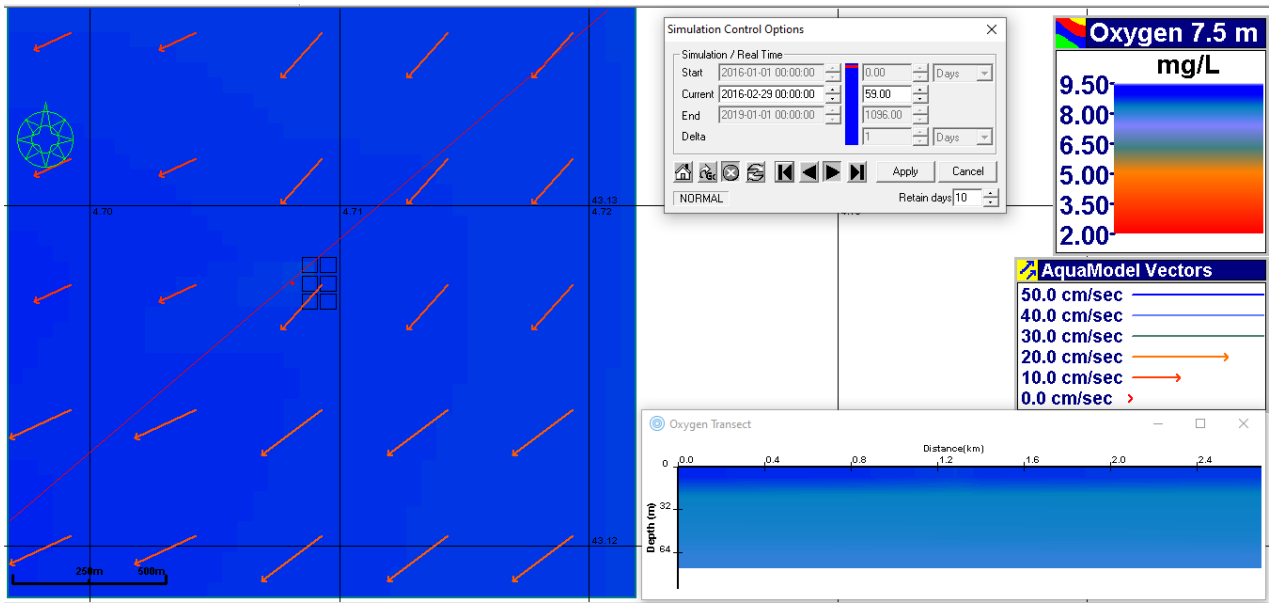


Figure 262: Dispersion of Oxygen deprived waters in February, 1st year

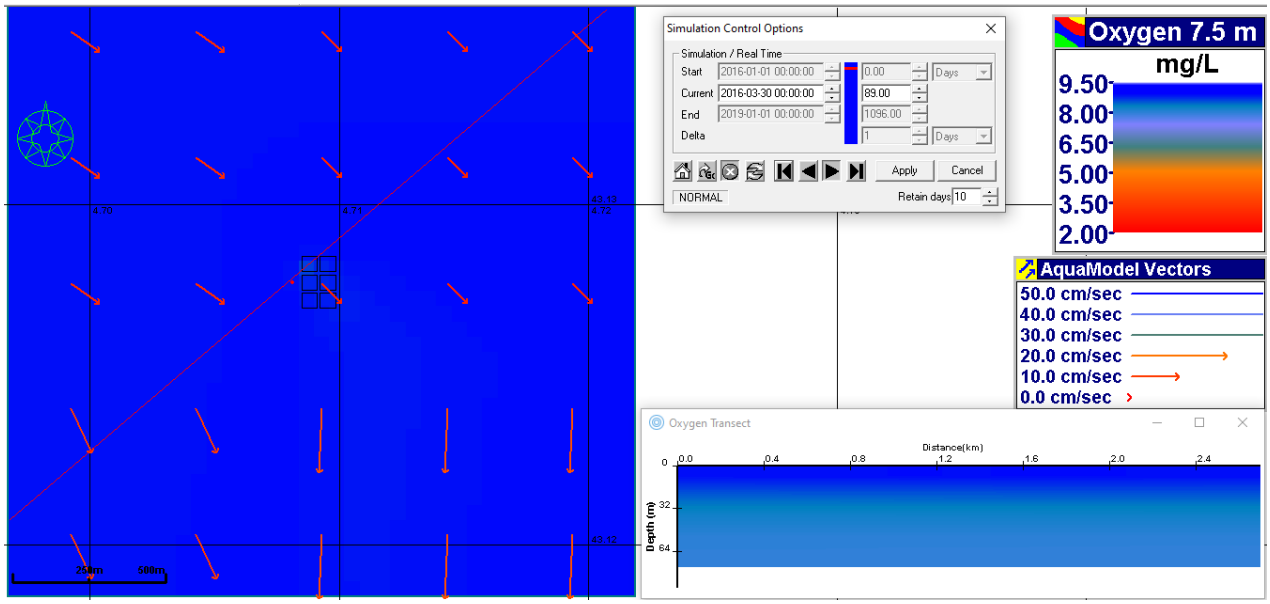


Figure 263: Dispersion of Oxygen deprived waters in March, 1st year

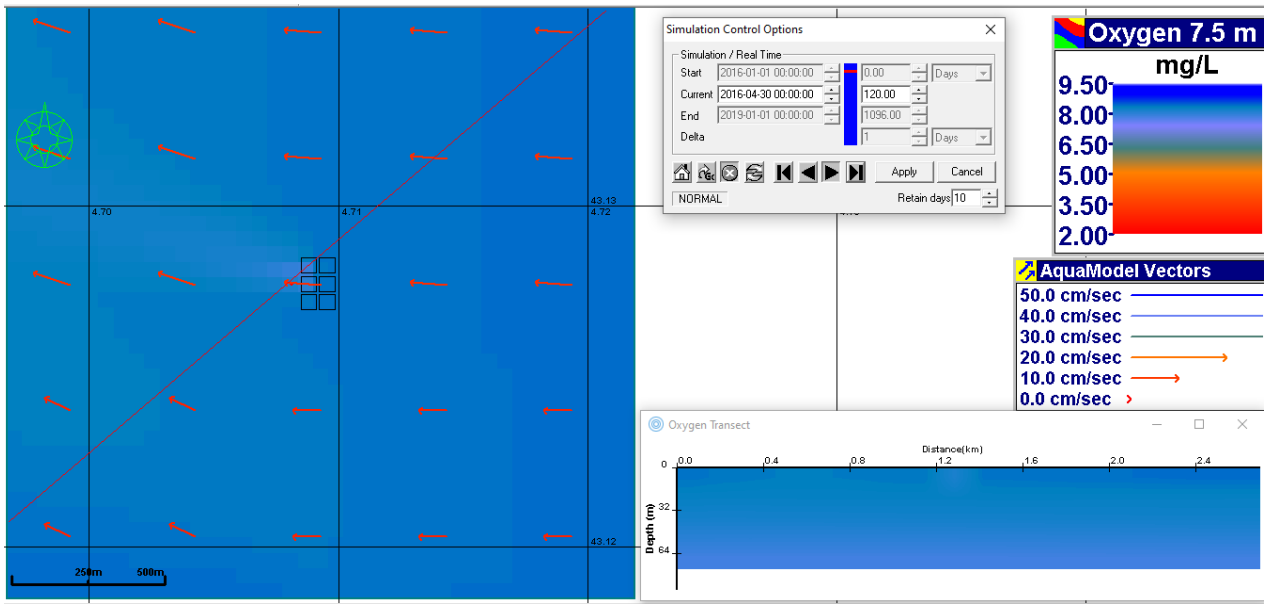


Figure 264: Dispersion of Oxygen deprived waters in April, 1st year

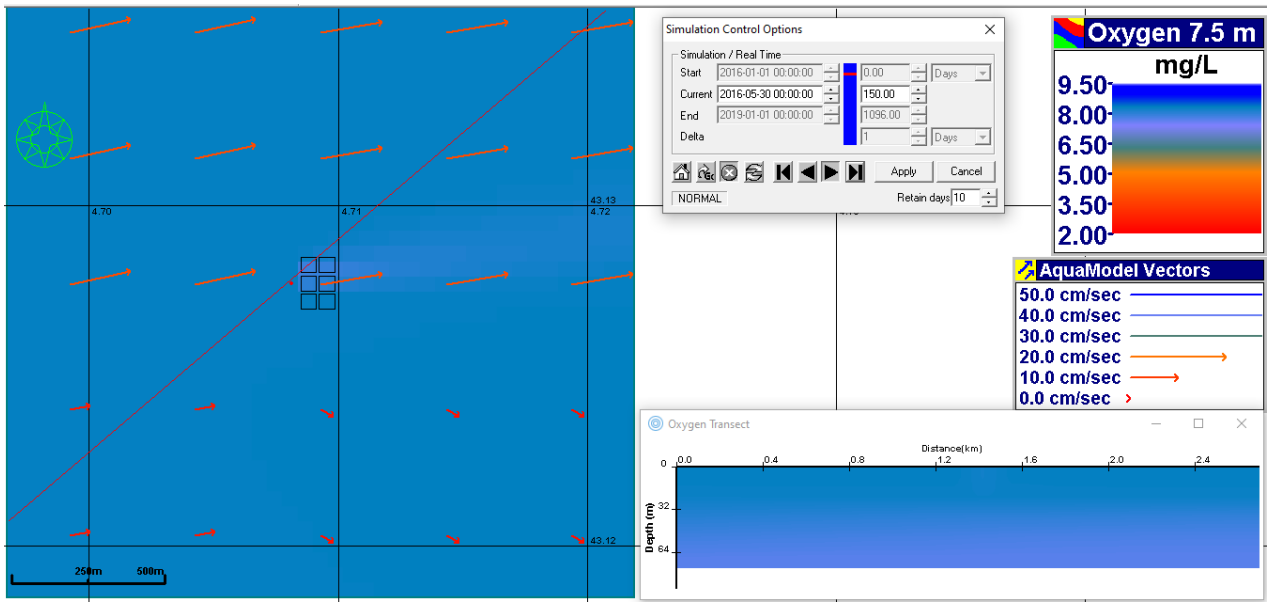


Figure 265: Dispersion of Oxygen deprived waters in May, 1st year

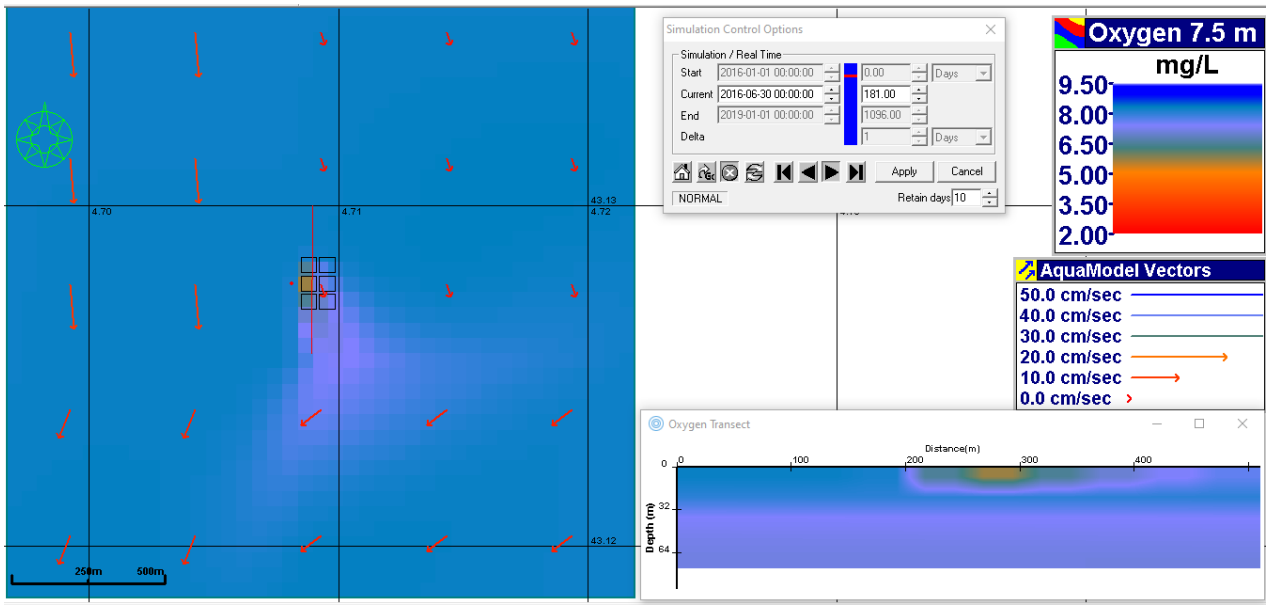


Figure 266: Dispersion of Oxygen deprived waters in June, 1st year

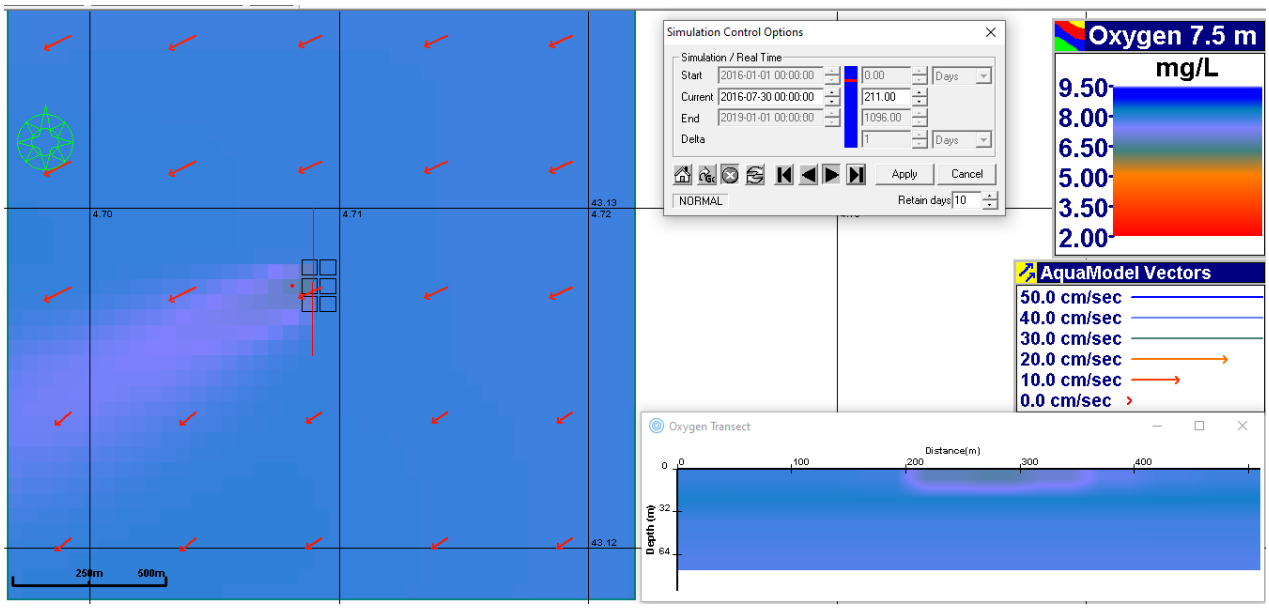


Figure 267: Dispersion of Oxygen deprived waters in July, 1st year

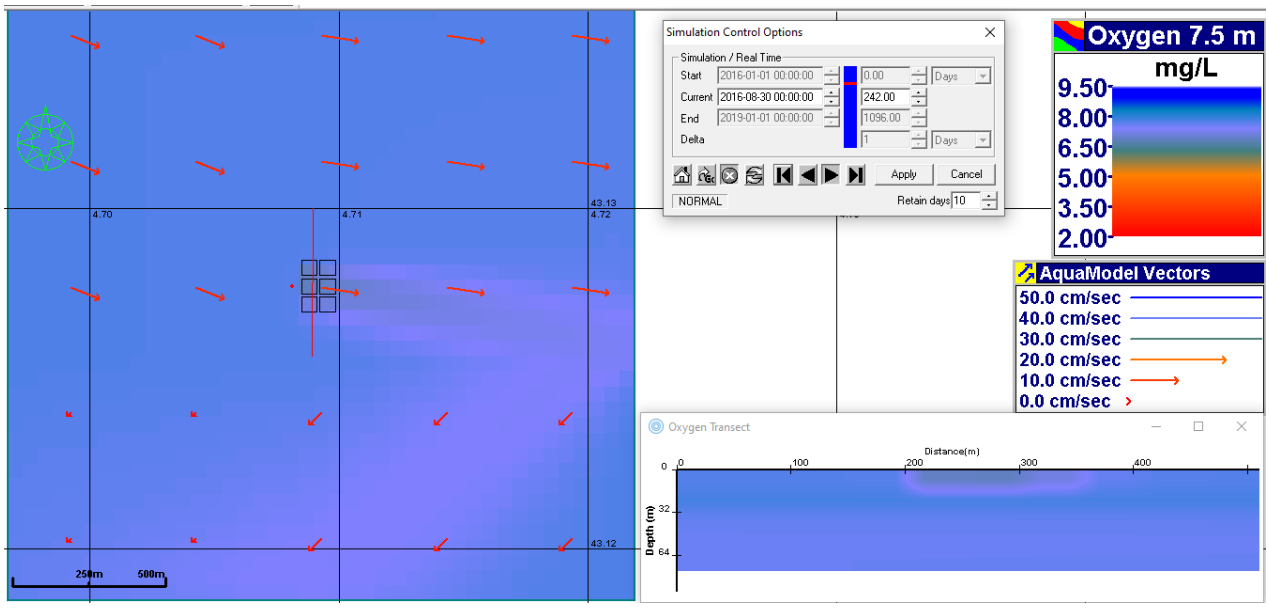


Figure 268: Dispersion of Oxygen deprived waters in August, 1st year

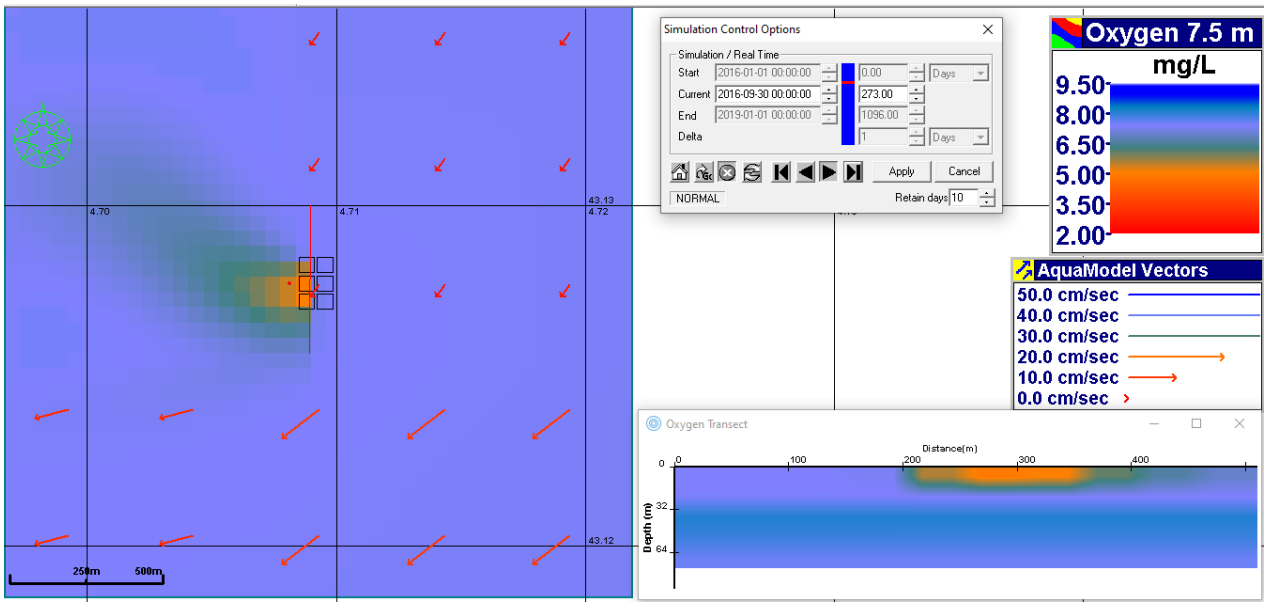


Figure 269: Dispersion of Oxygen deprived waters in September, 1st year

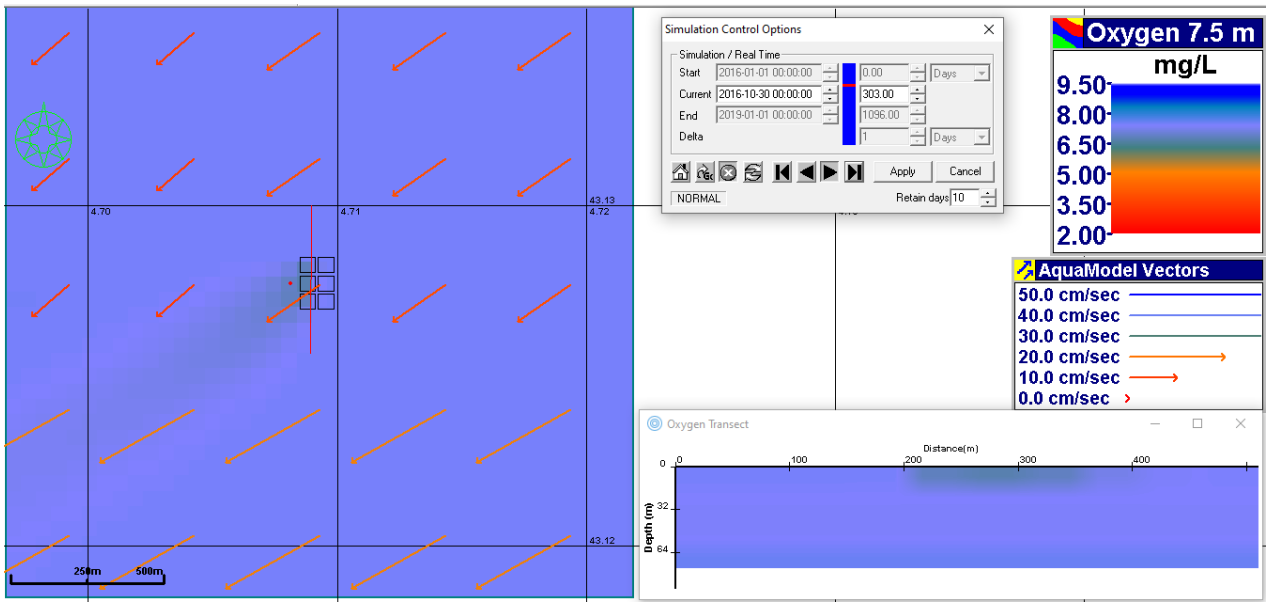


Figure 270: Dispersion of Oxygen deprived waters in October, 1st year

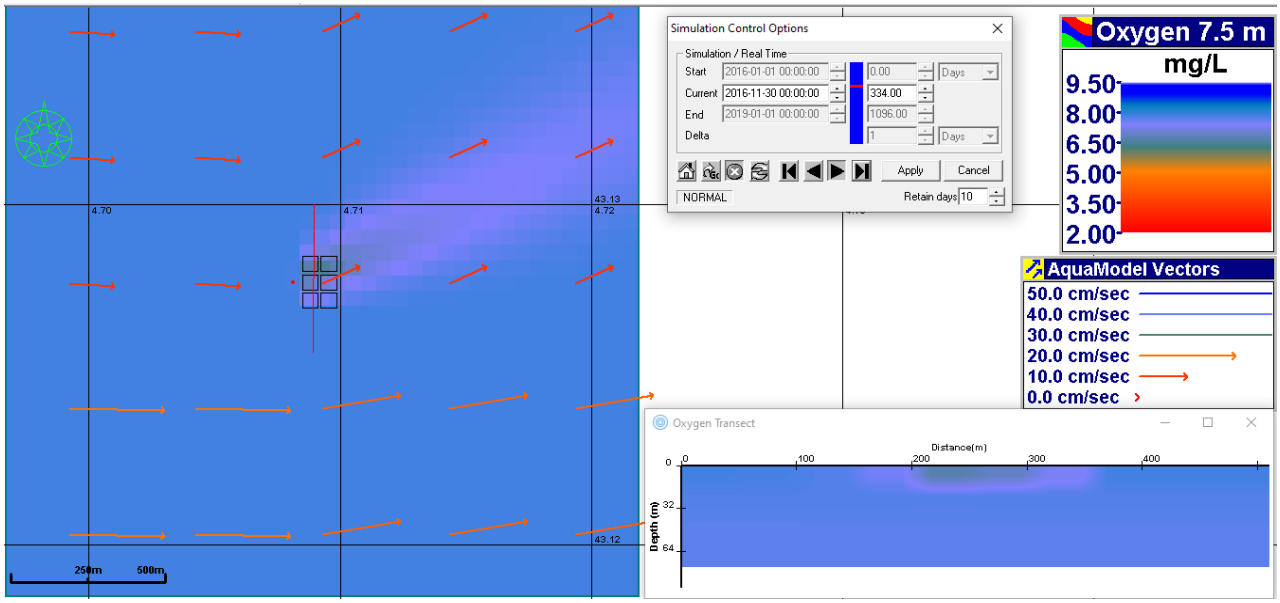


Figure 271: Dispersion of Oxygen deprived waters in November, 1st year

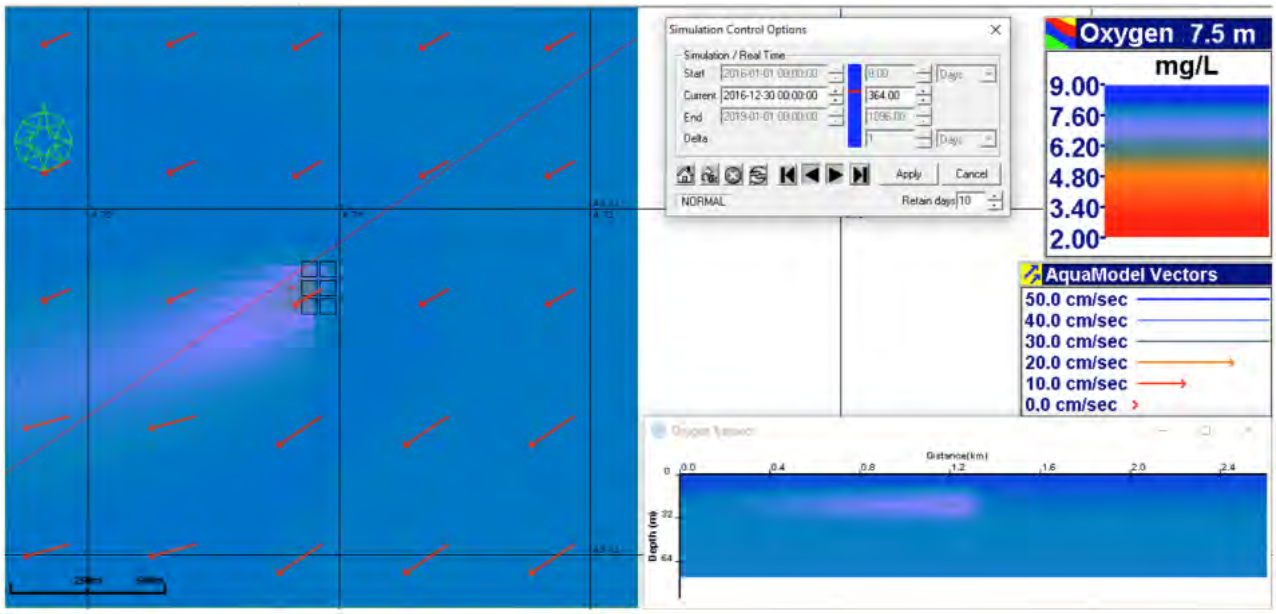


Figure 272: Dispersion of Oxygen deprived waters in December, 1st year

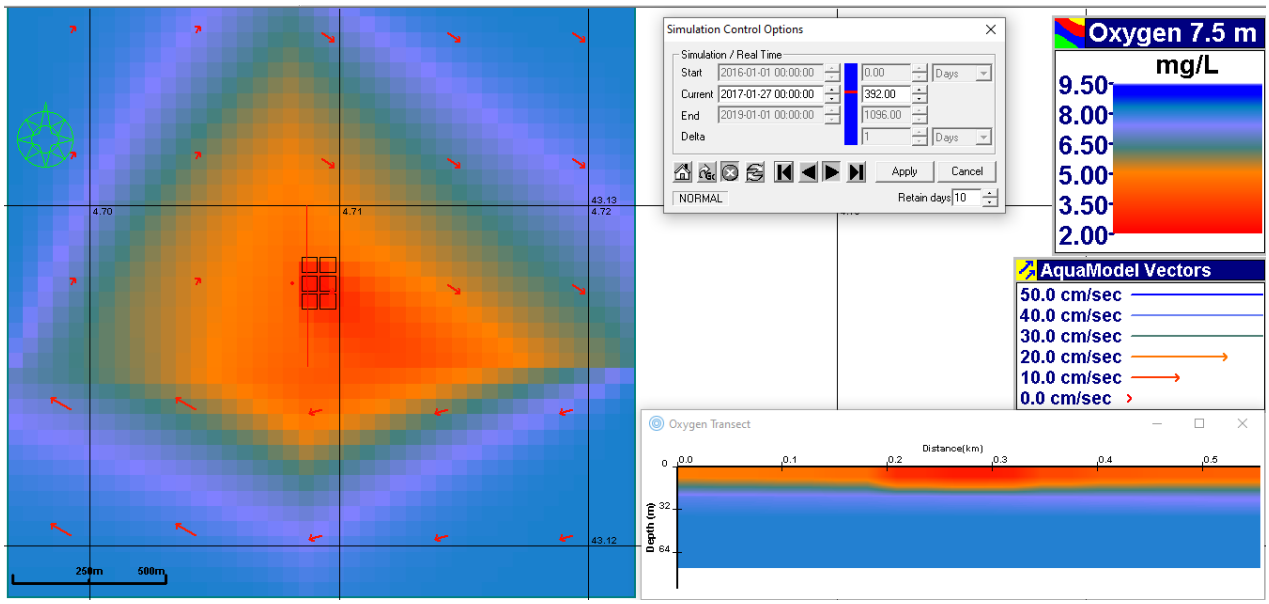


Figure 273: Dispersion of Oxygen deprived waters in January, 2nd year, peak value

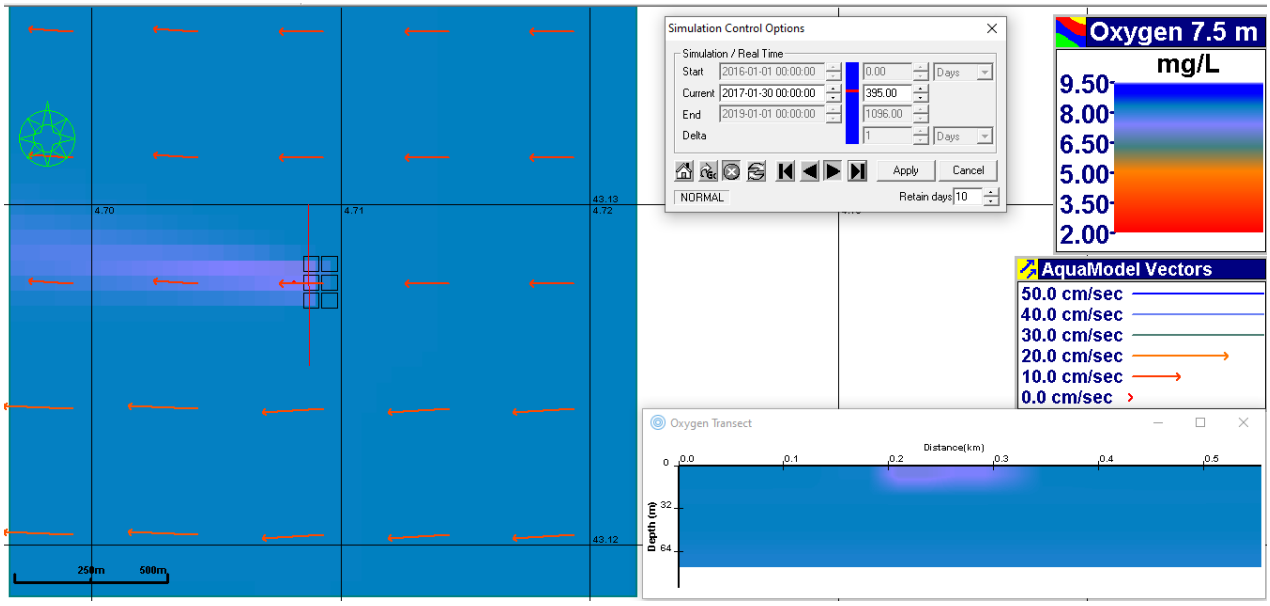


Figure 274: Dispersion of Oxygen deprived waters in January, 2nd year

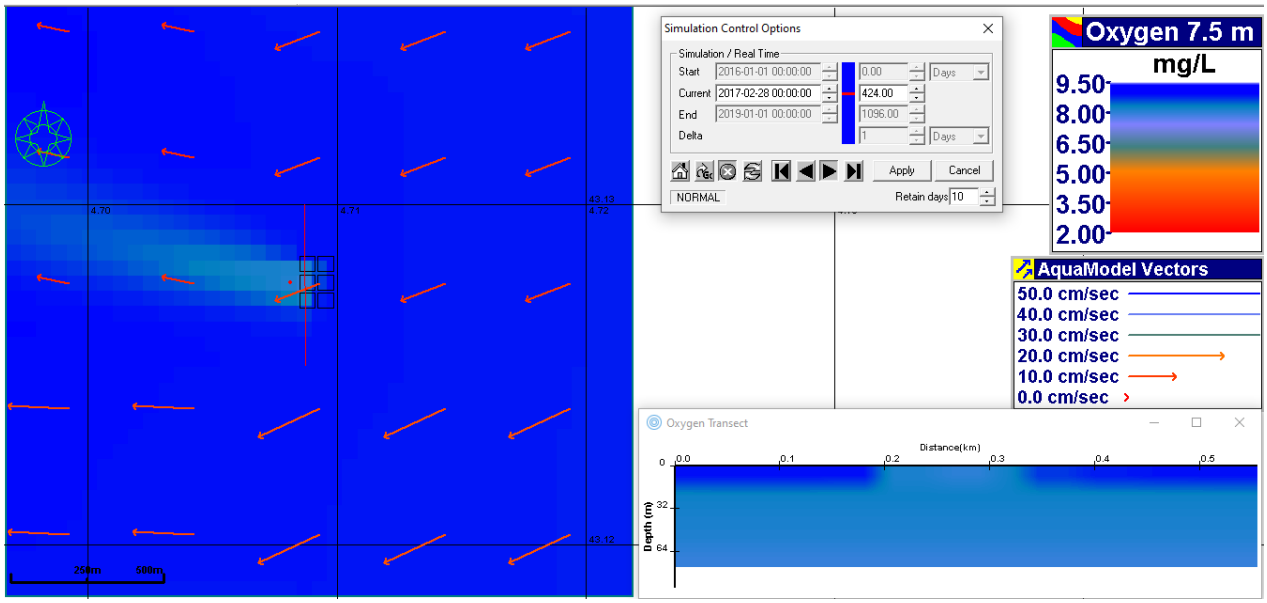


Figure 275: Dispersion of Oxygen deprived waters in February, 2nd year

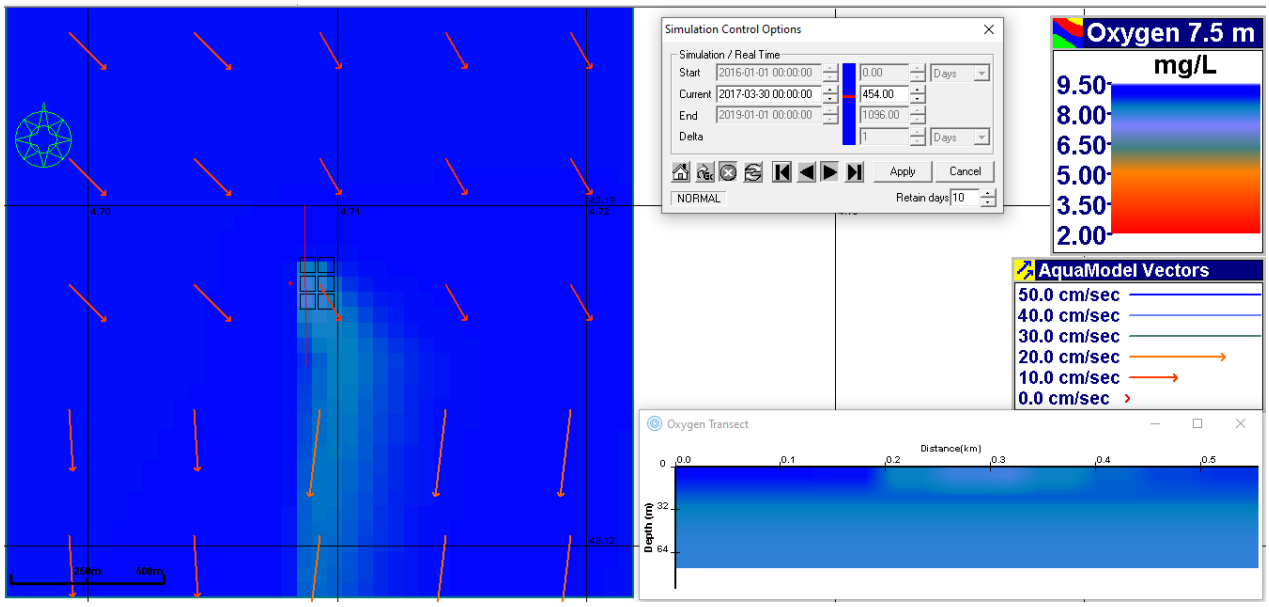


Figure 276: Dispersion of Oxygen deprived waters in March, 2nd year

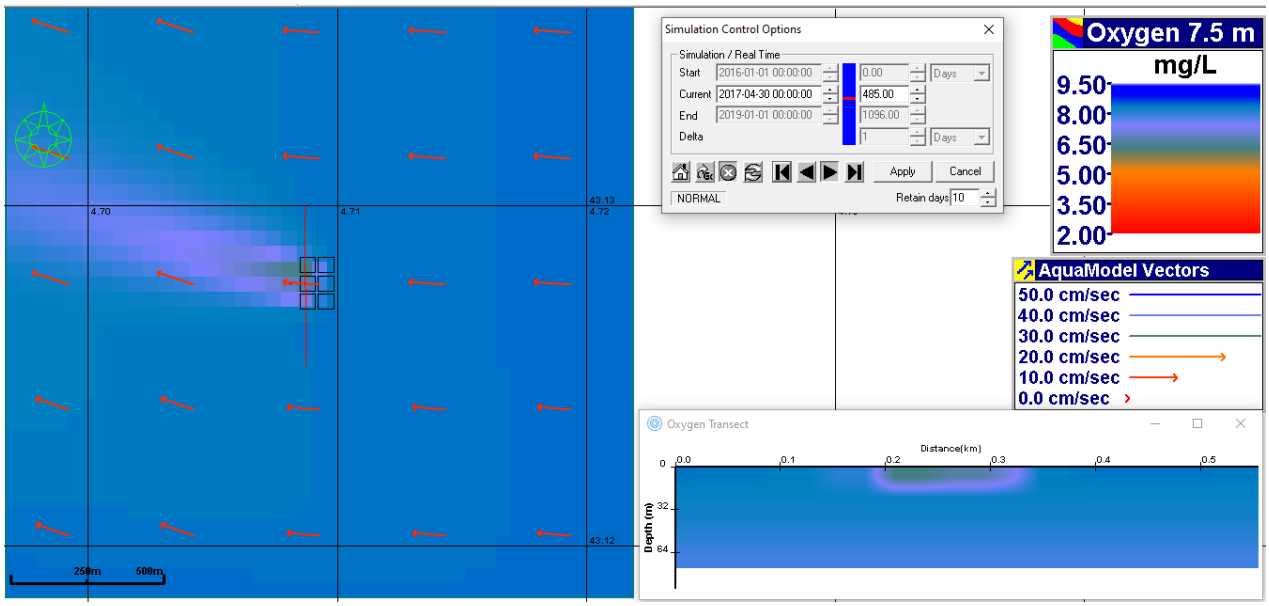


Figure 277: Dispersion of Oxygen deprived waters in April, 2nd year

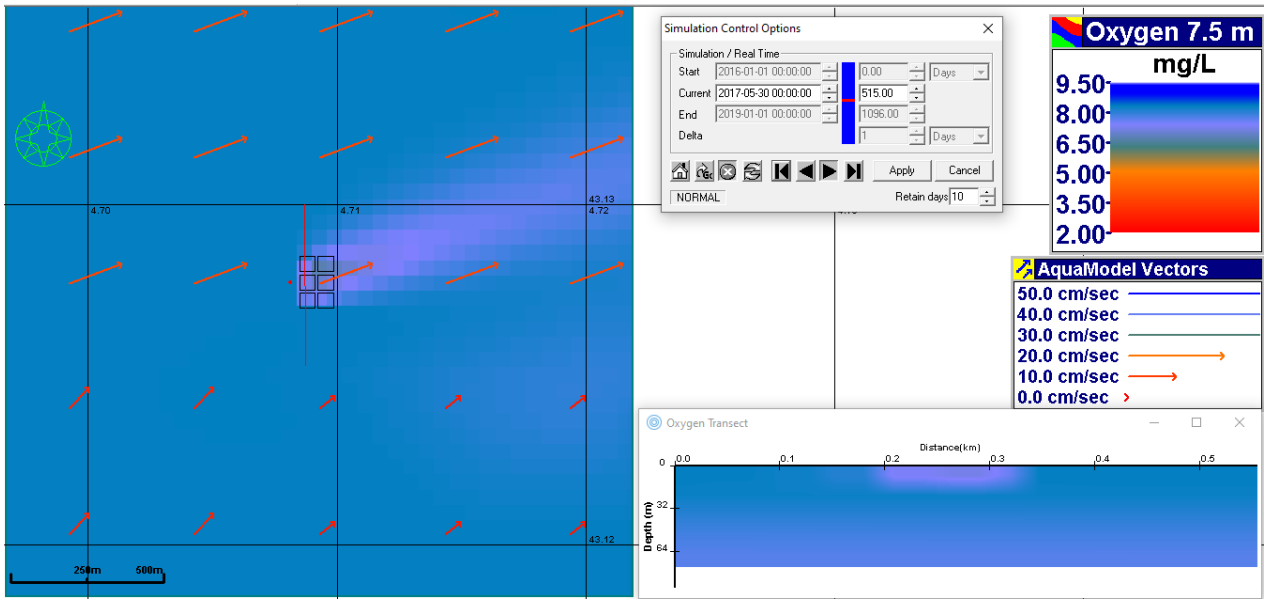


Figure 278: Dispersion of Oxygen deprived waters in May, 2nd year

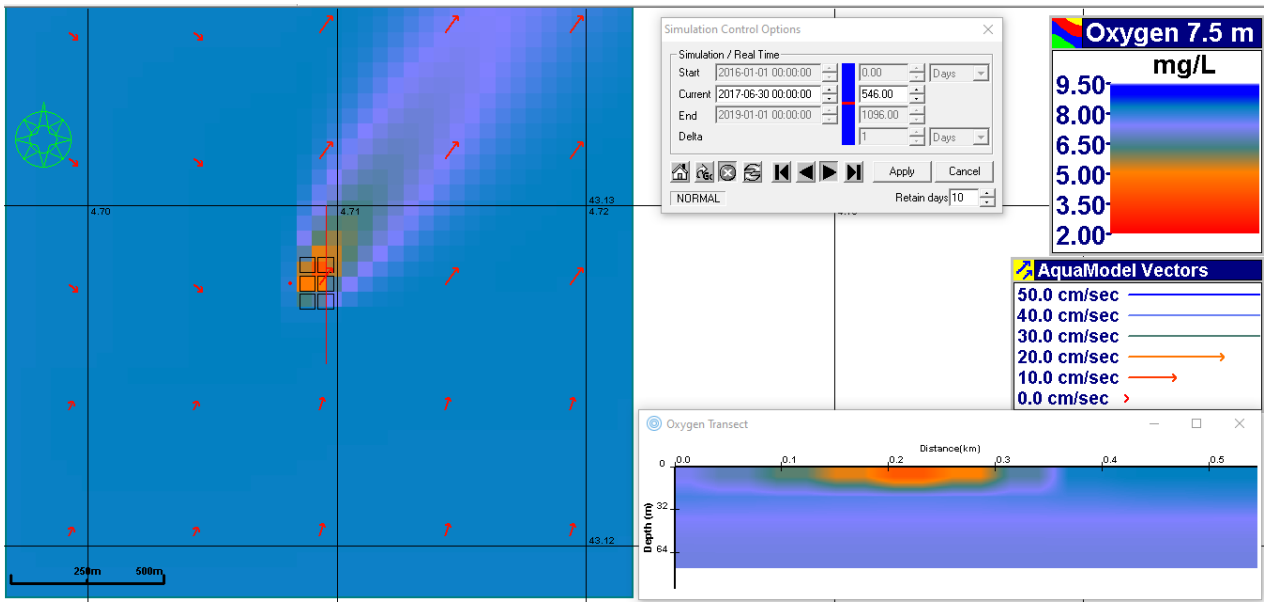


Figure 279: Dispersion of Oxygen deprived waters in June, 2nd year

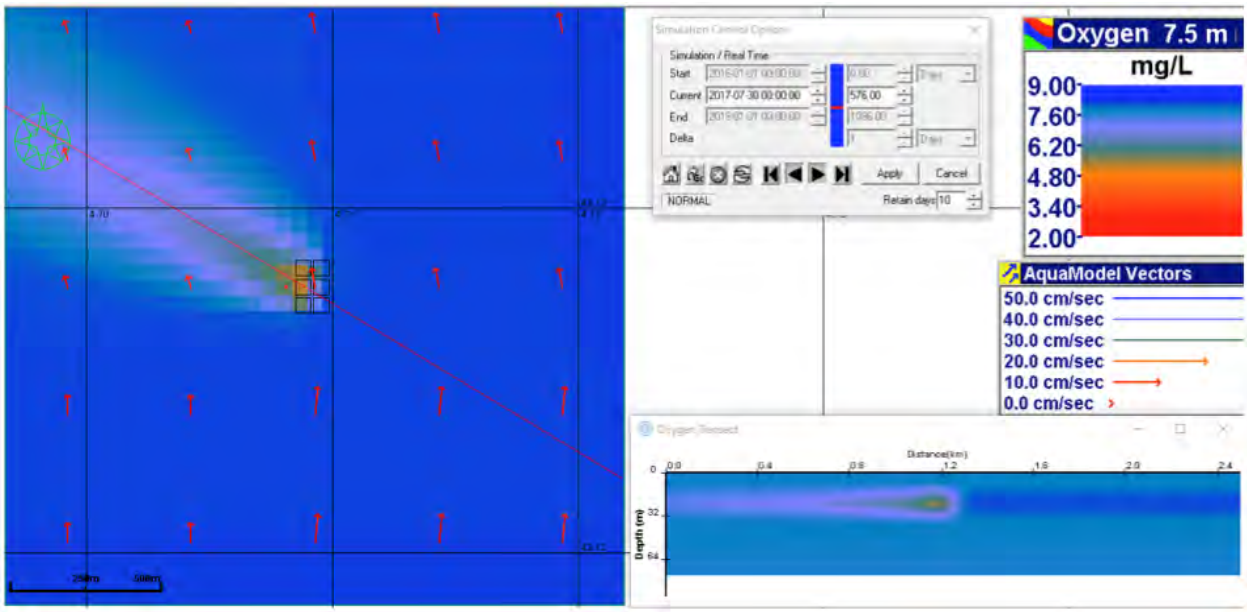


Figure 280: Dispersion of Oxygen deprived waters in July, 2nd year

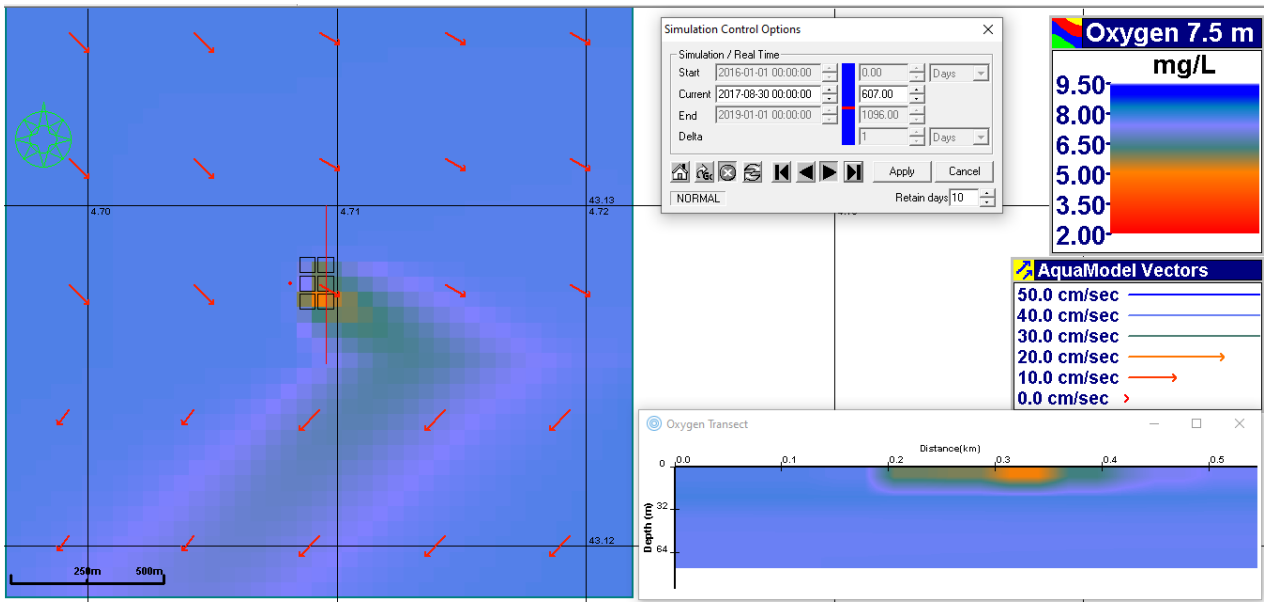


Figure 281: Dispersion of Oxygen deprived waters in August, 2nd year

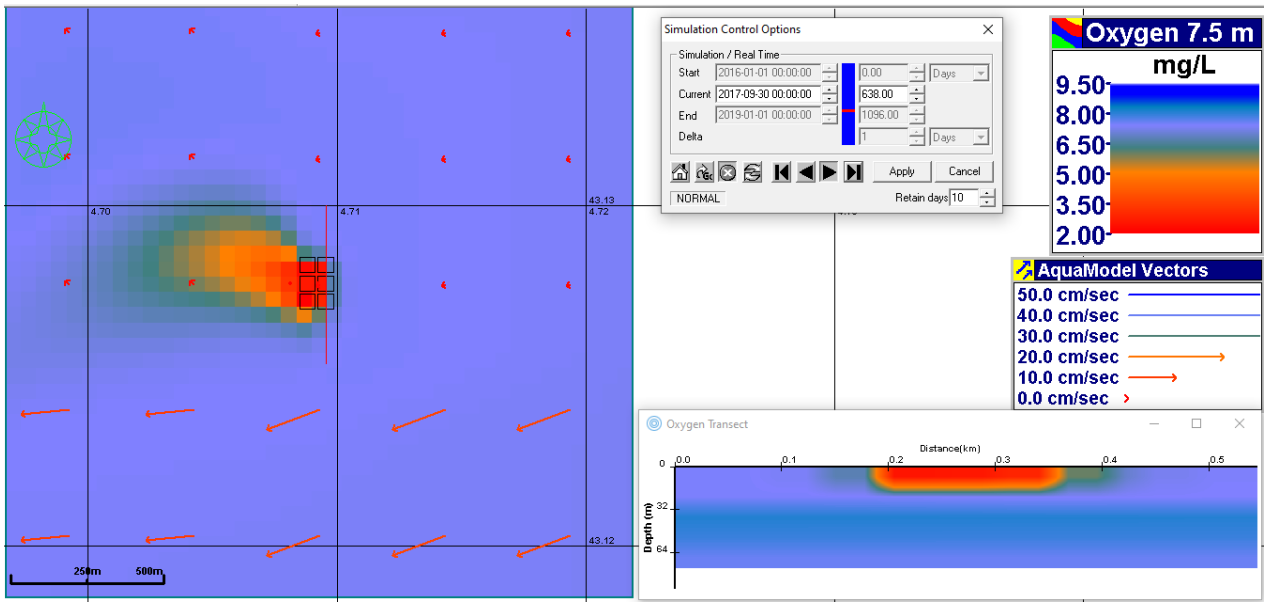


Figure 282: Dispersion of Oxygen deprived waters in September, 2nd year

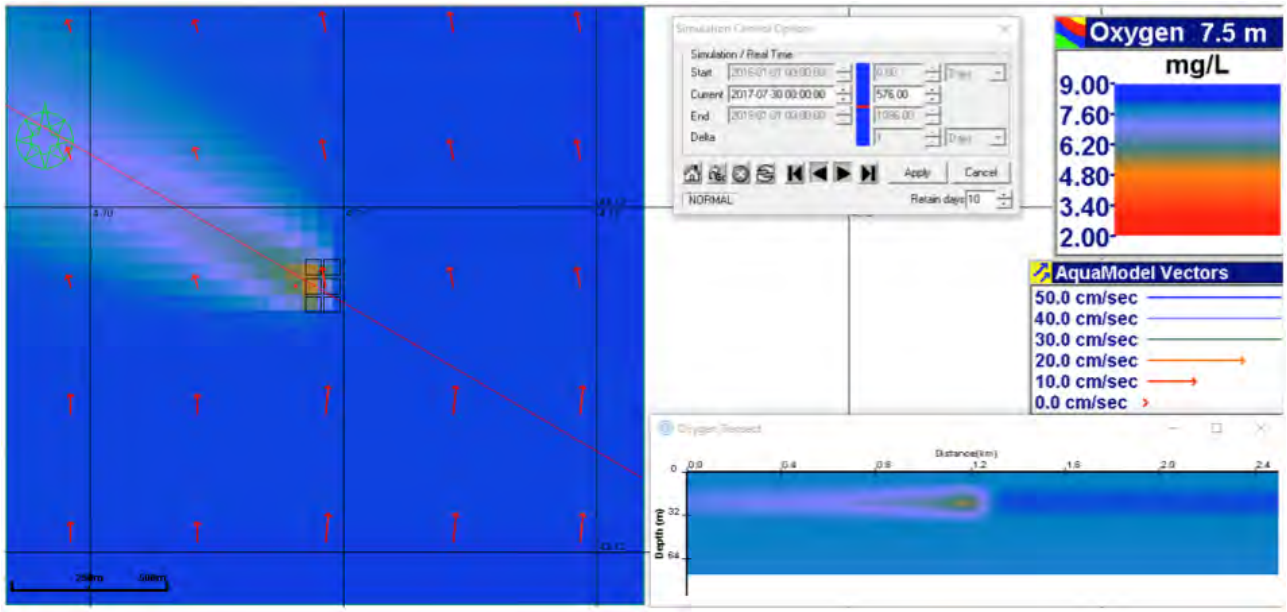


Figure 283: Dispersion of Oxygen deprived waters in October, 2nd year

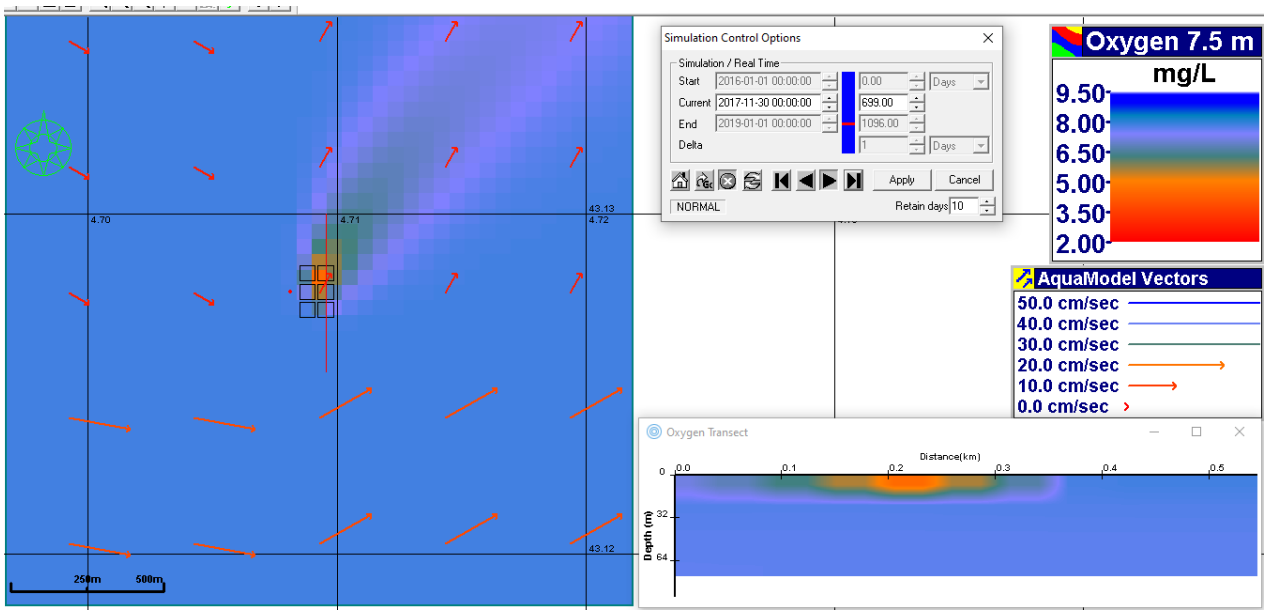


Figure 284: Dispersion of Oxygen deprived waters in November, 2nd year

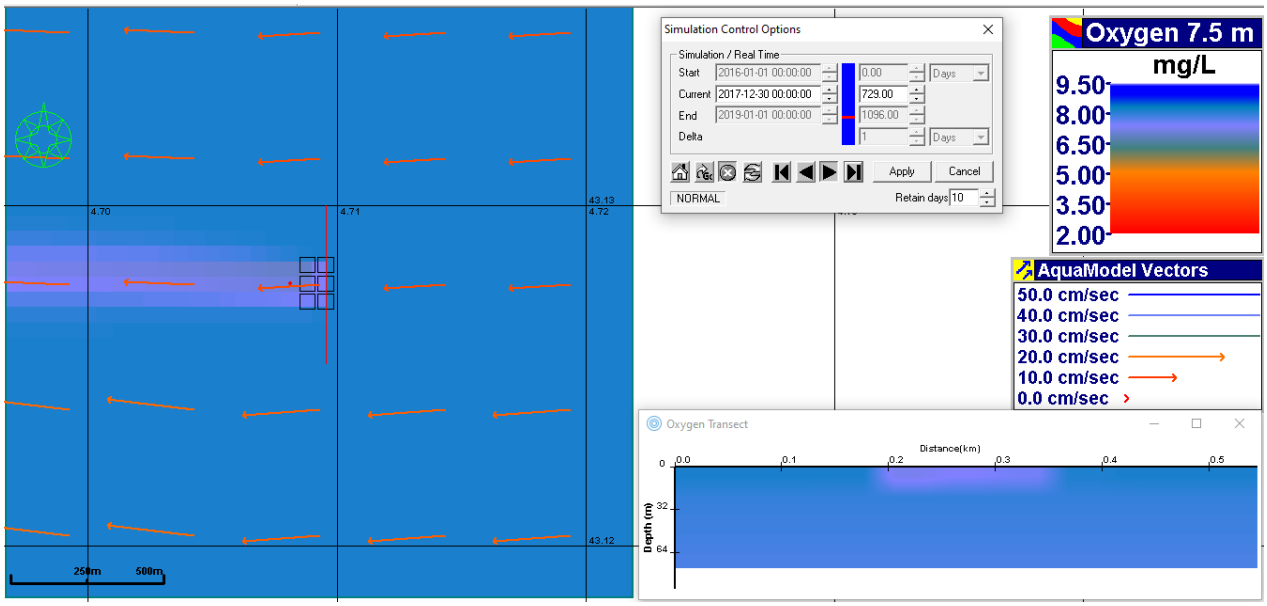


Figure 285: Dispersion of Oxygen deprived waters in December, 2nd year

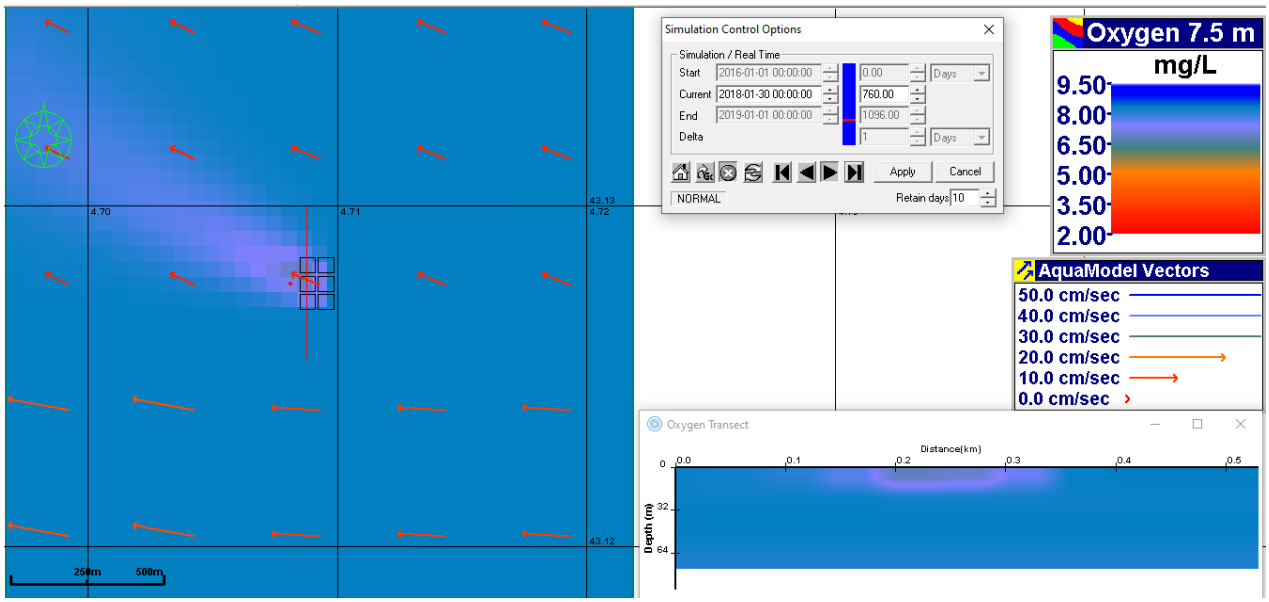


Figure 286: Dispersion of Oxygen deprived waters in January, 3rd year

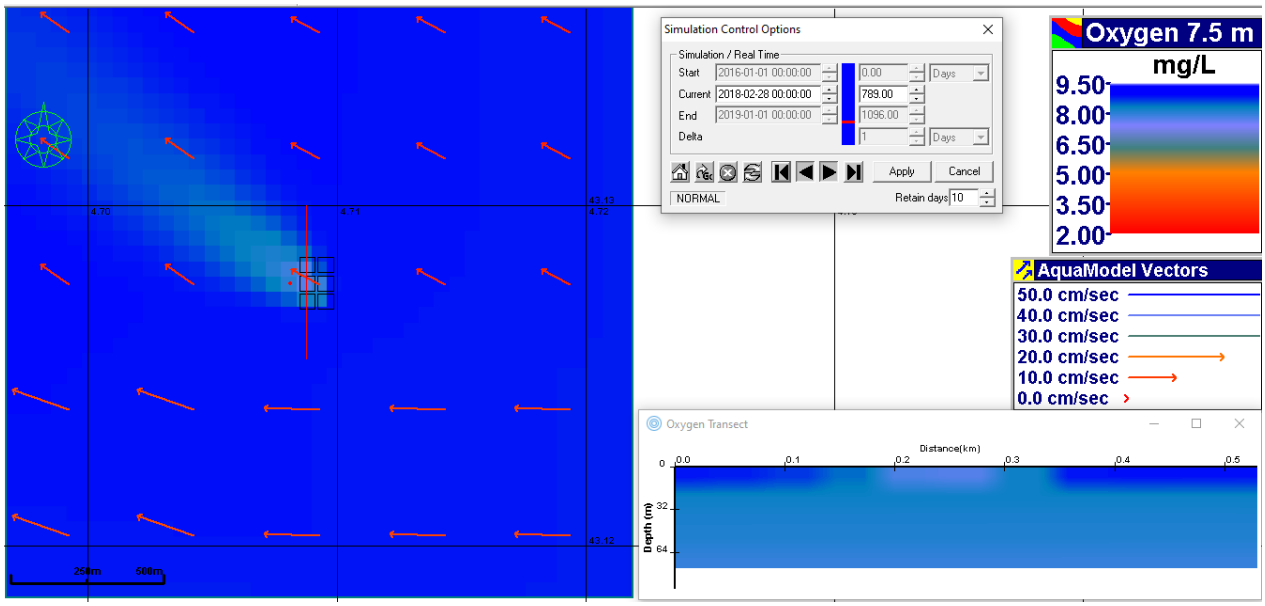


Figure 287: Dispersion of Oxygen deprived waters in February, 3rd year

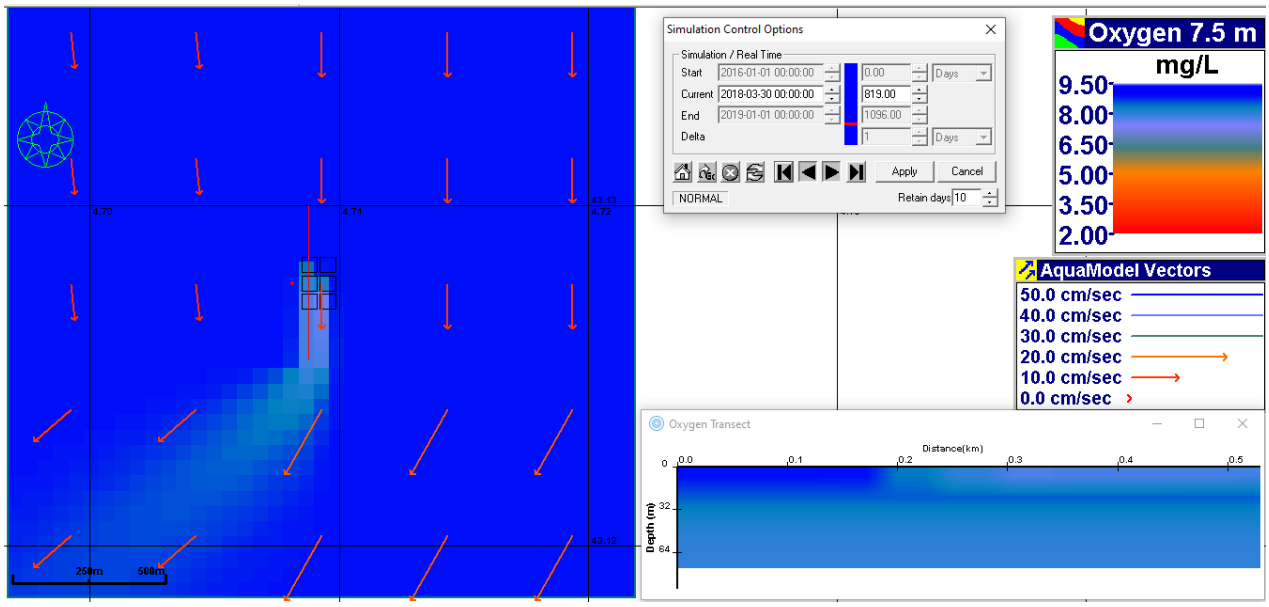


Figure 288: Dispersion of Oxygen deprived waters in March, 3rd year

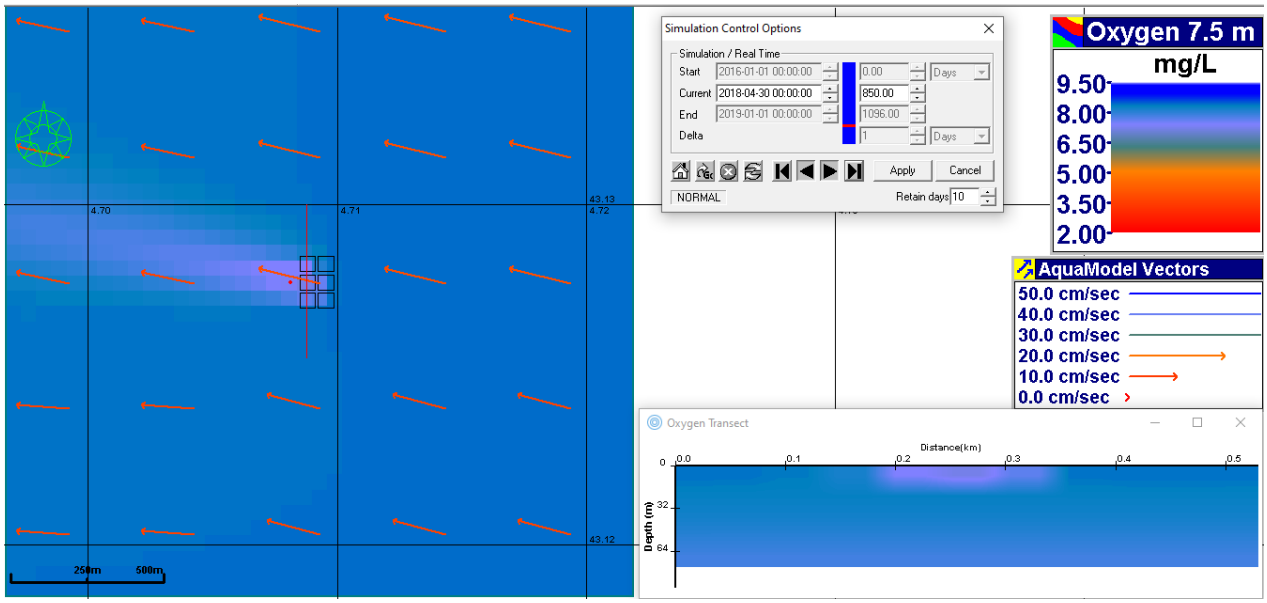


Figure 289: Dispersion of Oxygen deprived waters in April, 3rd year

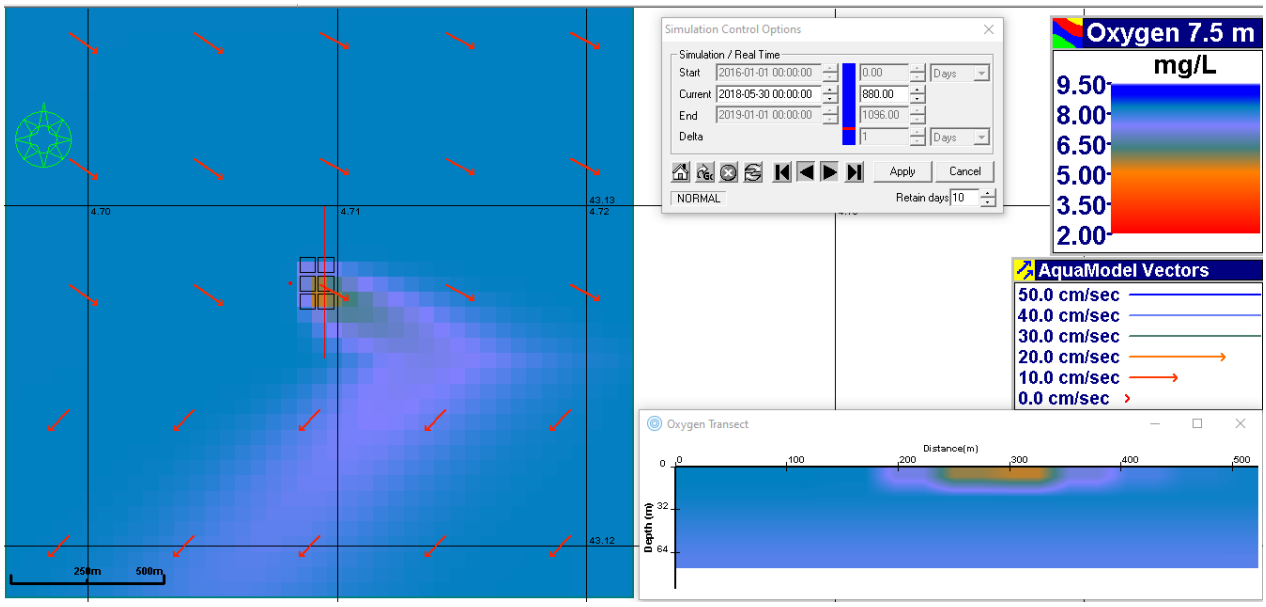


Figure 290: Dispersion of Oxygen deprived waters in May, 3rd year

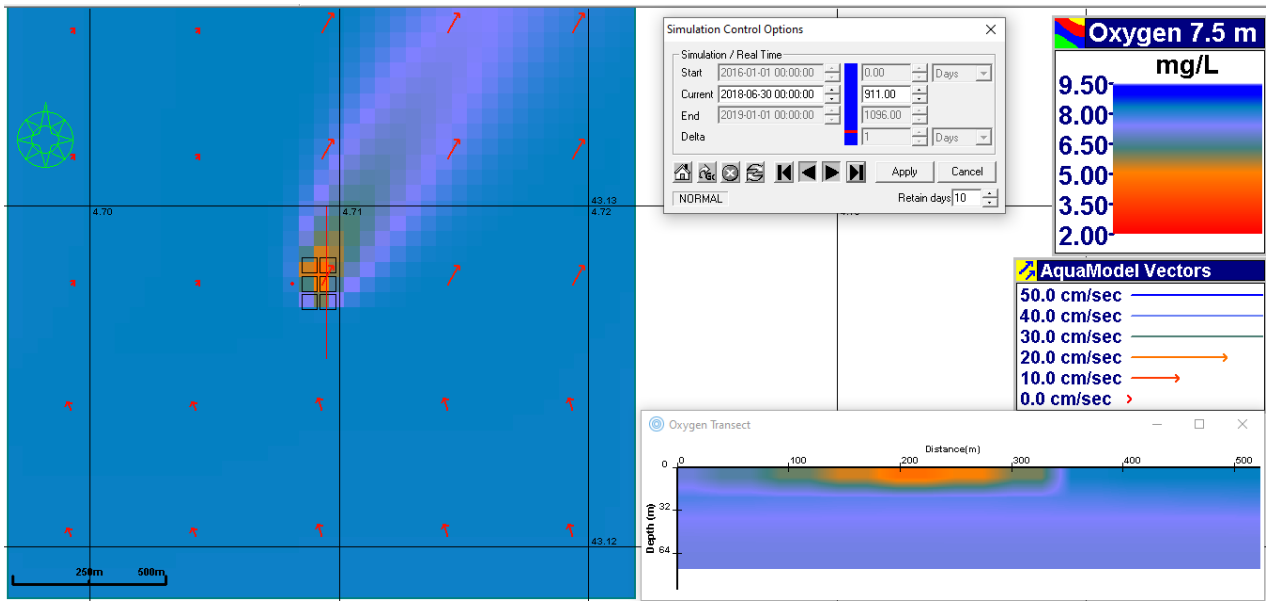


Figure 291: Dispersion of Oxygen deprived waters in June, 3rd year

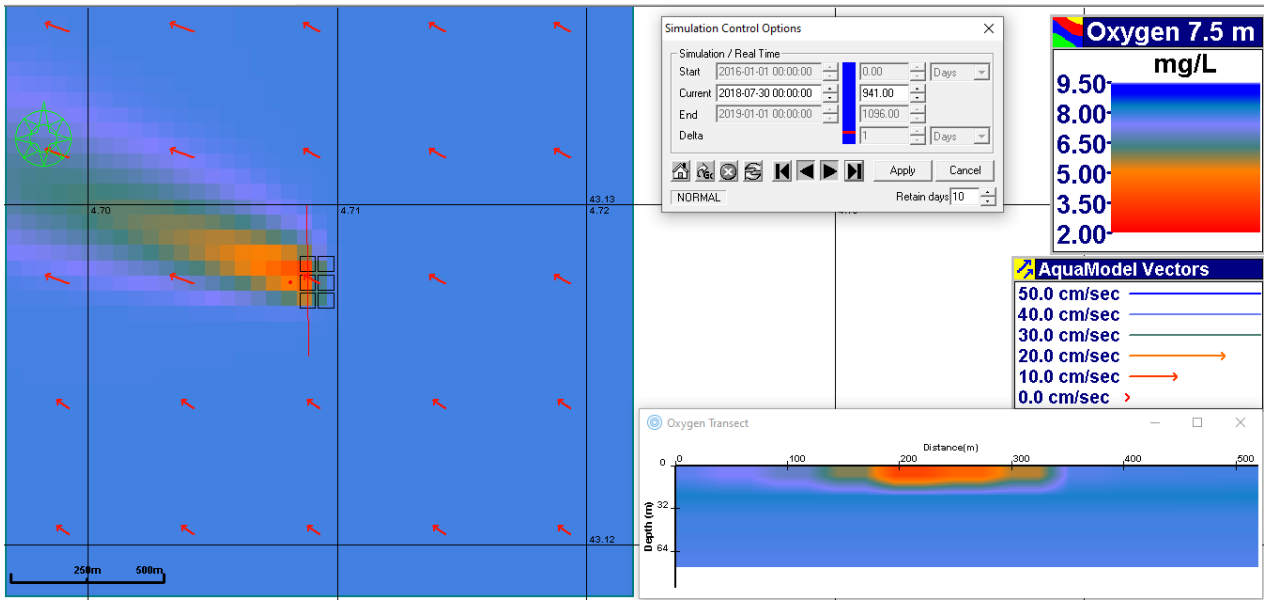


Figure 292: Dispersion of Oxygen deprived waters in July, 3rd year

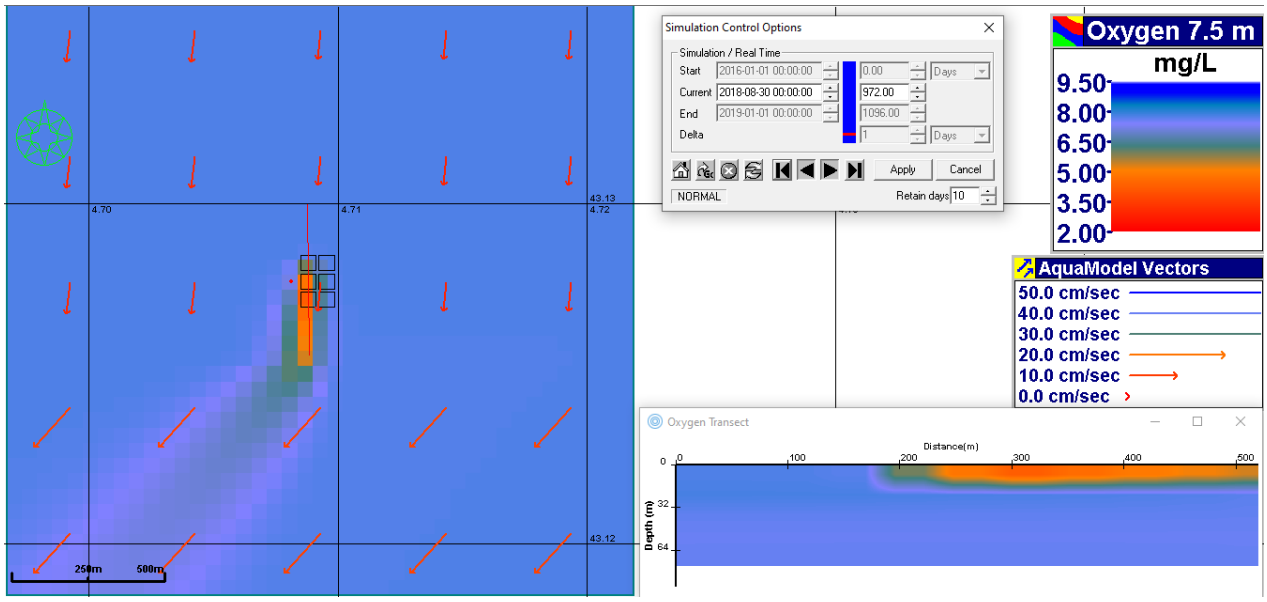


Figure 293: Dispersion of Oxygen deprived waters in August, 3rd year

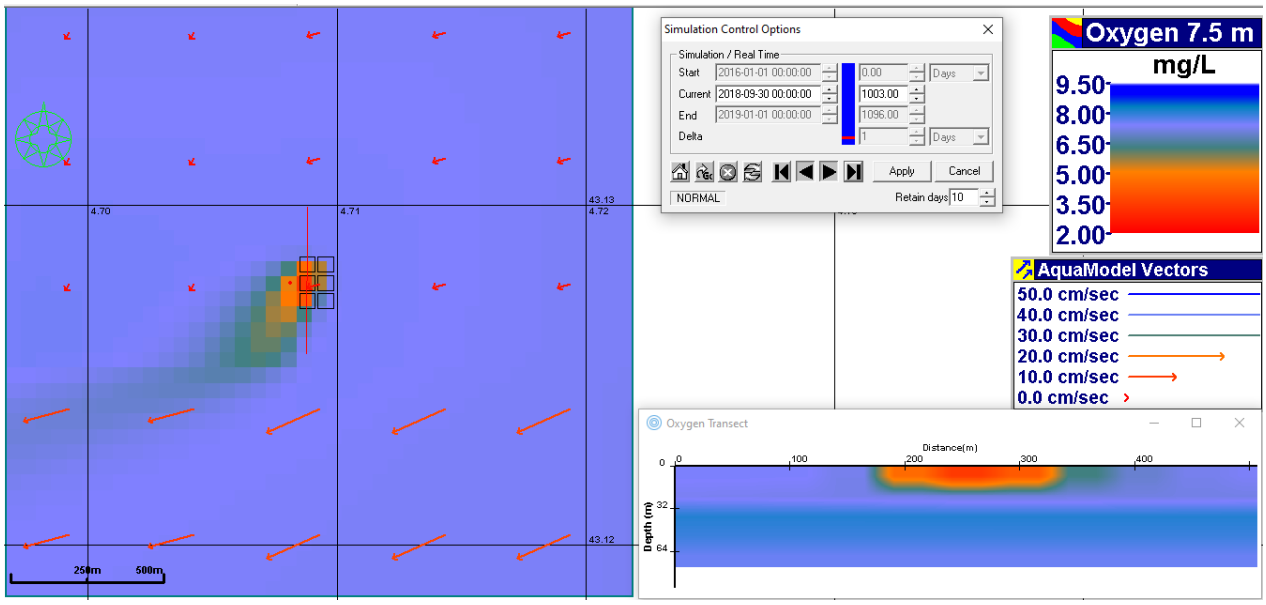


Figure 294: Dispersion of Oxygen deprived waters in September, 3rd year

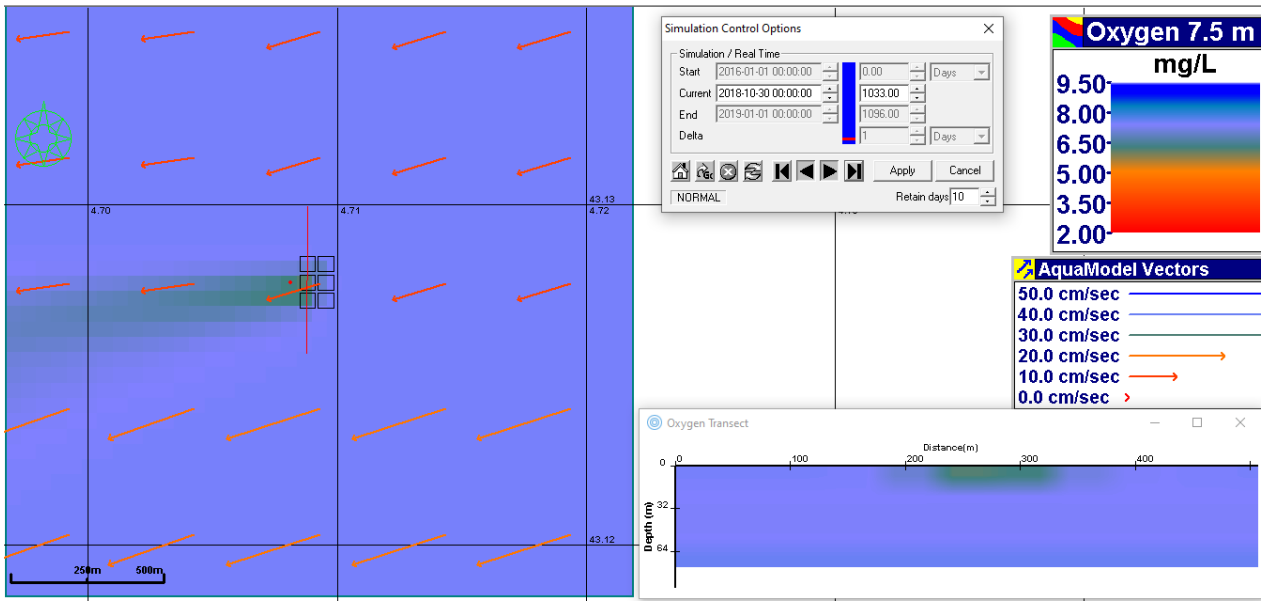


Figure 295: Dispersion of Oxygen deprived waters in October, 3rd year

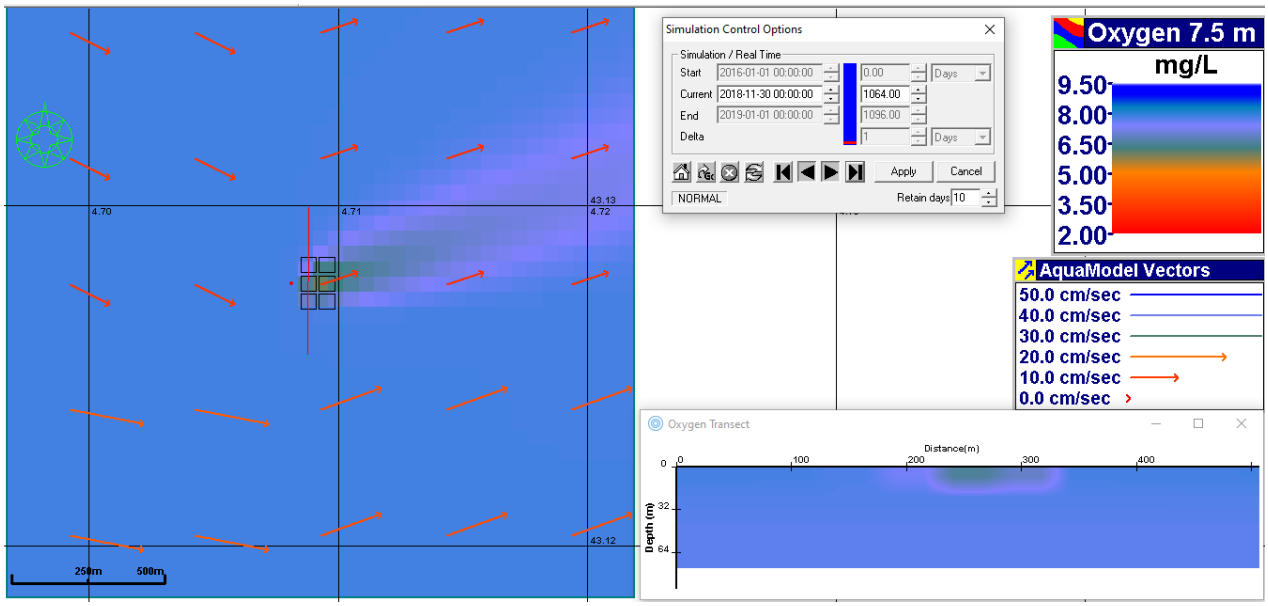


Figure 296: Dispersion of Oxygen deprived waters in November, 3rd year

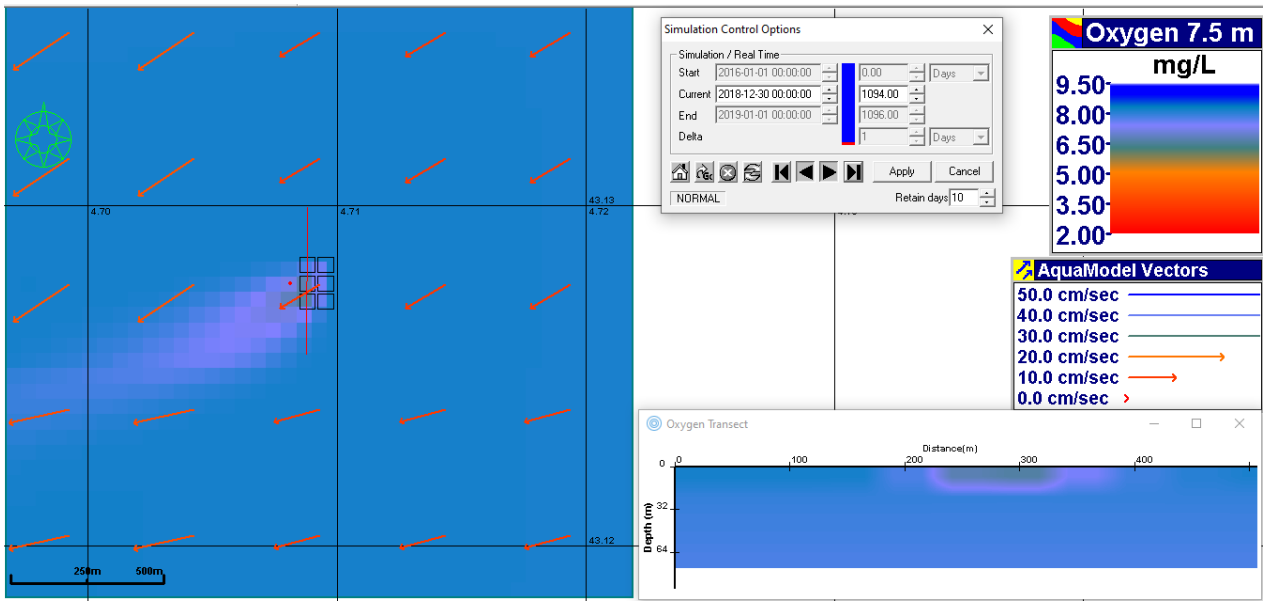


Figure 297: Dispersion of Oxygen deprived waters in December, 3rd year

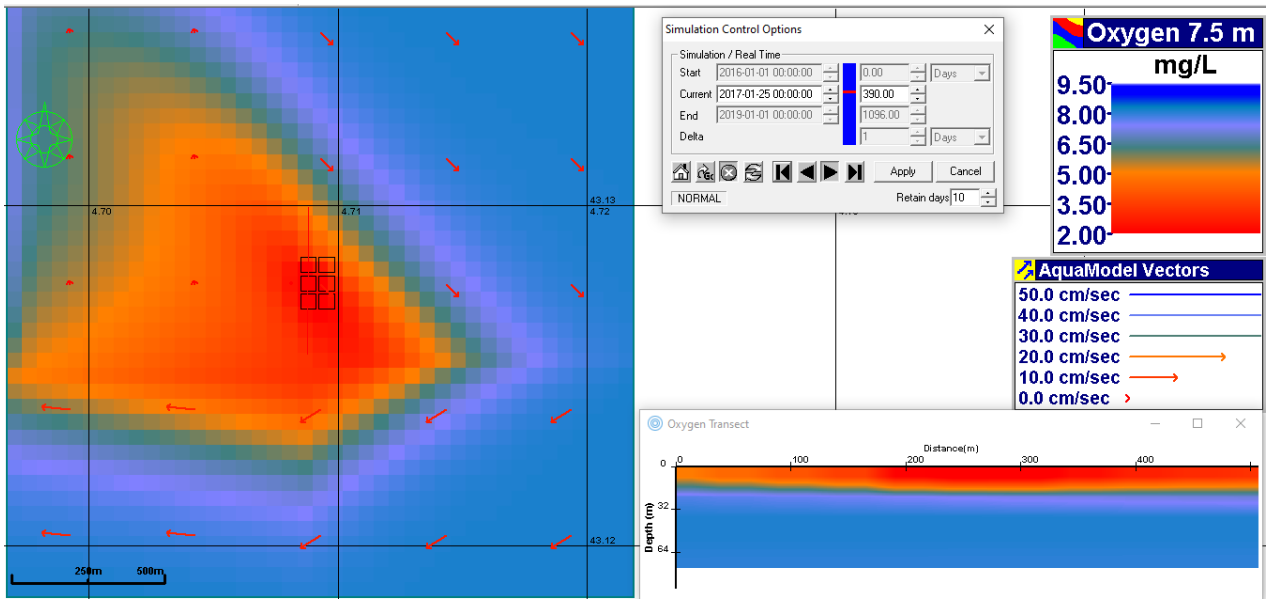


Figure 298: Dispersion of Oxygen deprived waters in January, 3rd year particular case

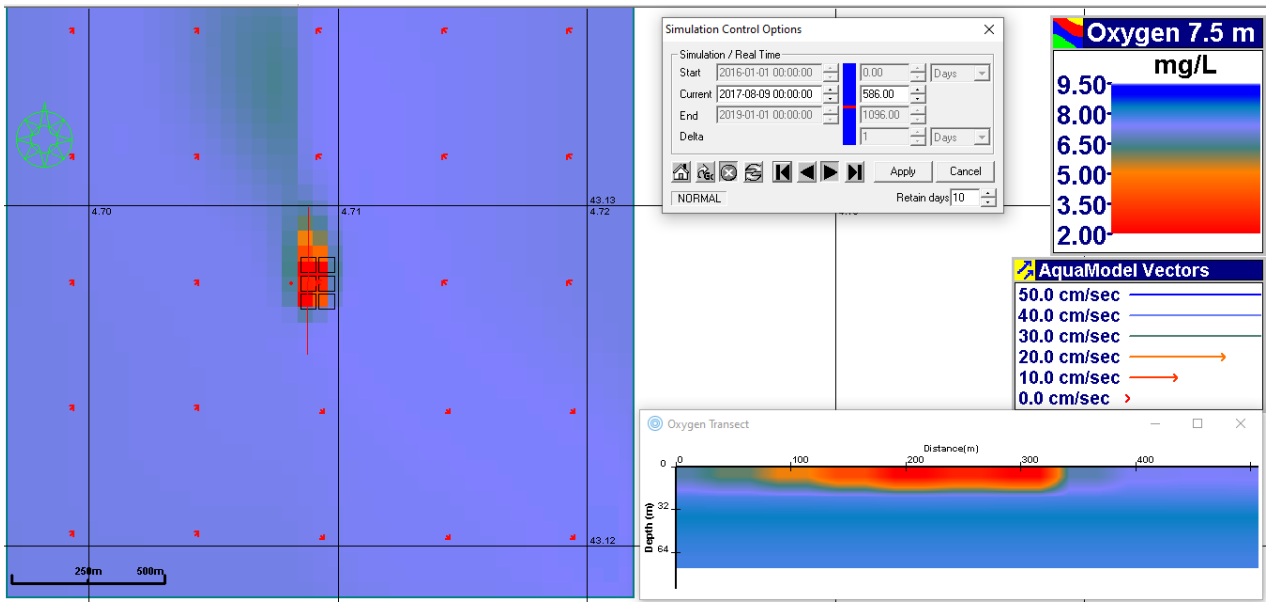


Figure 299: Dispersion of Oxygen deprived waters in June, 3rd year particular case

Considerations

The oxygen consumption, due to high biomass confined in a restricted farming volume, is intense, and lead to a sensitive depletion when circulation pattern is weak. While the surrounding waters are quickly restored at basal Oxygen level, due to the mixing of waters, the area close to the farm (or inside this) seems to be in the need of a more intense renewal to support the high biomass on farming.

The present computation is based on several main parameters, as fish metabolic rate, that is species-specific and depending on temperature; fish oxigen consumption, depending on temperature as well; feeding rate, given as imput by the operator, and flowfield, derived from satellite readings integrated into a comprehensive oceanographic model. Therefore, the oxigen consumption calculation is a rather simple figure, given that the imput data are well known and extensively described in literature. The oxygen supply through the flowfield is rather realistic, and the flowfield is supplied, by an event file set by the operator, by the real oxygen concentration derived from published sources in the same area and on the same time frame.

Provided that input data are concomitant and oxygen consumption a rather simple calculation, the confidence on the result may be considered as medium-high, and enough to support drawing general consideration on effectivennes of the BGF farming system.

5.1.7 Impact on landscape

The evaluation of the visual impact of a project consists in the quantification of the degree of disturbance produced in that context the project lays.

The offshore structure of the BGF project that could have an impact on the landscape is the platform itself and the wind turbine.

At the present design stage, the BGF platform has an elevation above the sea level of 8.6 m, given by 4 m of the deck level plus 4.6 m of external wall; the nacelle has a heigth above sea level of 119 m and the tip of the blade reach a total height above sea level of 205 m.

The overall dimensions of the structure are approximately 210 m x 162 m. It major size, the diagonal, is 265 m.

The platform has a permanent character, being planned to remain in service for a period of 20 years. The BGF intallation site is located at 13.2 nm, say 24.5 km from the nearest coast.

The analysis methodology can be assimilated to a level analysis, as shown in figure 302. The maximum visible distance will be determinated, to then calculate the maximum visibility; finally, the behavior of the visual field of the human eye will be evaluated.

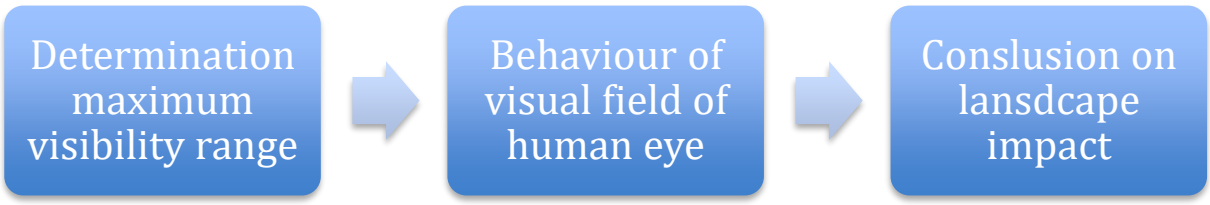


Figure 300: Process of landscape impact evaluation

For the determination of the maximum visible distance of an object, reference will be made to the methodology explained in the nautical charts of the Italian Navy Hydrographic Institute, used to identify the maximum distance at which a lighthouse can be spotted by a boat on the horizon line. This maximum visibility distance is evaluated through simple geometric considerations that link the distance between the two points to the sphericity of the terrestrial globe and to atmospheric refraction phenomena due to a light ray tangent to the starting point that meets the reference point, assuming that the density of the air varies with the altitude (see Figure 303).

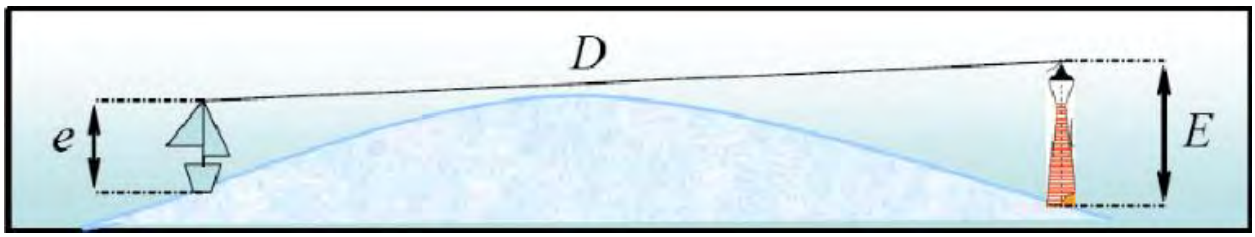


Figure 301: Maximum theoretical visibility of an object, given its height and the observer's height

The maximum distance at which an object can be sighted, defined as Geographical range (D), is given by the relationship between the following components:

- elevation of the object above sea level (E), in this case the tip of the blade of the BGF wind turbine;
- elevation of the observer (e).

The formula that includes these parameters, defined on the basis of trigonometric rules, and which allows to calculate the geographic range, is the following:

Geographic range = 2.04 (√e + √ E) (1)

The resulting geographical range (D) is expressed in nautical miles.

The height of the object above sea level (E) and the height of the observer (e) are measured in meters.

The coefficient 2.04 is a factor that takes into account the trigonometric relations, the phenomena of atmospheric optical refraction and the conversion from meters to nautical miles.

In particular, the value of 2.04 foresees that the value of the coefficient relative to atmospheric refraction is the average daily value, which consists of a dimensionless factor equal to 0.13.

Formula (1) assumes that there is no obstacle between the two points in question.

The following table shows the maximum theoretical visibility distances in kilometers of the BGF platform in relation to different potential altitudes of an observer, both at sea and on the coast.

Table 38: Maximum visibility rang of the BGF blade tip

Blade tip height (m)	Observer height (m)	Visibility range (nm -km)
205	2	32,2 - 59.63
205	10	35,8 - 66.30
205	20	38,5 - 71.30
205	30	40,5 - 75.0
205	50	43,8 - 81.1

On the basis of the calculation of the theoretical visibility, therefore, the BGF platform would theoretically be visible from all inhabited coastal towns located around about 80 km within an elevation of about 50 m above sealevel, given that no obstacles (buildings, trees, hills) prevent the view. Visibility of the blade tip is possible from Marseille to Montpellier, up to Arles and Nimes. Aix en Provence would not be in view, being covered by the coastal hills.

However, it should be kept in mind that, in cases where the plant is located at the end of the field of vision, only the upper portion of the structures is actually visible which, as in the case of blade tip, it consists of elements of very reduced volume compared to the base. Additionally, the low contrast between the sky and the blade color makes the rotor visibility less apparent.

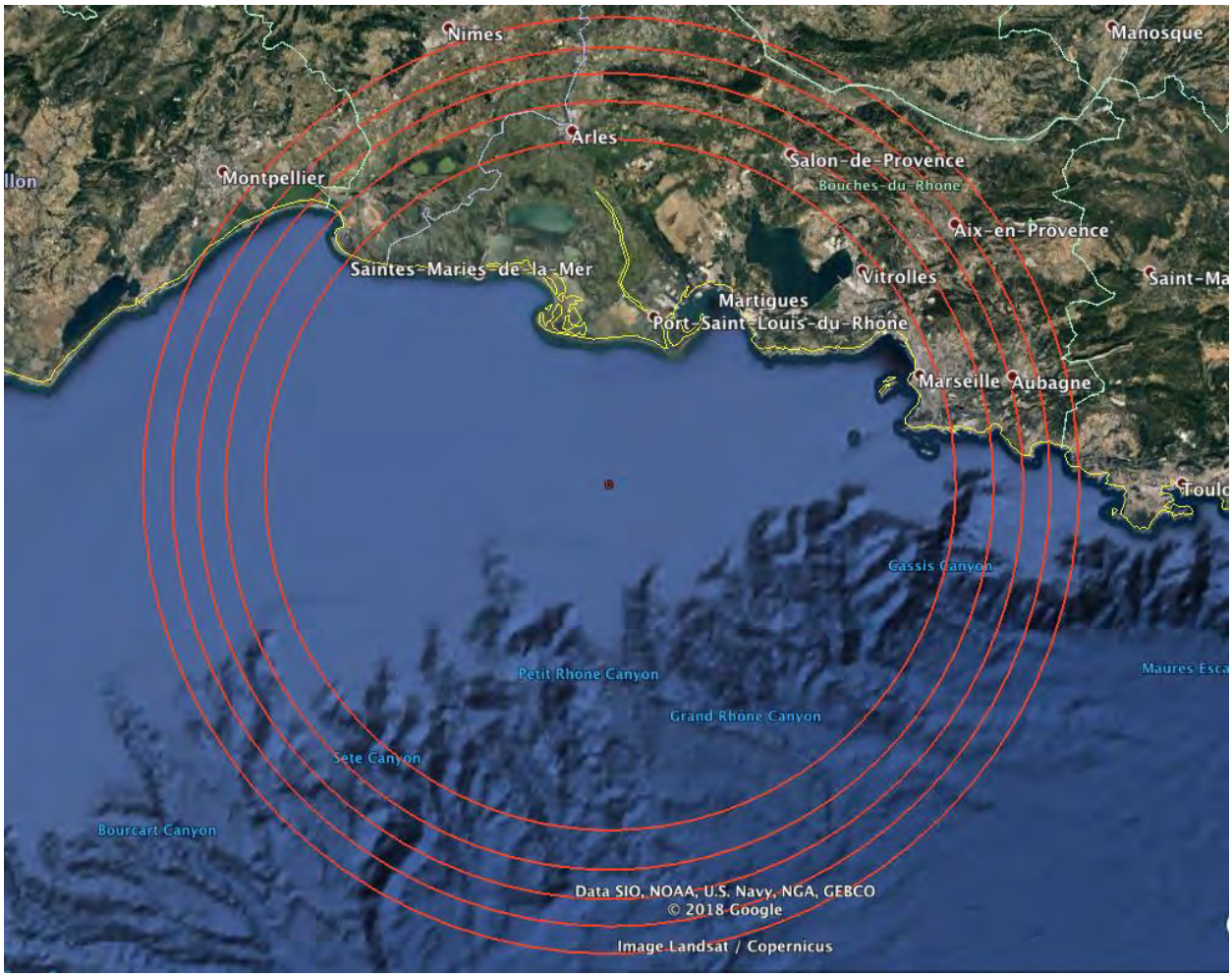


Figure 302: Visibility range of the BGF blade tip, for observers at 2, 10, 20, 30, 50 m above sea level

The degree to which a particular anthropic element can be clearly perceived within an environmental context is called "visibility". The visibility of an element is strictly dependent on the intrinsic physical characteristics of the element (height, width) and on the observer's field of vision.

According to the generally adopted criterion, the visibility of an element within a given context is limited to cases in which the element occupies at least 5% of the complete visual field of the observer's eye.

The measurement of the visual field of the human eye is based on parameters that provide the basis for evaluating and interpreting the impact of an element, evaluating the extent to which the element itself occupies the central field of eye visibility (both horizontally and vertically).

Horizontal visual field

The visual field of each eye taken individually varies between an angle of 94 and 104 degrees, depending on the person. The maximum visual field of the human eye is therefore characterized by the sum of these two fields and therefore ranges between 188 and 208 degrees.

The central field of visibility for most people instead covers an angle between 50 and 60 degrees (see Figure 305). Within this angle, both eyes observe an object simultaneously. This creates a central field of greater magnitude.

This central field of visibility is called 'binocular field'; in this field the images are sharp, the perception of depth and the discrimination between colors are verified.

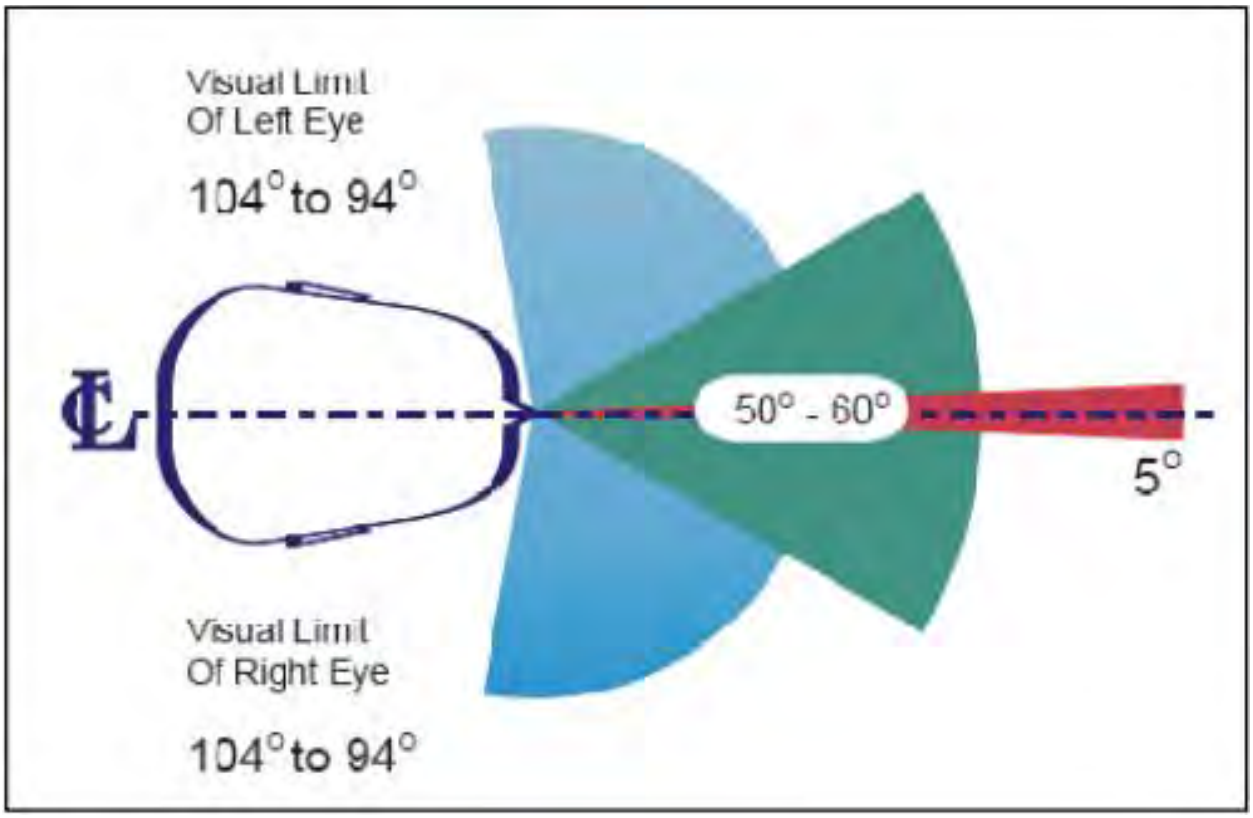


Figure 303: Visibility fields in horizontal plan

The visual impact of an element on the horizontal visual field of man therefore depends on the way in which this element impacts the central field of visibility. An element that occupies less than 5% of the central binocular field is usually insignificant for the purpose of assessing its impact in most of the contexts in which it is inserted (5% of 50 degrees = 2.5 degrees).

Vertical visual field

Evaluations similar to those described for the horizontal visual field of the human eye can be made for the vertical visual field. As shown in Figure 306, the vertical visual field of the human eye corresponds to an angle of 120 degrees (50 degrees above the standard line of sight, which stands at 0 degrees, and 70 degrees below the standard line of sight). The central field of visibility has a width of 55 degrees, while the normal visual cone varies between 10 degrees below the standard line of sight if the observer is standing and 15 degrees below the standard line of sight if the observer is seated.

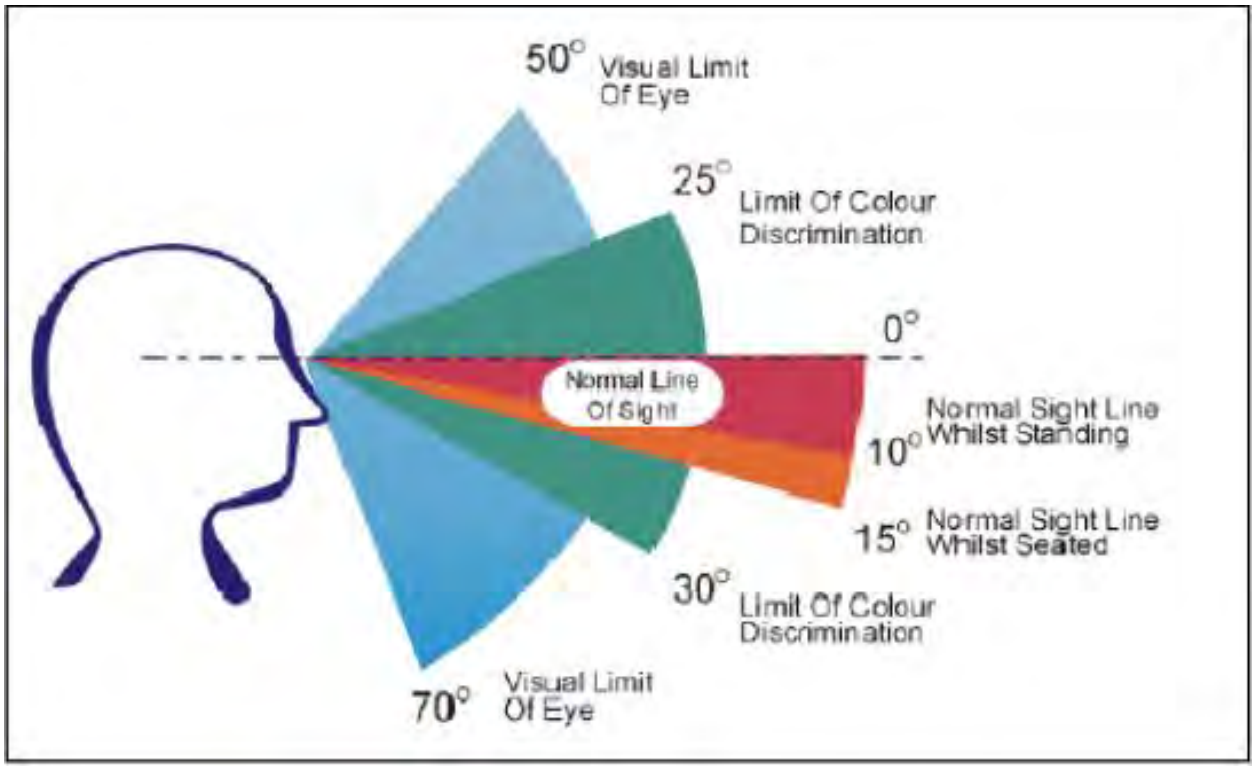


Figure 304: Visibility fields in vertical plan

The visual impact of an element on man's vertical visual field therefore depends on the way in which this element impacts the central field of visibility, as for the horizontal visual field. An element that occupies less than 5% of the normal visual cone occupies a minimum portion of the vertical visual field and is therefore visible only if concentrating directly on the element (5% of 10 degrees = 0.5 degrees).

Visibility based on the horizontal field of view

The visual impact of the offshore structures in project on the horizontal visual field is evaluated considering the maximum horizontal dimension that is the value of the diagonal of the plant:

- BGF Platform: 265 m;

A visual element can be cathegorized as:

- Visually dominant: the element has a dominant role within the visual field;
- Potentially distinguishable: the element is distinguishable and the level of disturbance strongly depends from the degree of contrast with the surrounding landscape;
- Insignificant: the element, although visible, does not significantly interfere with the view of the landscape.

The results show that at the distance to which the offshore structure is placed, the landscape disturbance introduced by them can be considered insignificant, as it is limited to a minimum

portion of the horizontal field of view. In particular, considering that the BGF platform has a height of 8.6 m, the visibility range is 22.6 km for an observer at 10 m, say, can hardly be seen from the nearest coast.

At the minimum distances of 24.5 km for the platform from the nearest land, in case of exceptional visibility, this will occupy at most about 0.6 ° of the horizontal field of view. To reach a significant visibility, say have the BGF platform covering 5 % of his visual field, the observer has to get closer than 7 km from BGF.

Visibility based on the vertical visual field

An analogous reasoning can be conducted for the vertical visual field, in order to verify at what distance the considered element is reduced to an imperceptible component of the field of view. The trigonometric calculation was carried out considering the maximum heights of offshore structures, ie:

- BGF wind turbine blade tip : 208 m;

Similarly to what emerged for the horizontal field of view, the result of the analysis of the vertical field of view shows that, at the distance to which the offshore structure is placed, its visibility from the coast is not significant, being necessary to get closer than 5.2 km to the BGF platform to get an angle wider than 2.5 °. From the nearest coast, the vertical visible angle for a structure of 208 m is > 0.5 °. The disturbance to the landscape introduced can be considered insignificant, as it is limited at a minimum percentage of the vertical visual field.

5.1.8 Risk of major accidents

This paragraph will be addressed in a later stage, when the design of devices preventing intrusions or fish escapees will be more mature.

5.2 RANK OF COMPONENTS

The four components taken in account in the present study will be affected by impacts caused by the BGF activity with different orders of magnitude:

- Seawater
- Marine communities
- Terrestrial communities
- Landscape

However, it's opportune to assign a rank of importance to any resource involved into the BGF operational life, with the aim of highlighting or decreasing its intrinsic value on the basis of two criteria, Rank A and Rank B respectively.

Rank A is a criterion that aims to objectively assign a weight to the resource, based on its availability and functionality; ranks from 1 to 5 are characterized in Table 39 below:

Table 39: Rank A

Rank A	Resource feature	Value assigned
1	Common	0.75
2	Common locally	1.5
3	Rare	2.25
4	Protected	3
5	Strategic/Structural	3.75

The rationale of this ranking system lies in the evaluation of ecosystemic importance of the resource.

Rank B is a criterion that accounts for the stakeholders' interest towards the resource conservation, somehow aggregating a concern on the state of the resource. Ranks are from 1 to 5, as characterized in Table 40 below:

Table 40: Rank B

Rank B	Resource feature	Value assigned
1	Scarce- no concern	0.25
2	Low - Some stakeholders' secundary concern	0.5
3	Medium – Most of stakeholders' secundary concern	0.75
4	High - Some stakeholders' primary concern	1
5	Maximum- Most of stakeholders' primary concern	1.25

The Ranks A and B are added to obtain the definitive resource rank.

Definitive rank value range between 1 and 5.

Definitive ranks will be used as correction factors to determine the overall impact on the resource.

Table 41: Definitive rank values

Component	Resources	Rank A	Rank B	Definitive rank
Sea water	Nutrients	0.75	0.25	1
	Oxygen	0.75	0.25	1
Marine communities	Phytoplankton	0.75	0.25	1
	Benthos	0.75	0.5	1.25
	Odontocetes	3.75	1	4.75
	Mysticetes	3.75	1	4.75
	Fish	1.5	1	2.5

	Seals	3.75	1	4.75
	Sea Turtles	3	1	4
	Pelagic birds	3	0.75	3.75
	Migratory birds	3	1	4
	Bats	3.75	1	4.75
Landscape	Visibility	1.5	1.25	2.75

This rank assignment is based on consideration drawn from the specificity of the environmetal context and of the legal frame where the BGF is expected to be installed. The proximity with a number of protected areas at maximum level, the presence of iconic animals as seabirds, turtles and cetaceans, the relevant turistic pressure and the public concern on conservationist themes have driven the categorization of the ranks, leading to a high weight to pressures involved in nature conservation.

This procedure maintains in itself a certain degree of subjectivity, unfortunately not completely avoidable in impact evaluation procedures.

5.3 IMPACT MATRIX

The impact matrix is calculated as result of several matrixes, showing the detailed characteristics of the impact and concurring in determining the severity of impact. The used method is a simplification of the Leopold Matrix (Leopold et *al*., 1971), adding 2 rank coefficients to weight the impact significance. The impact feature matrices (Frequency, Extension, Duration, Reversibility) are similar to those recommended in UNI EN ISO 14001 application.

Frequency: it indicates how frequently the stressors acts, or how many times the activity generate the pressure.

FREQUENCY	
1	RARE, 2 TIMES/YRS
2	INTERMITTENT, 4 TIMES/YRS
3	REGULAR, MONTHLY
4	RIPETITIVE, 1-2 TIMES/WEEK
5	CONTINUOUS, 3 TIMES/WEEK

Spatial extention: it display the amplitude of geographical effects of the stressors, e.g. for migrating bird is approching the species areal.

SPATIAL EXTENSION	
1	ISOLATED, ON SITE
2	CONFINED, INFLUENCING LOCAL COMMUNITY
3	LOCAL

4	REGIONAL, BEYOND LOCAL COMMUNITY
5	GLOBAL

Duration: indicates the lasting in time of stressors effect, e.g for reproducing animals, until new specimens reach sexual maturity in the same population.

DURATION	
1	LOW TERM
2	3-12 MONTHS
3	1-3 YEARS
4	> 3 YEARS
5	LONG LASTING

Reversibility, indicating if the effect can be recovered and at which degree.

REVERSIBILITY	
1	TOTALLY REVERSIBLE
2	HIGHLY REVERSIBLE
3	AVERAGE REVERSIBLE
4	LOW REVERSIBLE
5	NOT REVERSIBLE

For each factor and stressor, the four above matrixes are applied, and the resulting numbers are added. The sum gives a value between 0 and 20, that determine the severity if impact, basing on the following ranges:

SEVERITY		
Sum of values, range		
0-4	NO CONSEQUENCES	1
5-8	LIGHT, LOW DANGER	2
9-12	MODERATE, POSSIBLE TO RESTORE	3
13-16	HEAVY, DIFFICULT TO RESTORE	4
17-20	VERY HEAVY, POTENTIALLY FATAL	5

The probability scale indicates the probability assigned to the pressure agent to cause the impact, e.g. the probability of a rotating blade to hit a bird in presence of avoidance

PROBABILITY

1	REMOTE, <11%
2	LOW, 12-33%
3	MODERATE, 34-67%
4	HIGH, 68-90%
5	VERY HIGH, >90%

The resulting values (from 1 to 5) of severity, mutiplied by the probability of the event, gives as result a number between 1 and 25, representing the Significativity (or magnitude) of the Impact:

SIGNIFICATIVITY
1-5 LOW SIGNIFICATIVITY
6-15 SIGNIFICANT
16-25 VERY SIGNIFICANT

This last number, multiplied by the weight resulting from the Rank A and B combined (see table 41), gives the overall impact, varying between 0 and 100.

OVERALL IMPACT
NOT RELEVANT, 1-20
LOW, 21-40
MODERATE, 41-60
RELEVANT, 61-80
HEAVY, 81-100

5.3.1 Impact of aquaculture activities

NUTRIENTS RELEASE IN WATER COLUMN

Seawater	Nutrients
Frequency	5
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	5
Significativity	Significant
Total rank	1
Overall impact	Not relevant

OXYGEN CONSUMPTION IN WATER COLUMN

Seawater	Oxygen
Frequency	5
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	5
Significativity	Significant
Total rank	1
Overall impact	Not relevant

PHYTOPLANCTON GROWTH

Marine communities	Phytoplancton
Frequency	5
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	5
Significativity	Significant
Total rank	1
Overall impact	Not relevant

BENTHIC COMMUNITIES

Marine communities	Benthos
Frequency	5
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	4
Significativity	Low Significativity
Total rank	1.25
Overall impact	Not relevant

PELAGIC BIRDS

Marine communities	Pelagic birds
Frequency	5
Extension	4
Duration	5
Reversibility	1
Severity	4
Probability	4
Significativity	Very Significant
Total rank	3.75
Overall impact	Moderate

FISH

Marine communities	Fish
Frequency	5
Extension	2
Duration	4
Reversibility	1
Severity	3
Probability	4
Significativity	Significant
Total rank	2.5
Overall impact	Low

VISIBILITY

Landscape	Visibility
Frequency	5
Extension	3
Duration	4
Reversibility	1
Severity	4
Probability	4
Significativity	Significant
Total rank	2.75
Overall impact	Moderate

IMPACT OF NOISE INTO MARINE ENVIRONMENT

ODONTOCETES

Marine communities	Odontocetes
Frequency	3
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	3
Significativity	Significant
Total rank	4.75
Overall impact	Low

MYSTICETES

Marine communities	Mysticetes
Frequency	3
Extension	2
Duration	1
Reversibility	1
Severity	2
Probability	3
Significativity	Significant
Total rank	4.75
Overall impact	Low

FISH

Marine communities	Fish
Frequency	3
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	3
Significativity	Significant
Total rank	2.55
Overall impact	Not relevant

SEA TURTLES

Marine communities	Sea Turtles
Frequency	4
Extension	1
Duration	1
Reversibility	1
Severity	2
Probability	2
Significativity	Low significativity
Total rank	4.75
Overall impact	Not relevant

IMPACT OF WIND FARM ON MARINE COMMUNITIES

PELAGIC BIRDS

Marine communities	Pelagic birds
Frequency	4
Extension	4
Duration	5
Reversibility	1
Severity	4
Probability	4
Significativity	Very Significant
Total rank	3.75
Overall impact	Moderate

5.3.2 Impact of wind farm on terrestrial communities

MIGRATORY BIRDS

Terrestrial communities	Migratory birds
Frequency	2
Extension	5

Duration	5
Reversibility	1
Severity	4
Probability	1
Significativity	Low Significativity
Total rank	4
Overall impact	Not relevant

BATS

Terrestrial communities	Bats
Frequency	2
Extension	4
Duration	5
Reversibility	4
Severity	4
Probability	1
Significativity	Low Significativity
Total rank	4
Overall impact	Not relevant

5.3.3 Impact of wind farm on landscape

VISIBILITY

Landscape	Visibility
Frequency	5
Extension	3
Duration	5
Reversibility	1
Severity	4
Probability	4
Significativity	Very Significant
Total rank	2.75
Overall impact	Moderate

5.3.4 Impact of entangling structures on marine communities

FISH

Marine communities	Fish

Frequency	3
Extension	1
Duration	3
Reversibility	1
Severity	2
Probability	2
Significativity	Low Significativity
Total rank	2.5
Overall impact	Not relevant

PELAGIC BIRDS

Marine communities	Pelagic birds
Frequency	4
Extension	4
Duration	5
Reversibility	1
Severity	4
Probability	4
Significativity	Low Significativity
Total rank	3.75
Overall impact	Not relevant

5.3.5 Impact of electromagnetic fields on marine communities

FISH

Marine communities	Fish
Frequency	3
Extension	4
Duration	1
Reversibility	1
Severity	2
Probability	2
Significativity	Low Significativity
Total rank	2.5
Overall impact	Not relevant

5.3.6 Impact of moorings on marine communities

BENTHOS

Marine communities	Benthos
Frequency	5
Extension	1
Duration	5
Reversibility	2
Severity	4
Probability	5
Significativity	Very Significant
Total rank	1.25
Overall impact	Low

Table 42: Matrix of overall impacts. O = not relevant; Green = low impact; Yellow = moderate impact

Component	Resources	Aquaculture	Noise	Rotor blades	Entangling structures	Electromagnetic fields	Moorings
Sea water	Nutrients	O					
	Oxygen	O					
Marine communities	Phytoplankton	O					
	Benthos	O					
	Odontocetes						
	Mysticetes						
	Fish		O		O	O	
	Seals						
	Sea Turtles		O				
	Pelagic birds				O		
	Migratory birds			O			
	Bats			O			
Landscape	Visibility						

5.4 MITIGATION MEASURES

Cetaceans and fish are subject to a low level of impact, and the only mitigation possible consists in selecting machinery at the lowest possible noise level. The possibility of entangling will be further evaluated, when the definitive design of nets and fish farm submerged ancillaries will be ready.

The impact on landscape can hardly be mitigated. This impact is common to all offshore installation: the BGF platform is a massive structure with a very high mast and blades, which tip is potentially visible from very long distances. Being these distances in the range of dozens of km, the structure visibility is possible only with clear weather and in absence of mist or fog over the seascape. Currently the BGF is located at the limit of the territorial waters, and the only possible mitigation consists in a displacement at greater distance from the coast, provided that costs for cabling, mooring and personal displacent remain acceptable.

Moorings and organic deposition affect a rather large area of seabed. Due to the irrelevance of the affected surface compared to mediterranean community area, to the lack of any conservational interest, and to the reversibility of impacts, this do not raise a particular environmental concern.

A limited risk of collision persists for some species of pelagic birds, and the risk is probably enhanced by the presence of the fish farm, attracting birds by its own structure and feeding opportunities. Migratory birds display a negligible risk, but this is mainly due to the very small blade-swept area, compared to the extension of a migration route. Nevertheless, poor visibility may enhance the collision risk, and a detecting device may be advisable.

Possible mitigations:

Bird/Bat collision risk

- Keep rotating blades at the maximum possible height above sealevel;
- Keep rotation speed at lowest possible;
- Feather and arrest blades below productive wind speed;
- Prevent birds resting on platform surfaces, nets or cages;
- Avoid releasing at sea of feeds, fish or carcasses:
- Implement acoustic scaring devices;
- Avoid lights directed to sky or seawater
- Avoid Metal-halide and LED lights
- Avoid highest part of visible spectrum (red/reddish colour)
- Adopt lights possibly close to green color at lowest possible intensity
- Adopt flashing and on-demand lights for passages whenever possible
- Implement a radar system for detecting approaching flocks in poor visibility conditions
- Install shut-off lights + other devices in case of bird flocks approaching

Visibility

- Decrease contrast of blades against horizon

Constraints:

- Blade height increase improve bird collision risk, but impair landscape impact;
- Low contrast blades improve landscape impact, but decrease visibilty for birds, thus increasing collision risk.

5.5 SUMMARY OF ENCOUNTERED DIFFICULTIES/ISSUES

This study has been performed on the basis of an overall platform design that is not yet reaching the definitive level, thus describing the general platform features but still missing a number of specific details. As a consequence, several section of the study has remained at a general level too, posponing a more detailed assessement at the Project's end, and as consequence of a detailed design availability.

This study is based completely on data found in literature, and no terrain activities of any kind are forecast within this Work package. Data are mainly retrieved from official websites or available papers on the web, and may be insufficient in temporal coverage or details.

Data to fit the Band Model are those available on papers, as bird density at sea, flight heights, proportion at rotor height and night activity per species. A local influence on bird behaviour may exists, but can not be taken into account presently. In the same way, migrators behaviour may depend from local (and highly variable) conditions, as the real migration path. Bird presence offshore is inferred also from feeding ranges in literature, and is reported as highly variable depending from local opportunities. Bird density increasing following BGF operations, is here considered as fully logical, but supported by a limited number of references.

Wind turbine productivity is based on data from a buoy in the Gulf of Lions, at a distance of 100 km, with similar wind exposition, in fully offshore conditions.

Data on bat presence offshore is largely absent, and a quantitative collision risk assessment unfeasible, although a collision risk may be hypotesized.

The model used for effluent estimation has been fitted with a flowfield derived from Copernicus website. Models needs to be validated on local or similar conditions, and at the present stage confidence on obtained simulations are to be kept within the limit of likelhood of the model, in itself rather simplistic to be able to take in account the real complexity of open-sea dynamic. Nevertheless, the model can be positively considered on a near-field range.

Wind turbine noise production is desumed from a scant literature, and models of attenuation are generic and not considering speed noise mofication due to local water column and bottom features, as well the shape of the emitting body. Resonance and combined machineries noise effects can not be considered at this stage, even when their cohesistence is logical.

Landscape viewshed can only be estimated from maps, while a proper assessment would need some activities and a photographic survey on place.

Last, the assessment of impacts maintains in itself a certaing degree of subjectivity, that unfortunately can not be totally eliminated.

CHAPTER 6: FINAL RECOMMENDATION

The siting of process of a MOI platform can be considered as the main basis for its environmental and social acceptability: during the site choice, the location presenting some disdvantages can be discarded, increasing the rate of success of the final location. While usually this process is performed within the EIA process during the alternatives evaluation, in the present project has been done in a preliminary phase, during Deliverable 2.2 production. This has result in

an effective screening of several sites environmental potentialities, thus locating the BGF where environmental issues are minimal. However, the environmental analysis has shown that the biomass concentration in a limited water volume, although not giving a particular environmental concern, represents a potential issue for fish farming activity, possible leading to design improvements.

A particular attention should be paid during subsequent design phases in preveting that wild animals would take advantage from platform's structure and operation to approach it frequently, feed on residuals or simply be attracted by lights or emerged or submerged structures.

The present impact estimation of noise is only theorethical, being the real BGF noise level, as frequencies and sound pressure levels, not yet hypotizable with a sufficient degree of confidence. The structure is very complex, and a monitoring plan is necessary to record noises and correct, when necessary, any excessive noise introduction into the marine environment.

The BGF platform, as multi-funcional unit, presents a degree of complexity uncommon for marine structures, and whose environmental peculiarities have not been extensively investigated so far. This work represents a first environmental assesssment based on the platform features known at the present stage of design, useful to focus on the main potential impact of such a complex installation. This assement will be updated in the project progress, as new platform features, potentially interacting with marine environment, will be designed.

CHAPTER 7: CONCLUSION

The impact assessment performed at the present stage of design, when most of the general platform features are known, demonstrates that the general concept of the structure does not results in any particular concerns on its environmental acceptability.

The height of the nacelle and the blade tip, even increasing long distance visibility, on the other hands remains outside the flight heigths of most of marine birds, decreasing collision probability.

The platform is located at 24.5 km offshore, and its wind turbine will result visible only in clear weather conditions.

The platform has a low profile over the seascape, and has been located very far from the coast in areas of any peculiar importance for marine community conservation.

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