Gulf of Lions case study – France and Spain: Planning the offshore Gulf of Lions in regards with ecosystems

D48 Knowledge synthesis about ecological stakes related with soft substratum habitats

OFB

September 2022

ACKNOWLEDGEMENT

The work described in this report was supported by the European Maritime and Fisheries Fund of the European Union - through the Grant Agreement number 887390 - MSPMED - EMFF-MSP-2019, corresponding to the Call for proposal Call EMFF-MSP-2019 (Maritime Spatial Planning) Topic: EMFF-MSP-2019 Type of action: EMFF-AG for Projects on Maritime Spatial Planning (MSP).

Authors warmly thank all contributors to this work.

Project Full Title	**Towards the operational implementation of MSP in our common Mediterranean Sea**
Project Acronym	**MSP-MED**
Gant Agreement Nr.	**887390**
Project Website	**www.mspmed.eu**

Deliverable Nr.	**D48**
Status (Final/Draft/Revised)	**Draft**
Work Package	**WP2 - Setting-up of maritime spatial plans**
Task Number	**2.2.1**
Responsible Institute	**OFB**
Author/s	**Anne-Sophie Fanget**
Recommended Citation	**Fanget A.S. (2022). Knowledge synthesis about ecological stakes related to soft substratum habitats in the Gulf of Lions. EU Project Grant No EASME/887390/MSPMED/EMFF-MSP-2019. Towards the operational implementation of MSP in our common MEDiterranean sea (MSPMED). OFB. XX pp.**
Dissemination Level (Public/Partnership)	**Public**

Document History			
Version	**Date**	**Modification Introduced**	
		Modification Reason	**Modified by**
1	04/07/2022	Initial report	OFB
2	26/10/2022	Final report	OFB

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Introduction

The Ocean, that covers over two-thirds of the planet, plays a central and fundamental role in our human societies. It provides habitats for a rich marine biodiversity and invaluable ecosystem services which include global food security and climate regulation by sequestering carbon dioxide and heat (Halpern et al., 2012). The health of the Ocean is compromised by human activities. Overexploitation, pollution and global warming affect the structure, the function and the resilience of marine ecosystems worldwide and threaten human well-being and livelihood.

In the last decades, public policies attempted to cope with the increasing threats to marine biodiversity. In Europe, where approximately 40% of the population lives in coastal area, a holistic approach, named the Integrated Maritime Policy (IMP; European Commission, 2007) launched in 2007 by the European Union (EU). The IMP aims to foster the sustainable management of the oceans and seas based on a collaborative and ecosystem-based management approach (Meiner, 2010). The Marine Strategy Framework Directive (Directive 2008/56/EC; MSFD, 2008), adopted in 2008, is the environmental component of the IMP that aims to protect the marine biodiversity. The MSFD sets a target to achieve or maintain Good Environmental Status (GES), applying an Ecosystem-Based Approach (EBA; see Brigolin et al. et al., 2021 for further information) for all EU marine waters. The MSFD is closely interlinked with the Maritime Spatial Planning Directive (Directive 2014/89/EU; MSPD, 2014), the economic pillar of the IMP. MSPD provides a tool for EU Member States to coordinate and regulate spatially and temporarily the distribution of human uses in marine spaces. MSPD aims to foster the sustainable development of the blue economy, to minimize conflicts and promote synergies among uses and to ensure the long-term needs of marine conservation. MSPD is implemented at national and sea-basins level and favors cross-border cooperation.

In this context, France that has the second largest maritime domain in the world, published a National Strategy for the Sea and Coast (*Stratégie National pour la Mer et le Littoral*, SNML) in 2017, setting out long-term objectives in terms of environmental protection, blue economy development and management of maritime activities. In metropolitan France, the maritime space has been divided into four sea basins (i.e. Easter Channel – North Sea, North Atlantic – Western Channel, South Atlantic, Mediterranean Sea). For each sea basin, a planning document – the Sea Basin Strategy Document (*Document Stratégique de Façade*, DSF)[1] – refines the general orientations established at a national level and implements the European MSPD and MSFD.

The Mediterranean Sea (ca. 2.5 million km²) is a semi-enclosed sea commonly divided into two basins, the western Mediterranean basin (ca. 0.85 million km²) and the eastern Mediterranean basin (1.65 million km²), that are connected through the Strait of Sicily. It is recognized as a biodiversity hotspot. While the Mediterranean Sea is representing only 1% of the global ocean volume, it hosts more than 17,000 marine species (4 to 18% of the world's known marine species) and approximatively a fifth are considered to be endemic (Coll et al., 2010). Over the last decades, human-induced pressures have grown exponentially and have altered Mediterranean marine ecosystems (Halpern et al., 2008; Coll et al., 2012). In this context,

[1] DSF are available at the following address: https://www.geolittoral.developpement-durable.gouv.fr/documents-english-version-r549.html

implementing European environmental directives to address the needs of both nature and humans is required. Since several years, the EU supports the implementation of MSPD in EU Member States facing the Mediterranean Sea by funding several projects (e.g. ADRIPLAN (2013-2015), SUPREME (2017-2018), SIMWESTMED (2017-2018), PORTODIMARE (2018-2021) projects)[1]. MSP-MED project (Toward the operational implementation of MSP in our common Mediterranean Sea, 2020-222)[2], co-funded by the Directorate-General for Maritime Affairs and Fisheries (DG MARE), builds on these past initiatives. MSP-MED aims to help the development of MSP in six Member States of the EU (Spain, France, Greece, Italy, Malta and Slovenia) facing the Mediterranean Sea and to promote cross-border initiatives.

In the framework of MSP-MED, France, through the French Biodiversity Agency (*Office Français de la Biodiversité*, OFB), is in charge of a work package (named WP 2) that aims to support the work of the competent authorities in the establishment and adoption of maritime spatial plans. Within WP 2, each partner of MSP-MED has been able to develop specific tasks based on distinct national needs. France, alongside Spain, is working on “Planning the offshore Gulf of Lions in regards with ecosystems” (task 2.2, Fig. 1). The Gulf of Lions (ca. 15,000 km²) is a cross-border area lying in the western Mediterranean basin, from Cap de Creus in Spain to Cap Sicié in France. This case study aims to provide planners with information on ecosystems stakes and sensitivities. OFB, the French Institute for Energy Transition (*France Energies Marines*, FEM) and the Spanish Institute of Oceanography (*Instituto Español de Oceanografia*, IEO) worked jointly and produced three deliverables within task 2.2. Deliverable 7 consists in a knowledge synthesis of ecological stakes related to cetacean, sea turtles, seabirds and canyon deep habitats (sub-task 2.2.1; Assali et al., 2022) while deliverable D8 provides knowledge on the interactions between Mediterranean ecosystems and offshore floating windfarms development in the Gulf of Lions (sub-task 2.2.2; Henry et al., 2022). Deliverable D9 assesses the anthropogenic contributions to underwater noise due to maritime traffic and offshore windfarm operation (sub-task 2.2.3; Bou-Cabo et al., 2022). Note that within the SIMWESTMED project, a deliverable dedicated to map exposure risk of marine megafauna to concomitant pressures was also produced (Dalleau et al., 2018)[3].

Over the last decades, France and Spain have carried out extensive research in the Gulf of Lions. Relevant information on the marine geology, oceanography and ecology of the Gulf of Lions are available. As mentioned, knowledge syntheses have already been produced within the framework of MSP-MED and other projects (e.g. Sardà and Domínguez-Carrió, 2013). Nevertheless, little attention has been paid, so far, to marine soft sediments. Marine sediments constitute one of the largest habitat types on Earth, covering roughly 80% of the ocean bottom (Nybakken and Bertness, 2005). In the Gulf of Lions, soft sediments cover nearly 98% of the surface area of the continental shelf.
Sediments have a reputation for being flat and brown, and are getting less attention than colorful coral reefs or seagrass beds, for instance. However, soft sediments host a diverse array of

[1] Information on past MSP projects in the Mediterranean Sea can be found at the following addresses: http://adriplan.eu/, http://www.msp-supreme.eu/, https://maritime-spatial-planning.ec.europa.eu/projects/supporting-maritime-spatial-planning-western-mediterranean-region, https://www.portodimare.eu/

[2] https://mspmed.eu/

[3] Deliverable by Dalleau et al. (2018) and information on the SIMWESTMED project can be found at the following address: https://maritime-spatial-planning.ec.europa.eu/projects/supporting-maritime-spatial-planning-western-mediterranean-region

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organisms and play a pivotal role in marine ecosystem functioning (Lohrer and Hancock, 2004). Marine and coastal development projects (e.g. urbanization, marine renewable energy) are mainly concentrated on soft sediment habitats, being habitats the most impacted by human activities (Holon et al., 2015). Mainly populated by common species that do not benefit from any particular status, soft sediment habitats are seldom considered in management and conservation efforts. Some pressures, like anchoring, are even transferred on soft sediment habitats to protect priority habitat types or priority species (e.g. *Posidonia oceanica*) that are protected by French law.

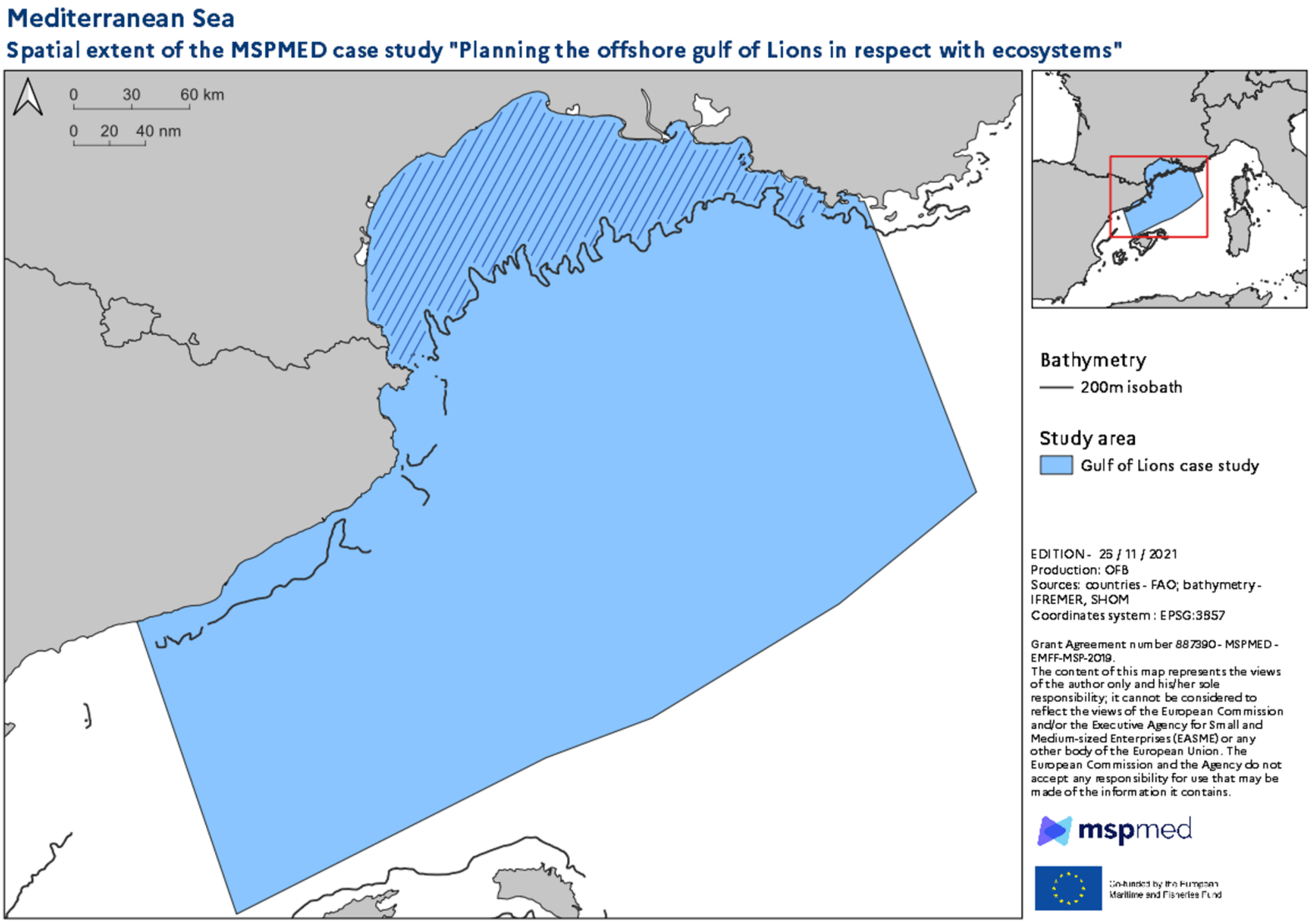

Figure 1: Spatial extent of the MSP-MED case study "Planning the offshore Gulf of Lions in respect with ecosystems". The work carried out on soft sediment habitats is focused on the continental shelf (shaded area). Source: OFB.

At present, there is a need to better study and understand soft sediment habitats, including their responses to rising anthropogenic impacts.
This report aims to provide an updated synthesis of ecological stakes related to soft sediment habitats in the Gulf of Lions. To this end, key information and documents have been referencing to draw a global view of existing knowledge and data on soft sediments and their associated habitats. Identification of existing data is based on bibliography and 22 bilateral interviews (Fig. 2). Bibliography includes scientific and grey literature (e.g. technical reports, environmental

impact report, management plans). Bilateral interviews were carried out online with national and local competent authorities, managers of marine protected areas and scientific experts. Elements collected throughout this methodology were gathered and synthesis within this report to (1) foster knowledge and results chain (data-method-results) sharing and to (2) highlight persistent knowledge gaps and recommendations that could help the implementation of the national MSP process. A particular attention was given to geo-located data. All collected spatial information were processed in QGIS open source software (QGIS 3.10.12).

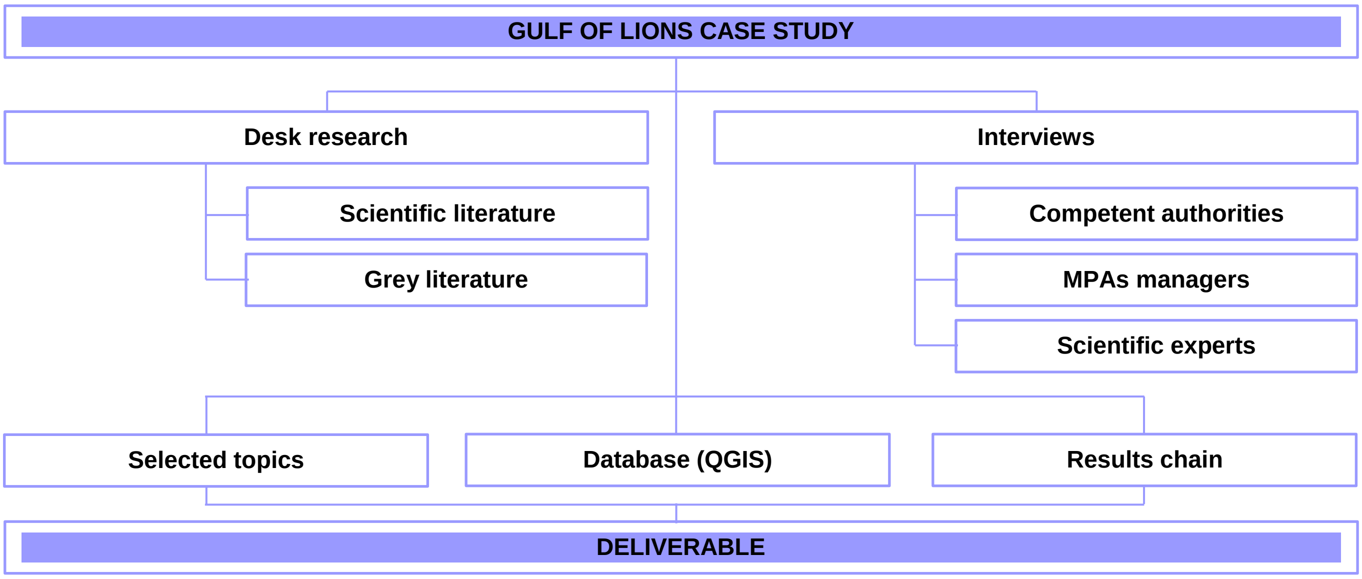

Figure 2: Methodology used in the Gulf of Lions case study related to soft sediment habitats.

Background

General framework

The Gulf of Lions is a siliciclastic passive and prograding continental margin. Located in the north-western sector of the Mediterranean Sea, the Gulf of Lions is bounded to the west and to the east by Pyrenean and Alpine orogenic belts, respectively. It comprises a crescent-shaped continental shelf with a maximum width of 70 km in the central part. This shelf is relatively flat and dips gently seaward to the shelf break, located at a water depth between 120 and 150 m. The continental slope is deeply incised by an intricate network of submarine canyons descending to the abyssal area of the Algero-Balearic Basin (Berné and Gorini, 2005).

Hydrodynamic features

The Gulf of Lions is a low energy, wave-dominated and microtidal area. The general circulation is dominated by the geostrophic Northern Current which flows south-westward along the continental slope (Millot, 1990; Fig. 3). It forms a density front that separates the low-salinity shelf water from the more saline open sea water. The Northern Current influences the shelf-slope exchanges in limiting the off-shelf dispersal and enhancing along-slope dispersal (Durrieu de Madron et al., 1999).

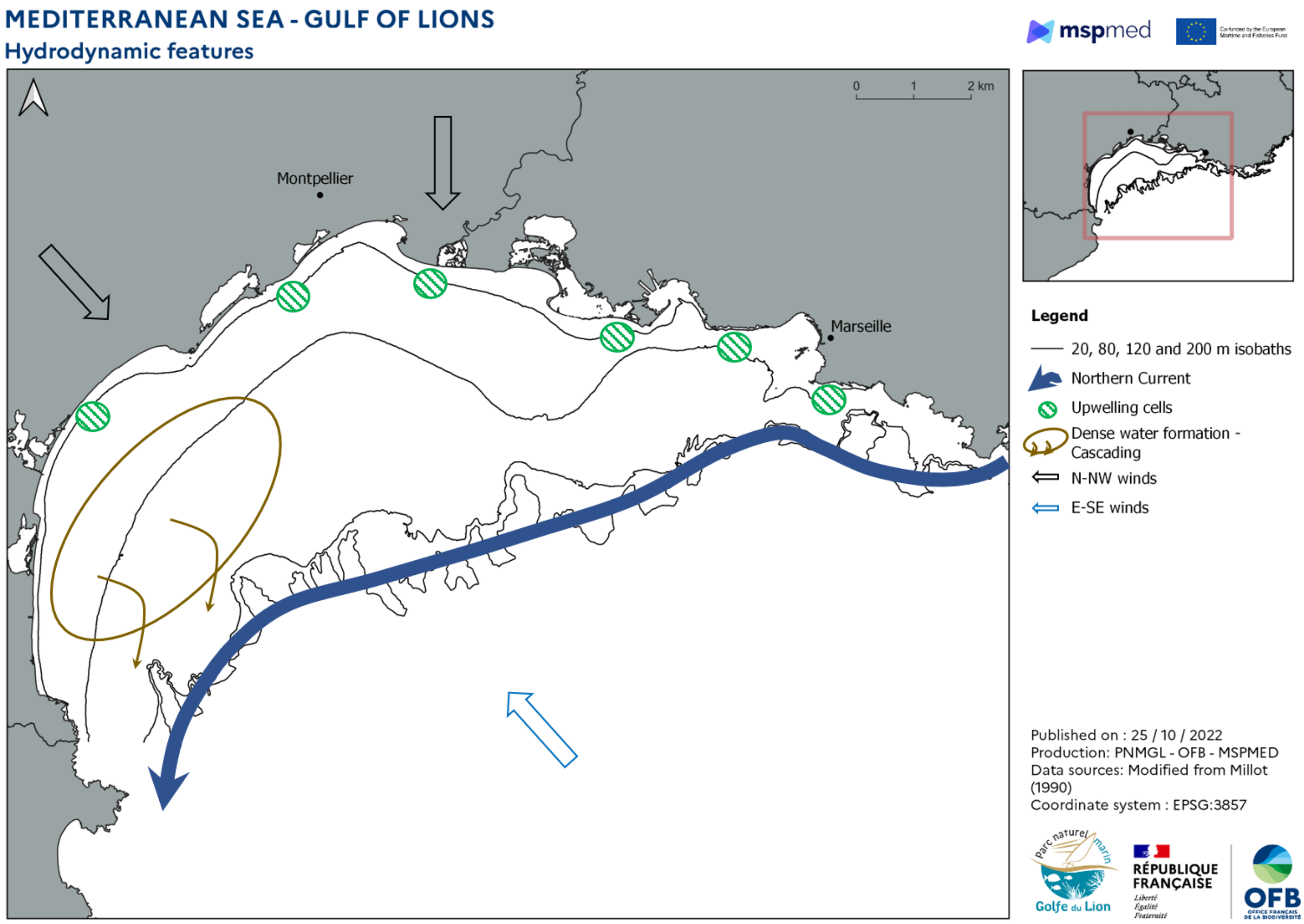

Figure 3: Main hydrodynamic features in the Gulf of Lions (modified from Millot (1990)).

In the Gulf of Lions, shelf circulation and wave conditions are wind-dependent (Millot, 1990). Winds are predominantly from the N-NW (continental cold and dry winds *Mistral* and *Tramontane*, respectively). These winds, associated with a short fetch, generate small waves on the inner shelf (significant wave height lower than 2 m and peak period lower than 6 s; Sabatier, 2001) and have a little impact on sediment transport. N-NW winds cause strong cooling and homogenization of the shelf-water which facilitate dense water formation (Estournel et al., 2003) and generate, locally, up-welling activity (Millot, 1990; Fig. 3). Conversely, episodic, intense and brief E-SE winds (*Marin*) associated with a long fetch, generate storm waves (significant wave height in excess of 7 m and peak period up to 12 s; Guillén et al., 2006; Palanques et al., 2006). Observational and modeling studies emphasized the role of severe E-SE storms on the resuspension and redistribution of sediments over the shelf. The storms induce a rise in sea-level at the shore and an intense cyclonic circulation on the shelf (Ulses et al., 2018). These storms are often associated to low pressure and major rainfall over the catchment area of the Rhone, generating major river floods. The combination of such flooding events together with E-SE storm waves ("wet storms"; Guillén et al., 2006) has major implication on sedimentary processes near the coast. It generates an intense wind-driven circulation able to transport sediment in an alongshore direction all over the inner shelf (Dufois et al., 2008). Bottom shear stress induces by these storms is sufficient to generate sediment resuspension on the outer shelf as well (Bassetti et al., 2006; Dufois et al., 2008).

River hydrology

The Gulf of Lions continental shelf is fed by a high sediment supply mainly originated from the Rhone River (80 to 95% of the total sediment inputs; Aloïsi et al., 1977; Sadaoui et al., 2016). With a mean annual discharge of 1 700 m^3s^{-1} (Pont et al., 2002) and a present-day sediment load estimated at 7 10^6 t yr^{-1} (with variations spanning from 2 10^6 t yr^{-1} to 20 10^6 t yr^{-1}; Pont et al., 2002; Sabatier et al., 2006), the Rhone River is, indeed, the main source of freshwater, nutrients and terrestrial organic matter to the Gulf of Lions. The water discharge displays a strong inter-annual and seasonal variability, with summer low water flux (lower than 700 m^3s^{-1}) and spring and autumn higher water flux (higher than of 3 000 m^3s^{-1}). During flood events, water discharge is generally higher than 5 000 m^3s^{-1} (Maillet et al., 2006). Floods deliver 80% of the annual sediment load, playing a pivotal role in the delivery of suspended particulate matter to the coastal area (Pont et al., 2002). The smaller Pyrenean and Massif Central rivers (i.e. Tech, Tet, Agly, Aude, Orb and Herault) deliver the remaining sediments to the Gulf of Lions shelf.

Freshwater and sediments delivered by the Rhone River are exported seaward through a surface plume (or surface nepheloid layer) and a persistent bottom nepheloid layer (BNL; Aloïsi et al., 1982). The plume is generally deflected to the southwest and its thickness (few meters), extension (ca. 30 to 60 km away from the river mouth; Gatti et al., 2006) and orientation are primarily controlled by interactions between the magnitude of the river discharge, the strength of the Northern Current and the wind conditions (*Mistral*, *Tramontane* and *Marin*; Estournel et al., 2001). Due to the dilution of the plume and the settling of large particles on the prodelta, off the river mouth (Ulses et al., 2008), the coastal area generally presents a strong seaward decrease of surface suspended particulate matter concentrations. The BNL (up to 15 m thick and thinning seaward) extends over the inner shelf and plays a significant role in the transfer of sediments and nutrients seaward. The BNL presents a seaward decrease of SPM concentration and size (Durrieu de Madron and Panouse, 1996; Many et al., 2016) and is regularly fueled by the settling of large particles from the plume (Many et al., 2016) and the resuspension of sediments by waves during E-SE storms (Dufois et al., 2014).

Sedimentology

Sediment distribution

The present-day morphology and sediment distribution on the continental shelf of the Gulf of Lions illustrate the effect of the last deglacial sea-level rise (last ca. 20,000 years BP[1]) and the associated retreat path of the Rhone distributaries (Aloïsi et al., 1977; Jouet et al., 2006; Berné et al., 2007). Sedimentological surface data (Annex 1) highlight that three main distinct zones are differentiated on the continental shelf (Fig. 4; Aloïsi et al., 1973; Bourrin et al., 2006; Augris et al., 2013).

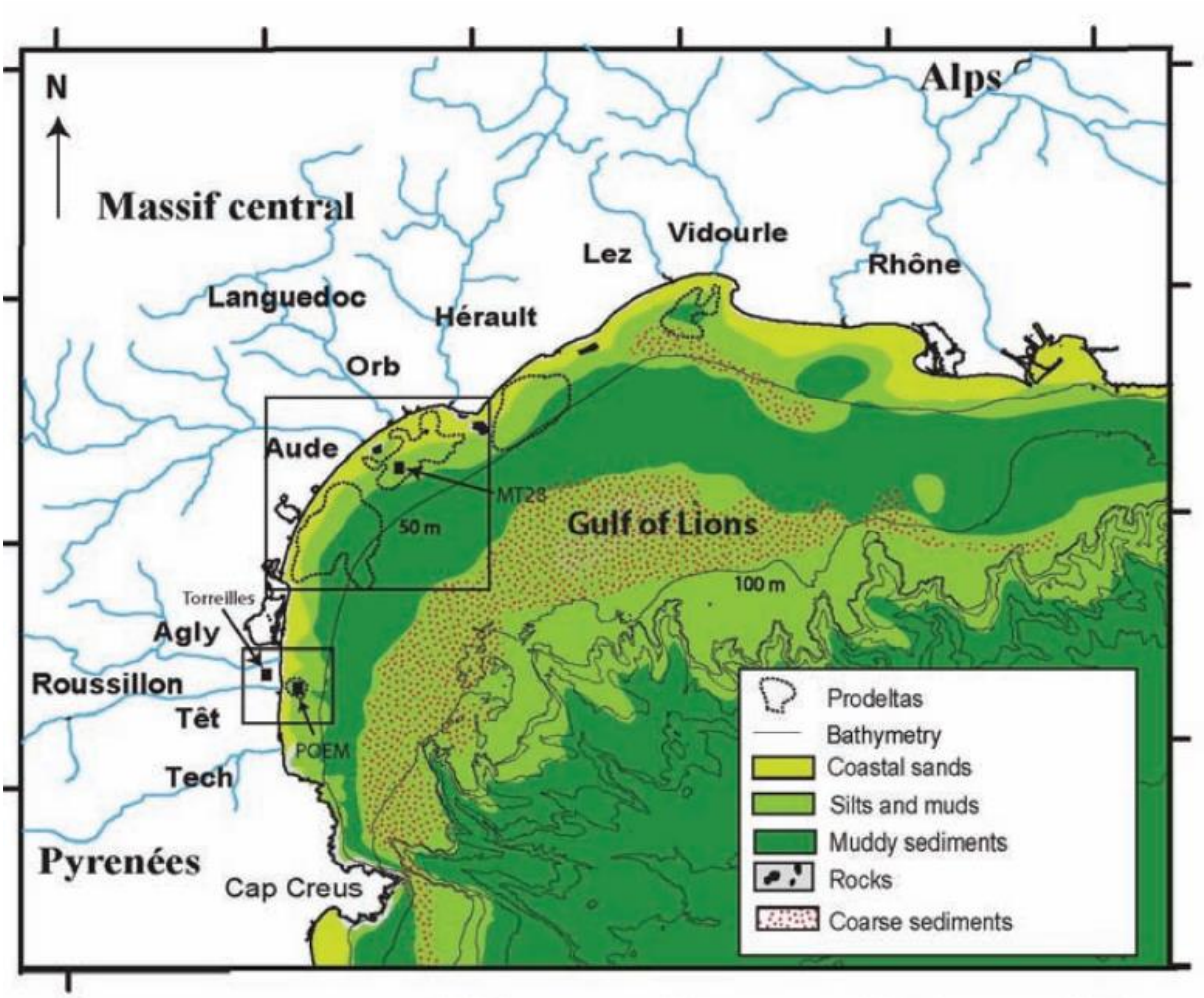

Figure 4: Grain size distribution of superficial bottom sediments in the Gulf of Lions (from Bourrin et al., 2006).

From 120 to 80 m water depth, the outer shelf is made of sand and sand-mud deposits. These sands, called "sables du large" (Bourcart, 1945), are characterized by high carbonate

[1] BP: Before Present (before 1950)

content (20 to 50%) due to significant biogenic component (Got and Aloïsi, 1990). These “relict offshore sands” correspond to coastal sands deposited during the Last Glacial Maximum (20,000 years BP).

From 80 to 20-30 m water depth, the median shelf is known as the “median mudflat”. It corresponds to a deglacial littoral prism made of prodeltaic muds (clay content from 16 to 26%; Augris et al., 2013). Within these muddy sediments, an elongated paleo-shoreface/deltaic system (known as the Early Rhone Deltaic Complex, Berné et al., 2007) is observed. This prominent sandy feature formed during a period of reduced sea-level rise or stillstand (Younger Dryas, ca. 12.9 ka to 11.7 ka cal. BP) and a period of increased sediment supply (Preboreal; Berné et al., 2007).

From 20-30 m water depth to the coastline, the zone includes the littoral sand and the inner shelf prism made of sands grading to sandy muds. The littoral sands comprise the dunes, beaches and the upper-shoreface and lower-shoreface and generally overlie a rocky substratum (Mesozoic to Pleistocene in age; Martin et al., 1981).

Coastal sedimentation

The French Mediterranean coastline can be divided into two main compartments. In the western Gulf of Lions, from Argelès-sur-mer to the Rhone delta in Camargue, the sandy coast is made of dunes, large beaches and salt marshes. In the eastern Gulf of Lions, from the Camargue to the Italian border, the rocky coast is characterized by dozens of narrow pocket beaches.

Shoreface sands (including upper-shoreface and lower-shoreface) represent a “buffer zone” where waves have a significant impact on sediment transport and distribution. The transition between the shoreface and the inner shelf, characterized by the mean closure depth, is located between 3 and 8 m water depth in the Gulf of Lions (Sabatier et al., 2004). The upper-shoreface is represented by a highly variable position and shape of bar-and-trough system. In general, in the Gulf of Lions, it is characterized by a succession of 1 to 3 bars and a mean slope of 1 to 3% (Aleman et al., 2011). The lower shoreface, located offshore from the outer bar, is characterized by a very gentle and uniform slope (<1%). Bars-and-trough systems play a key role in wave breaking and in constituting the main active sand stock. It represents thus an important control on shoreline movement. It is note that whenever the sand reservoir is depleted, the beach evolution trend is negative (Certain et al., 2005). The superficial sediments of the shoreface are represented by well sorted fine to medium sands. However, significant cross-shore variations are observed with a general seaward decrease of grain size (Jago and Barusseau, 1981). Longshore variations are also seen in the grain size distribution. The coarsest sediments are generally found in the vicinity of the river mouths and a downdrift decrease in grain-size is observed along the coast.

In terms of longshore component, the Gulf of Lions can be divided into different sedimentary compartments. Each compartment is identified by accretional and erosional evidence (Fig. 5; Brunel et al., 2014) and is generally separated from the adjacent component by physical barriers such as rocky capes that totally or partially interrupt the longshore transport. Along the sandy coast of the Gulf of Lions, several sedimentary compartments are identified (Fig. 5; Cerema, 2020). The direction of longshore sediment transport and constraints due to rocky

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capes, river mouths or harbor jetties leads to the development of a pattern of sedimentary cells (Fig. 5) that segment the main sedimentary compartments (Brunel, 2010; Certain et al., 2005).

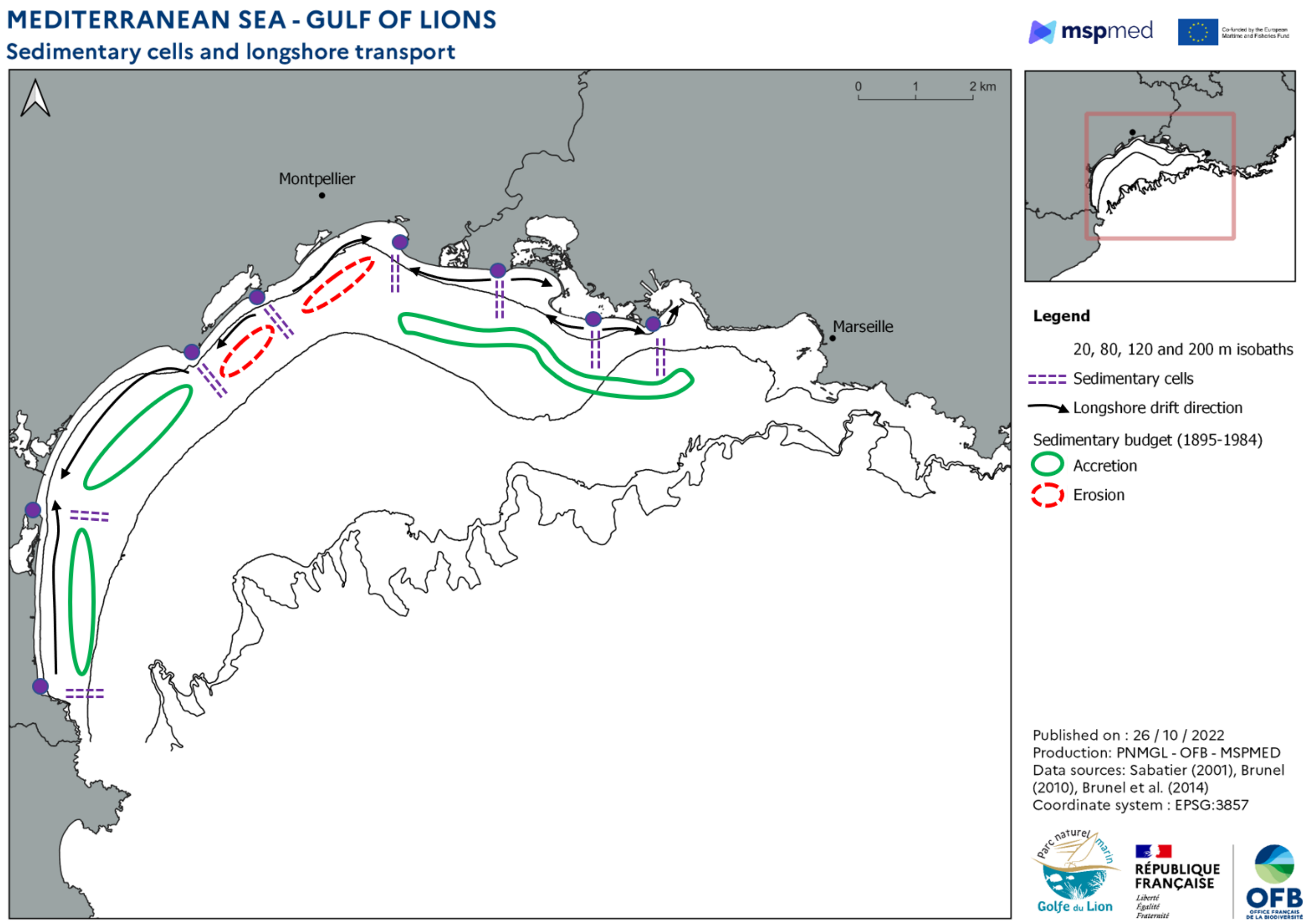

Figure 5: Main sedimentary compartments and longshore sediment transport in the Gulf of Lions. Sedimentary budget (accretion/erosion) is also reported for the period prior to the development of coastal infrastructures (information from Sabatier, (2001), Brunel (2010); Brunel et al. (2014)).

Geomorphology

Few major morphological features are observed on the Gulf of Lions continental shelf (Fig. 6). Sand ridges, located between 95 and 110 m water depth are observed within a limited area located at the south-west of the Gulf of Lions. They have variable heights (up to 9 m) and a main WNW-ESE orientation. They are characterized by an irregular topography and by a linear and elongated shape (Bassetti et al., 2006). Sand ridges, characterized by macrofaunal assemblage typical of shallow water environment (3 to 50 m water depth), formed during the Younger Dryas, a period of slow down of sea-level rise (Bassetti et al., 2006).

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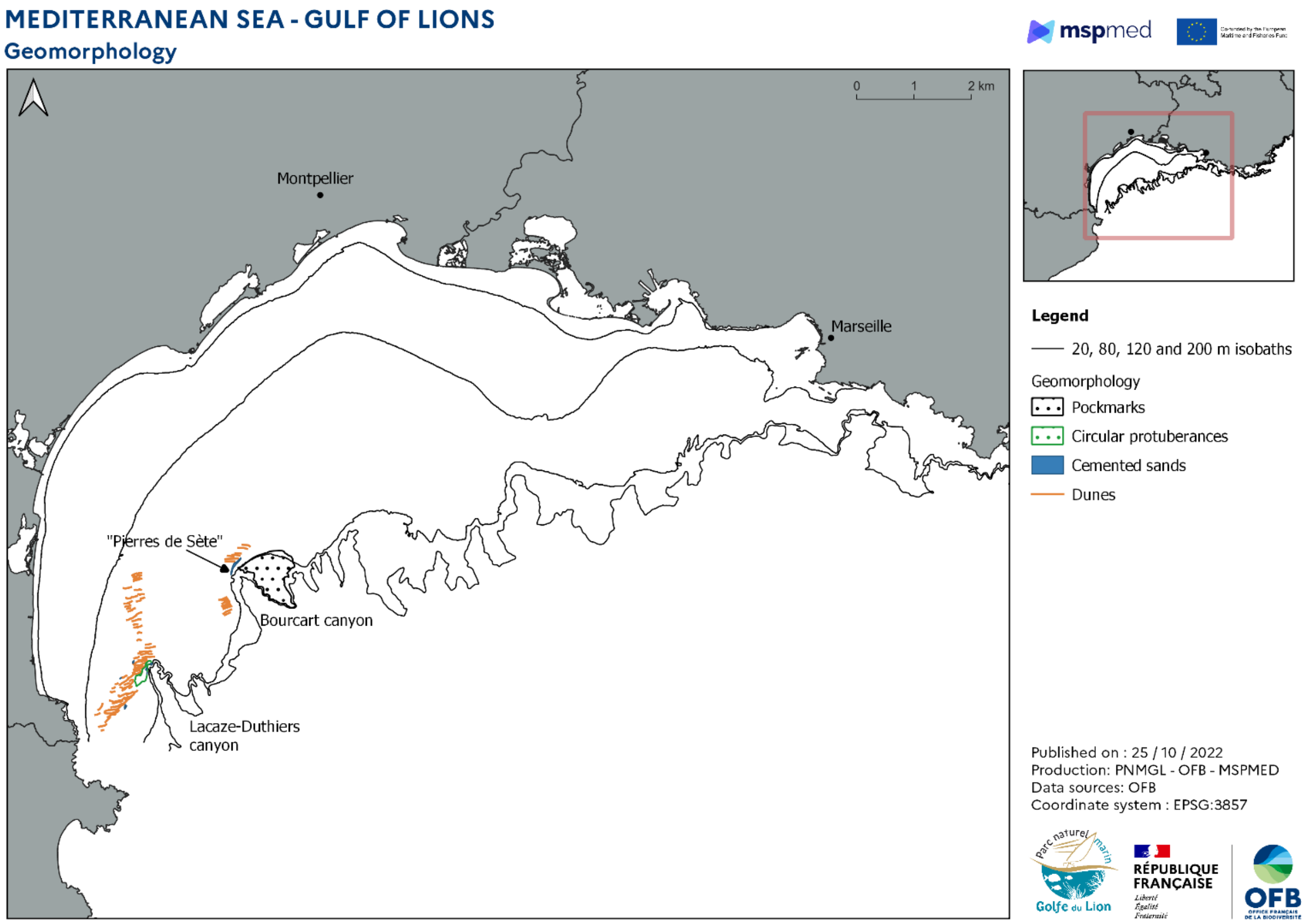

Figure 6: Major geomorphological features observed on the Gulf of Lions continental shelf.

Transverse dunes are also observed near the Lacaze-Duthiers and Bourcart canyon heads (Fig. 6). These dunes have an average height of 4 m and an average spacing of ca. 130 m (Bassetti et al., 2006; Alonso, 2016). Transverse dunes orientation is NNW-SSE in the NE part of the dunes area, while its turns progressively to a main NW-SE orientation in the SW corner. During periods of easterly winds (i.e. storms), transverse dunes are episodically considered active (Bassetti et al., 2006). This system of circalittoral sand ridges and transverse dunes is a rarity in the Mediterranean Sea.

Another striking morphological feature corresponds to an elongated relief culminating up to 20 m above the surrounding sea-floor and known as “Pierres de Sète” (Fig. 6; Jouet et al., 2006). This structure is made of siliciclastic sands cemented. Cementation of the beach rocks of “Pierres de Sète” occurred at ca. 21 cal. kyr BP, a period of decrease or even stop of the sea-level (Berné et al., 1998; Jouet et al., 2006).

Evidence of a hundred pockmarks, with diameters ranging from 10 to 130 m and aligned along a preferential direction, is also observed on the Bourcart/Herault canyon interfluve (Fig. 6; Riboulot et al., 2014). Pockmarks formation and associated fluid seepages are governed by sediment accumulation and glacio-eustatic fluctuations (Riboulot et al., 2014).

Circular protuberances, with diameters of ca. 40 m, are also observed near the Lacaze-Duthiers canyon head, in the vicinity of the transverse dunes (Fig. 6). The origin of these protuberances is unknown at present and further investigations are needed (see Box 1).

Box 1:
FAMOS-GL project (Expected in 2023, OFB – University of Perpignan)

The geomorphological structures described above are still not fully characterized and further investigations are needed to:
- better characterized and understand the formation of these structures and their evolution,
- describe the "no data" zones,
- describe the ecological value and function of habitats associated with these geomorphological structures. These habitats can indeed shelter atypical species at local scale and are considered as a priority ecological stake at a national level (DSF).

Soft substratum habitats

A comprehensive and hierarchical pan-European classification has been developed by the European Nature Information System (EUNIS, EMODnet Seabed Habitats project[1]; Vasquez et al., 2021). EUNIS classification is based on environmental variables that constrain biological communities, like substrate type, energy level, depth and light penetration.

The continental shelf of the Gulf of Lions comprises a variety of seabed habitats (Fig. 7).

Code			Stage	Nature of substratum	Bathymetrical distribution (m)	Hydrodynamics	Vulnerability
Eunis (2019)	Eunis (2007)	National (MNHN)					
MB55	A5.23	III.2.1	Infralittoral	Fine sand	0 to 2.5-3	Strong	Tourism, pollution, dredging/dumping
		III.2.2	Infralittoral	Fine sand	2 to 25	Average	Pollution, dredging/dumping, fishing
MC651	A5.39	IV.1.1	Circalittoral	Mud	25-35 to 90	Weak	Pollution, fishing
MC451	A5.38	IV.2.1	Circalittoral	Gravel, sand, mud	30-35 to 95	Weak	Pollution, fishing
MC351	A5.46	IV.2.2	Circalittoral	Gravel with sandy-muddy fraction	30-35 to 90-100	Weak (except during storms)	Pollution, fishing
MD451	A5.47	IV.2.3	Circalittoral	Gravel with sandy-muddy fraction	90 to 200	Very weak	Fishing, dredging (locally)

Table 1: Characteristics of the main biocenoses in the Gulf of Lions and their vulnerabilities.

[1] EMODnet Seabed Habitats: https://www.emodnet-seabedhabitats.eu/

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Description of the main biocenoses encountered from infralittoral environment to circalittoral environment is mainly based on the recent work of La Rivière et al. (2021) and summarized below and in Table 1.

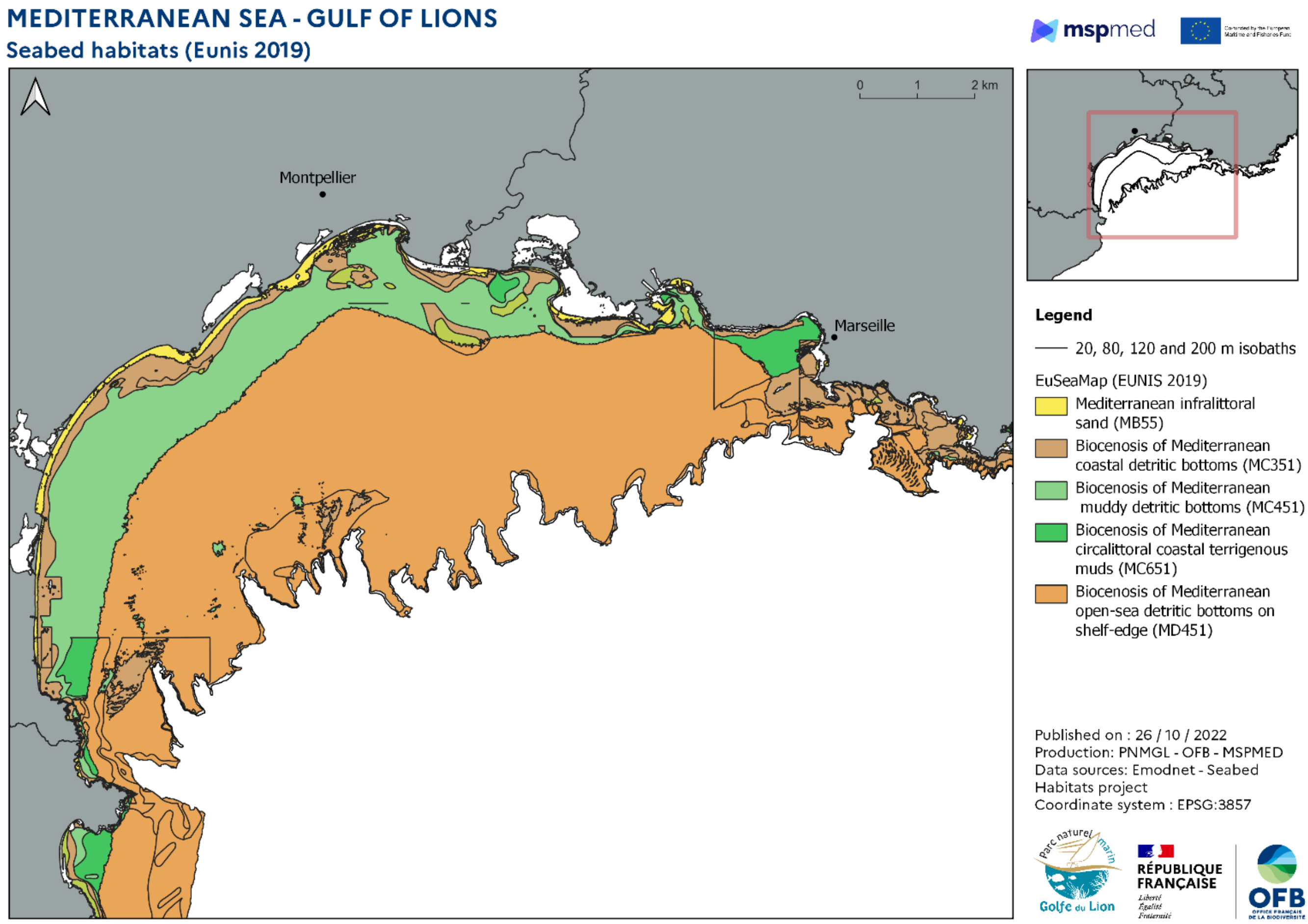

Figure 7: Infralittoral to circalittoral biocenoses on the continental shelf of the Gulf of Lions (EuSeaMap, 2021)

Mediterranean infralittoral sand (MB55)

Biocenosis of fine sands in very shallow waters

Stretches of submerged sand to a maximum depth of ca. 2.5-3 m (Fig. 7), this biocenosis is characterized by a high turbulence level generated by waves breaking near the surf zone. The sediment is dominated by fine sand with the presence of small gravels and shell debris.
It is characterized by the presence of polychaete annelids (*Spio decorates*), bivalve molluscs (e.g. *Donax trunculus*, *Macomangulus tenuis*) and decapod (*Philocheras monacanthus*, *Portumnus latipes*), amphipod (*Bathyporeia* spp., *Pontocrates altamarinus*) and isopod (*Eurydice spinigera*, *Parachiridotea panousei*) crustaceans.

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Within this biocenosis, the population dynamic is strongly linked to seasons. During periods of strong hydrodynamics (storms), sand is reworked. It is also subject to seasonal water temperature variations and to water runoff in spring and autumn.
This biocenosis plays an important role in maintaining the balance of the beaches and is a feeding area for juvenile flatfish.
Particularly frequented by tourists, this biocenosis is affected by trampling and human activities (including pollution). Beach nourishment is also considered has a significant pressure.

Biocenosis of well sorted fine sands

Stretches of fine sands continuing at greater depth the biocenosis of fine sands in very shallow waters; the sediment is usually made of homogeneous granulometry and terrigenous origin (Fig. 8A). The biocenosis begins at ca. 2-2.5 m and may reach a depth of 25 m (Fig. 7). Locally, the biocenosis of well sorted fine sands tolerates a slight lack of saltiness in the water near estuaries and surrounding some Mediterranean ponds. It thus presents a certain impoverishment, offset by the presence of some euryhaline species. When the wave action is too strong, the biocenosis can also be impoverished.
The biocenosis of well sorted fine sands is characterized by the presence of polychaete annelids (*Sigalion mathildae*, *Onuphis eremita*, *Exogone hebes*, *Diopatra neapolitana*), bivalve (e.g. *Acanthocardia tuberculata*, *Mactra stultorum*, *Fabulina fabula*) and gastropod (e.g. *Acteon tornatilis*, *Nassarius mutabilis*) molluscs, decapod (*Liocarcinus vernalis*), amphipod (*Ampelisca brevicornis, Hippomedon massiliensis, Pariambus typicus*) and isopod (*Idothea linearis*) crustaceans, echinoderms (e.g. *Astropecten* spp., *Echinocardium cordatum*) and fishes (*Pomatoschistus microps*, *Callionymus risso*). It is also observed that *Ditrupa arietina* (polychaete annelid) can reach very high density (10,000 ind. m²). The interannual density variation of this species is likely related to the frequency of resuspension events (Grémare et al., 1998; Labrune et al. et al., 2007).
Within this biocenosis, the population dynamic is strongly linked to seasons. The endogenous fauna is particularly diversified and numerous species of fish and shellfish are observed. This biocenosis is a feeding area for flatfish (e.g. *Solea solea*, *S. senegalensis*, *Bothus podas*), red mullet (*Mullus surmuletus*) and marbled fish (*Lithognathus mormyrus*).
It also plays an important role in maintaining the balance of the beaches; its being trimmed when the undertow is formed endangers the middle and high beaches, and its consolidation strengthens these.
This biocenosis is directly subject to human activities on the littoral (e.g. pollution emissions, turbid water and coastal development). Bottom trawling (prohibited within the 3 nautical miles) is also considered has a significant pressure as well as beach nourishment and dredging.

Biocenosis of Mediterranean circalittoral coastal terrigenous muds (MC651)

The sediment is always pure mud, more or less clayey, almost always of fluvial origin. Sedimentation is strong and coarse debris is rapidly buried. This biocenosis follows the infralittoral stage from 25-35 m to ca. 90-100 m depth (Fig. 7).

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This biocenosis is characterized by the presence of echinoderms (*Oestergrenia digitata*, *Labidoplax digitata*, *Leptopentacta tergestina*), molluscs (e.g. *Thyasira croulinensis*, *Abra nitida*, *Turritella turbona f. communis*), polychaete annelids (e.g. *Nephthys hystricis*, *Ninoe kinbergi*, *Sternaspis scutata*, *Lepidasthenia maculata*) and crustaceans (*Leptocheirus pectinatus*, *Medorippe lanata*, *Goneplax rhomboids*).
Rhone River flow (including organic matter) plays a major role in the dynamic of this biocenosis. It leads to rapid changes in the structure of the community with the sudden appearance and disappearance of some opportunistic species with short life cycles. Rich in invertebrate fauna, it can be a feeding area for benthic and epibenthic fish.
This biocenosis is particularly exposed to any kind of deposits (e.g. macro-waste, pollutants associated with fine particles, organic matter, heavy metals). Repeated trawling alters the nature of the physical environment leading to the quantitative depletion or even disappearance of invertebrate species consumable by fish and consequently to the rarefaction of the catches.

Biocenosis of Mediterranean muddy detritic bottoms (MC451)

This biocenosis develops in areas where a detritus bottom is covered with mud formed by terrigenous deposits from rivers. The sediment is a very muddy sand or sandy mud, or even a rather compacted mud, rich in shell debris. Sedimentation is slow enough to allow the development of sessile epifauna. Gravel, sand and mud are mixed in varying quantities, but mud always predominates. The renewal of water masses is relatively inactive within this biocenosis.

This biocenosis essentially contains species of dull coloration living in relation with sediments. It is characterized by the presence of actinia (*Anemonactis mazeli*), cnidarian (*Alcyonium palmatum*), bivalve (*Serratina serrata*), polychaetes (e.g. *Aricidea assimilis*, *Polyodontes maxillosus*, *Leiocapitella dollfusi*) and isopod crustacean (*Natatolana neglecta*). This biocenosis is also characterized by the sipuncula *Golfingia elongata* and the echinoderm *Pseudothyone raphanus*. The bivalve *Serratina serrata* is both a pioneer and a residual species when the biocenosis becomes established or disappears.

The biocenosis of muddy detritic bottoms follows the infralittoral stage from 35 m to ca. 90 m depth and can cover large areas (Fig. 7). The Rhone plays a major role in the presence and extension in time and space of the biocenosis of muddy detritic bottoms. Small rivers in the western part of the Gulf of Lions can also contributes.
This biocenosis is a feeding area for commercial species (including fish and shellfish). It is particularly exposed to pollution from domestic or industrial wastewater (including pollutants, organic matter, pesticides and heavy metals). Overfishing is also a threat.

Biocenosis of Mediterranean coastal detritic bottoms (MC351)

This biocenosis occurs on a substratum whose nature varies widely and depends largely on the typology of the nearby coast and of nearby infralittoral formations. This implies that substrata can be gravels and sands originating from predominant local rocks, shell debris from various molluscs, debris from branched bryozoans or debris of dead and more or less corroded

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Melobesiae (Fig. 8 B and C). The interstices between these various components are partially filled by a greater or lesser proportion of sand and mud, the muddy portion being usually less than 20%. Fragmentation of the debris is not due to the always weak hydrodynamics, but to the action of organisms that attack the limestone (e.g. *Cliona* spp., *Polydora* spp., lithophagous Pelecypoda) However, the regular or intermittent existence of bottom currents has frequently been stressed. This biocenosis stretches in the depths of 30-35 m to 90-100 m (Fig. 7).
Several dozen species belonging to many groups of phytobenthos and zoobenthos can be considered as characteristics of this particularly rich biocenosis. It is characterized by the presence of sponges (*Bubaris vermiculata*, *Suberites domuncula*), cnidarians (*Sarcodictyon catenatum*), echinoderms (e.g. *Astropecten irregularis*, *Anseropoda placenta*, *Genocidaris maculate*), molluscs (e.g. *Limaria loscombi*, *Palliolum incomparabile*, *Flexopecten flexuosus*, *Laevicardium oblongum*), polychaetes (*Laetmonice hystrix*, *Petta pusilla*), crustaceans (e.g. *Conilera cylindracea*, *Paguristes eremita*) and ascidians (e.g. *Microcosmus vulgaris*, *Polycarpa pomaria*, *Polycarpa gracilis*).
The biocenosis of coastal detritic bottoms occupies a considerable area on the continental shelf of the Gulf of Lions. This is a biocenosis with very high specific diversity and is an important fishing area, particularly for small craft.
This biocenosis is subject to varied sedimentary additions brought down either by permanent rivers or by rivers with an intermittent flow which cyclically increase the concentration of fine sediments and organic matter. There is the possibility of a natural evolution towards the biocenosis of muddy detritic bottoms, even, at depth, towards the biocenosis of shelf-edge detritic bottoms. Hydrodynamics that affect the biocenosis of coastal detritic bottoms are only exceptionally strong enough to avoid the sedimentation of fine terrigenous-origin particles. However, this natural variability is obscured by an increase in anthropic action, which constitutes a considerable threat (non-purified domestic and industrial wastewater loaded with fine matter, pollutants and organic matter). Trawling has also destructive effects on the epigeous flora and fauna. It also results in a physical alteration of the superficial part of sediments.

Biocenosis of Mediterranean open-sea detritic bottoms on shelf-edge (MD451)

This biocenosis consists in a mixture of small gravels from fluvial origin and shell debris belonging to the Quaternary thanatocenoses. A sandy muddy fraction is also observed. This biocenosis follows the biocenosis of coastal detritic bottoms and stretches in depths of 80-90 m to 120-130 m (shelf break; Fig. 7).
It is characterized by the presence of echinoderms (e.g. *Leptometra phalangium*, *Thyone gadeana*), amphipod (*Haploops dellavallei*) and isopod crustacean (*Natatolana borealis*).
The biocenosis of open-sea detritic bottoms on shelf-edge supports a significant density of benthopelagic teleosts, especially associated with *Leptometra phalangium* (Mnhn, 2012). Trawling activity is thus frequent and exerts a significant pressure on the biocenosis (destruction of the facies with *Leptometra phalangium* and rarefaction of spawners (e.g. hake)).

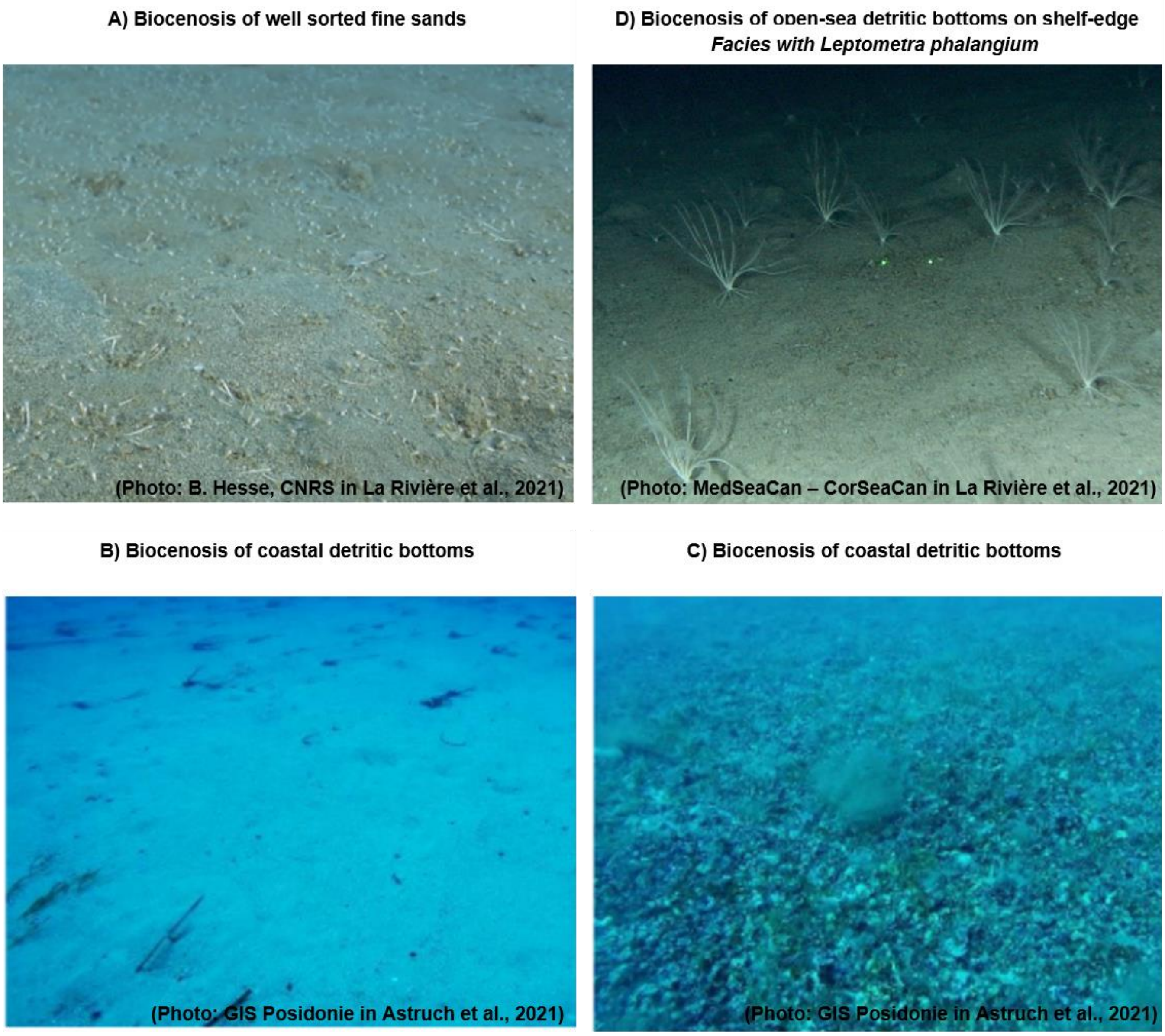

Figure 8: Photos of the biocenosis of well sorted fine sands (A), of the coastal detritic bottoms (B and C) and of the open-sea detritic bottoms on shelf-edge (Facies with *Leptometra phalangium*, D) observed in the Gulf of Lions.

Facies with Leptometra phalangium

This facies is characterized by the high abundance (30-50 ind. m²) of the crinoid echinoderm *Leptometra phalangium*, a species endemic to the Mediterranean Sea (Fig. 8D). This facies is located near the shelf break, between the lower limit of the circalittoral stage and the upper limit of the bathyal stage. This area is characterized by the regular occurrence of bottom currents. *Leptometra phalangium* erects its arms in a fan shape, perpendicular to the direction of the current to catch suspended particles (Bourcier & Zibrowius, 1973).

Facies with *Leptometra phalangium* is characterized by consistent species richness and high rates of productivity and hosts thus numerous commercial fish species (hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), horse mackerel (*Trachurus trachurus*), goat redfish (*Helicolenus dactylopterus*)). A shrimp, *Hippolyte leptometrae*, lives in strict association with *Leptometra phalangium*.

Bottom trawling is a threat for this facies.

Ichthyofauna

The MEDITS (Mediterranean Trawl Survey) survey program provides basic information on demersal and benthic species in terms of population distribution and demographic structure. In the Gulf of Lions, the bottom trawl surveys are carried out by IFREMER in May and June since 1994. Hauls are performed in daylight following a standardized protocol (Bertrand et al., 2002). On the continental shelf of the Gulf of Lions, hauls duration is 30 minutes and 65 stations are fixed according to a stratified random sampling based on three depth strata (i.e. 10-50, 50-100 and 100-200 m, Annex 2). The chosen gear (GOC 73) is a bottom trawl characterized by a 20 mm-diamond stretched mesh size at the cod-end. Horizontal and vertical openings of the gear is ca. 18 m and 2 m, respectively (Fiorentini et al., 1999). A list of 38 species (including fish, mollusk and crustaceans) are followed every year. Observations on these target species include the total number of individuals, the total weight, length frequency distribution and sex (including sexual maturity stage). For all the other species of commercial interest, the total number and total weight are also reported for each haul.

Data from each cruise is used to provide indicators for national stock assessments and indicators required by fisheries managers (General Fisheries Commission for the Mediterranean) or MSFD for instance. Data are routinely processed by the Halieutic System of Information[1] (IFREMER) to produce standardized indices of abundance.

In the Gulf of Lions, ca. 300 different species have been identified since the onset of the MEDITS survey. Nevertheless, many are low in abundance or even rare (Mérigot et al., 2007). The occurrence of each species (percentage) was examined for each MEDITS stations. A minimum threshold of occurrence (≥ 20%) has been set up to select only well-represented species (De Rock et al., 2021). 47 species of commercial interest or conservation issue (37 fish and 10 mollusc) have been selected (Tab. 2). Maps of fish and mollusc distribution (population density per km^2) are made available by IFREMER[2] (Fig. 9).

[1] Halieutic System of Information for Mediterranean Sea: link to the website

[2] Maps are available at the following link

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MEDITS code	Species	Usual Eng. name	Usual Fr. name	Occurrence	Spawning period
ALLOMED*	*Alloteuthis media*	Midsize squid	Casseron bambou	42	-
ALLOSPP*	*Alloteuthis* spp.	Unidentified squid	Casseron non identifié	29	-
ANTOMEG	*Gaidropsarus biscayensis*	Mediterranean bigeye rockling	Motelle mouchetée	20	-
ARFISOL	*Aristaeomorpha foliacea*	Giant red shrimp	Gambon rouge	41	Spring, autumn
ARGESPY	*Argentina sphyraena*	Argentine	Petite argentine	35	Winter to spring
ASPICUC	*Chelidonichthys cuculus*	Red gurnard	Grondin pin	27	January to July
BLENOCE	*Blennius ocellaris*	Butterfly benny	Blennie ocellée	20	-
BOOPBOO	*Boops boops*	Bogue	Bogue	53	Beg. March, beg. June
CALMMAC	*Callionymus maculatus*	Spotted dragonet	Dragonnet tacheté	28	-
CAPOAPE	*Capros aper*	Boarfish	Sanglier	30	-
CEPOMAC	*Cepola macrophthalma*	Red bandfish	Cépole commune	50	-
CITHMAC	*Chimaera monstrosa*	Rabbit fish	Chimère commune	26	-
CONGCON	*Conger conger*	European conger	Congre commun	44	-
ELEDCIR*	*Eledone cirrhosa*	Horned octopus	Pieuvre blanche	64	Spring, summer
ELEDMOS*	*Eledone moschata*	Musky octopus	Elédone musquée	30	Winter, spring
EUTRGUR	*Eutrigla gurnardus*	Grey gurnard	Grondin gris	67	February to August
GOBIFRI	*Lesueurigobius friesii*	Fries's goby	Gobie à grandes	53	-
GOBINIG	*Gobius niger*	Black goby	Gobie noir	30	-
GOBIQUA	*Deltentosteus quadrimaculatus*	Four-spotted goby	Gobie à quatre tâches	30	-
ILLECOI*	*Illex coindetii*	Broadtail shortfin squid	Encornet	46	May to November
LEPMBOS	*Lepidorhombus bosci*	Four-spot megrim	Cardine à quatre tâches	32	March to April
LEPTCAV	*Lepidotrigla cavillone*	Large-scaled gurnard	Cavillone commun	43	-
LOPHBUD	*Lophius budegassa*	Blackbellied angler	Baudroie rousse	34	All year
LOPHPIS	*Lophius piscatorius*	Common monkfish	Baudroie commune	24	Spring
MERLMER	*Merluccius merluccius*	European hake	Merlu	88	All year
MICMPOU	*Micromesistius poutassou*	Blue whiting	Merlan bleu	26	November to April
MICUVAR	*Microchirus variegatus*	Thickback sole	Sole-perdrix commune	24	-

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MEDITS code	Species	Usual Eng. name	Usual Fr. name	Occurrence	Spawning period
MULLBAR	*Mullus barbatus*	Red mullet	Rouget de vase	32	End of spring, summer
OCTOVUL*	*Octopus vulgaris*	Common octopus	Poulpe commun	21	January to October
PAGEACA	*Pagellus acarne*	Axillary seabream	Pageot acarné	24	July to October
PAGEBOG	*Pagellus bogaraveo*	Blackspot seabream	Pageot rose	21	Autumn, beg. spring
PAGEERY	*Pagellus erythrinus*	Common seabream	Pageot commun	30	May to August
PHYIBLE	*Phycis blennoides*	Greater forkbeard	Phycis de fond	35	Autumn, winter
SCOMSCO	*Scomber scombrus*	Atlantic mackerel	Maquereau	34	January to May
SCYOCAN	*Scyliorhinus canicula*	Small-spotted catshark	Petite roussette	33	All year
SEPIELE*	*Sepia elegans*	Elegant cuttlefish	Seiche	20	-
SEPIORB*	*Sepia orbignyana*	Pink cuttlefish	Seiche rose	24	-
SEPOSPP*	*Sepiola* spp.	Unidentified cuttlefish	Seiche non identitiée	36	-
SERACAB	*Serranus cabrilla*	Comber	Serran-chèvre	27	-
SERAHEP	*Serranus hepatus*	Brown comber	Serran-hépate	60	-
TODIEBL*	*Todaropsis eblanae*	Lesser flying squid	Toutenon souffeur	20	-
TRACMED	*Trachurus mediterraneus*	Mediterranean horse mackerel	Chinchard	44	April to September
TRACTRA	*Trachurus trachurus*	Atlantic horse mackerel	Chinchard d'Europe	66	April to September
TRAHDRA	*Trachinus draco*	Greater weever	Grande vive	20	-
TRIGLYR	*Trigla lyra*	Piper gurnard	Grondin lyre	29	-
TRISCAP	*Trisopterus capelanus*	Cod	Capelan de méditerranée	77	January to June
ZEUSFAB	Zeus faber	John Dory	Saint-Pierre	22	June to September

Table 2: Well-represented fish species (20%) in the Gulf of Lions (modified from De Rock et al. (2021)).

Previous analyses in the Gulf of Lions highlighted that demersal fish communities are distributed mainly along a depth gradient (from the coastal zone to the upper slope) and also along a longitudinal gradient, in association with benthic macrofauna and substratum (Gaertner et al. 1999, 2002).

Most demersal and benthic fish species present a bipartite life cycle with a dispersive pelagic larval phase and a more sedentary benthic adult phase. Juveniles and adults often occupy different habitat type (Beck et al., 2001). The settlement stage, in habitats that are often coastal, ensures the growth and survival of juveniles and thus having a nursery role. The transition from the juvenile stage to the adult stage corresponds to the recruitment stage, where the young fish recruits leave the nurseries and join the adult populations (Harmelin-Vivien et al. 1995;

Macpherson 1998). The replenishment of local adult fish populations depends on the success of their larval and juvenile phases.

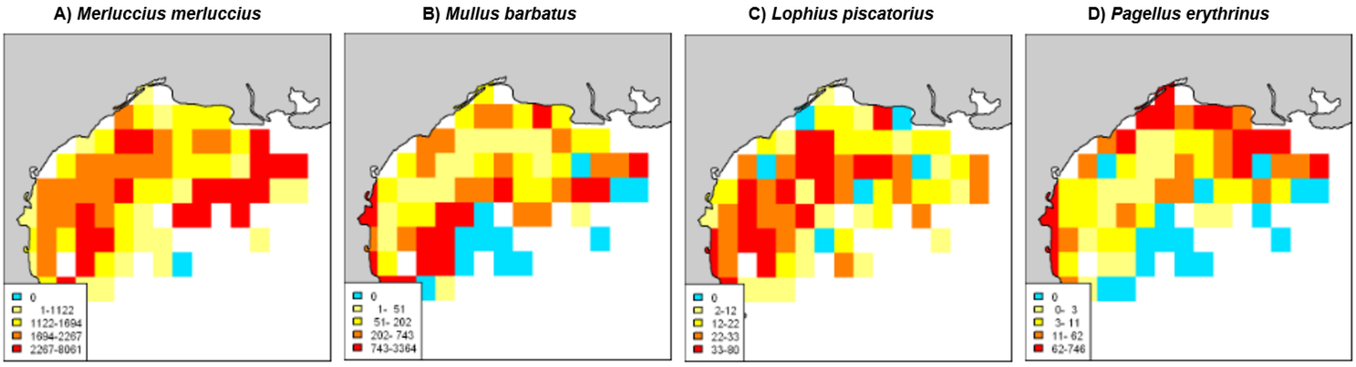

Figure 9: Distribution map of (A) the hake, (B), the red mullet, (C) the common monkfish, and (D) the common seabream (population density per km²) on the continental shelf of the Gulf of Lions (IFREMER, SIH).

Nursery areas have been defined as essential habitats for fish. A two-year NOURMED survey (2018-2019) dedicated to the study of demersal fish nursery in soft-bottom coastal habitats (Annex 3). NOURMED survey aimed to collect quantitative and geospatial data necessary to better identify nurseries in the Gulf of Lions and to support management strategies that will ensure sustainable uses of these essential habitats. Unfortunately, due to funding difficulties, NOURMED survey has been carried out during only two years. It is necessary to acquire a long-time series data (3 to 6 years) to reach the objectives of the NOURMED survey (Vaz et al., 2020).

For most species, nursery, feeding and spawning functions cannot be fulfilled by a single habitat. To identify essential fish habitats through life cycle, it is necessary to better understand population dynamic and connectivity. To this end, acoustic telemetry has been used recently in the Gulf of Lions (Annex 4). The underwater movements of target coastal fishes (e.g. *Sparus aurata*, *Mugil* spp., *Sarpa salpa*) have been studied (RES-MED and CONNECT-MED projects). The CONNECT-MED project (2017-2021) aims to better understand the connectivity of fish at the lagoon-sea interface in the Gulf of Lions. It provides information on the fidelity of species to lagoons, the time spent in lagoons and at sea according to seasons and the regional connectivity of species. This information is particularly essential for the implementation of a sustainable management of species of commercial interest.

Most of data produced through the scientific campaigns (MEDITS and NOURMED) give a summer vision of the fish stock assessment and population dynamic. These data have to be completed with data concerning the other seasons. Indeed, the settlement in nurseries may occur at different times of the year according to species spawning period for instance (Garcia-Rubies and Macpherson, 1995). The GOLDYS project (March 2022 to February 2023, 40 operations per season) aims at better characterized the seasonal dynamics of species of commercial interest. Following the same protocol that the MEDITS survey, the GOLDYS project will produce information on the spatio-seasonal patterns of demersal fish communities and a better characterization of the nursery and spawning areas and of the spawning periods.

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Recently the field of observation has been enlarged with the use of environmental DNA analysis (eDNA). eDNA is an interesting method since it is a non-destructive method for the habitats. This approach is being developed for monitoring biodiversity (presence/absence inventory). Quantitative application is also used but is still very innovative and require significant calibration. Data necessary for calibration have been obtained during the most recent MEDITS cruise in 2022 and will be tested to assess the relevance of this monitoring approach applied to demersal fish population. eDNA metacording approach More analyses should be produced in the Gulf of Lions (see Box 2).

Box 2:
PIAF project (Expected in 2023, IFREMER – Andromède)

PIAF project aims to conduct an environmental DNA metacording study in the Gulf of Lions. More than 200 sections will be study in order to monitor the biodiversity of the demersal fish communities in the Gulf of Lions. Several indices will be calculated (e.g. species richness, functional diversity indicator, the ratio of pelagic to benthic-demersal species). Indices variability will be compared between sections, depths and regions.

In the Gulf of Lions, many data have been collected over the last decades in order to provide information on demersal and benthic species in terms of population distribution, demographic structure and population dynamic (Tab. 3). Figure 10 summarizes the data collected in the Gulf of Lions and their associated information.

Project	Year(s)	Institution	Topic	Link
MEDITS	1994-Present day	IFREMER	Stock assessments of demersal fish	Website
DEMERSCAN	2020	IFREMER, AMOP	Assessing fish body condition of demersal fish communities	PDF
NOURMED	2018-2019	IFREMER	Essential nursery habitats	PDF (2018), PDF (2019)
CONNECT-MED	2017-2021	IFREMER, IRD, University of Montpellier	Connectivity	N/A
RES-MED	2020-2022	University of Barcelona, University of Perpignan	Connectivity	Website
GOLDYS	2022-2023	IFREMER, CRPMEM Occitanie	Seasonality dynamics of demersal fish	N/A

Table 3: Synthesis of the main projects studying demersal fish communities in the Gulf of Lions.

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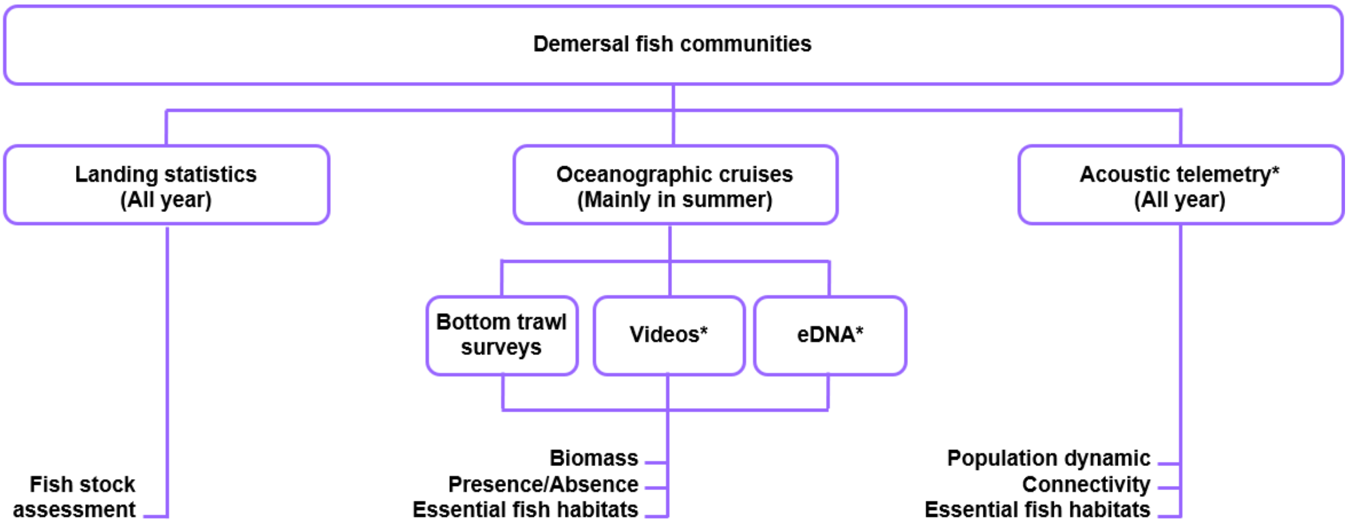

Figure 10: Information related to demersal fish communities collected in the Gulf of Lions over the last decades. The method (e.g. survey, acoustic telemetry) used as well the associated information are indicated. * indicates a non-destructive method.

Ecological quality status

Benthic macrofauna

As described previously, soft sediments form a vital habitat for a high diversity of benthic macrofauna communities that are an important element of the marine ecosystem and are a primary link in the trophic chain and nutrient cycling. Benthic macrofauna communities are thus critical in maintaining a healthy marine ecosystem and study their diversity is essential to assess the level of disturbance experienced by marine habitats (Dauvin et al., 2003).
MSFD requires EU Member States to take measures to achieve and maintain GES in the marine environment. Assessing the environmental status of marine waters is thus fundamental. Due to their sessile, sedentary and relatively long life, benthic macrofauna are considered as suitable and sensitive indicators of temporal and chronicle natural (see Box 3) and human disturbances. Human disturbances have significant impact on the biodiversity (Descriptor 1, MSFD) and the seafloor integrity (Descriptor 6, MSFD) of benthic habitats. Indicators and threshold values have to be defined to assess human activity (see paragraph: activities management for further information on human disturbances).

In the Gulf of Lions, the ecology and biology of benthic communities have been investigated since the 1960s (e.g. Beaubrun, 1995; Labrune et al., 2007; Hermand et al., 2008; Mellon-Duval et al., 2009). Hundreds of sampling stations have been investigated on the continental shelf over the past decades (Annex 5). Although the Gulf of Lions is one of the best sampled marine areas with the Mediterranean Sea, there is still a lack of data (particularly on the outer shelf, Annex 5) regarding the composition and diversity of its soft-bottom communities (Labrune et al., 2008). The assessment of soft-bottom macrofauna diversity requires a time series of samples and involves long and tedious sorting and identifying procedures. Identifying macrofauna at a higher taxonomic level than species (taxonomic sufficiency) is regularly used to assess the effects of major disturbances (e.g. Somerfield and Clarke 1995; Gomez Gesteira et al. 2003). Identification to the species level only on a restricted number of major taxonomic groups which are used as surrogates for total macrofauna, is also used (Olsgard et al., 2003; Mackie et al., 2005; Labrune et al., 2007). At present, more studies have to be carried out on the use of surrogates for total macrofauna. Nevertheless, polychaetes have been shown to constitute a good surrogate for describing species richness (Olsgard et al., 2003; Labrune et al., 2007).

Box 3:
Climate-driven changes in macrobenthic communities in the Gulf of Lions (Bonifácio et al., 2019)

Major temporal changes in the composition of macrobenthic communities have been highlighted in the Gulf of Lions. These fluctuations are driven by natural disturbance. Climate variability and more precisely the negative phase of the wintertime Western Mediterranean Oscillation (WeMo) index that influences hydro-sedimentary processes is thought to have a strong impact on the population dynamic. This work highlights that winter could be a better integration period as a proxy to study benthic community changes and that in assessing the status of benthic communities it is important to consider natural disturbances and not only human disturbances.

Several univariate indices are used to described the diversity, richness, dominance and evenness of benthic communities. Univariate indices such as the species richness, the Margalef diversity index (Margalef, 1958), the Shannon index (Shannon and Weaver, 1962), the Pielou evenness index (Pielou, 1969) and the Simpson index (Simpson, 1949) are commonly used.

Over the last decades, several benthic indices have also been developed to assess the ecological quality status of benthic marine habitats. Indices such as the AZTI Marine Biotic Index (AMBI), the multivariate AMBI (m-AMBI) and the biotic index (Grall and Glémarec) have been proposed. These indices are particularly subject to organic enrichment and eutrophication pressure and widely used near coastal environments. Bottom trawling and dredging exert significant pressures on benthic habitats. Indices such as the trawling disturbance index (TDI), the modified TDI (mTDI), the partial TDI (p-TDI) and the modified vulnerability index (mT) have been developed. These indices are based on biological traits of benthic species. Indices like M-AMBI and TDI are based on a classification of taxa on a scale of sensitivity/tolerance to a defined pressure according to literature and expert judgment (Labrune et al., 2021).

Indices based on the deviation of community composition between reference stations and tested stations have been also developed. The Community disturbance index (CDI), the general-purpose biotic index (GPBI) and the Bray-Curtis similarity index have been tested. These indices have the advantage that they are potentially able to detect any kind of pressure effects inducing changes in benthic macrofauna community composition and structure (Labrune et al., 2021).

Indices based on an ecosystem approach (EBQI) have also been developed in the Gulf of Lions and applied to the biocenosis of the Mediterranean coastal detritic bottoms. Rarity index is also used to described atypical or unusual species assemblages.

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Benthic foraminiferal communities

Due to their high density, diversity, ubiquity, and short life span, infaunal benthic foraminifera (Annex 6) have been increasingly used to assess the ecological status of marine environments. Several indices based on living foraminiferal faunas have been developed. These indices are mainly based on stress-tolerant species or stress-sensitive species. In the Gulf of Lions, the Tolerant Species Index (TSI-Med), the AZTI Marine Biotic Index based on Foraminifera (Foram-AMBI) and the Foram Stress Index (FSI) have been implemented over the last years. These indices measure the response of the foraminiferal communities to organic matter enrichment (Parent et al., 2021). Furthermore, the potential conservation of their tests in the sediment archive offer the possibility to assess past environmental baseline condition. Knowing that natural reference conditions are very hard to find in the Gulf of Lions, benthic foraminiferal faunas appear as very interesting indicators.

The main indices used in the Gulf of Lions are summarized in Figure 11.

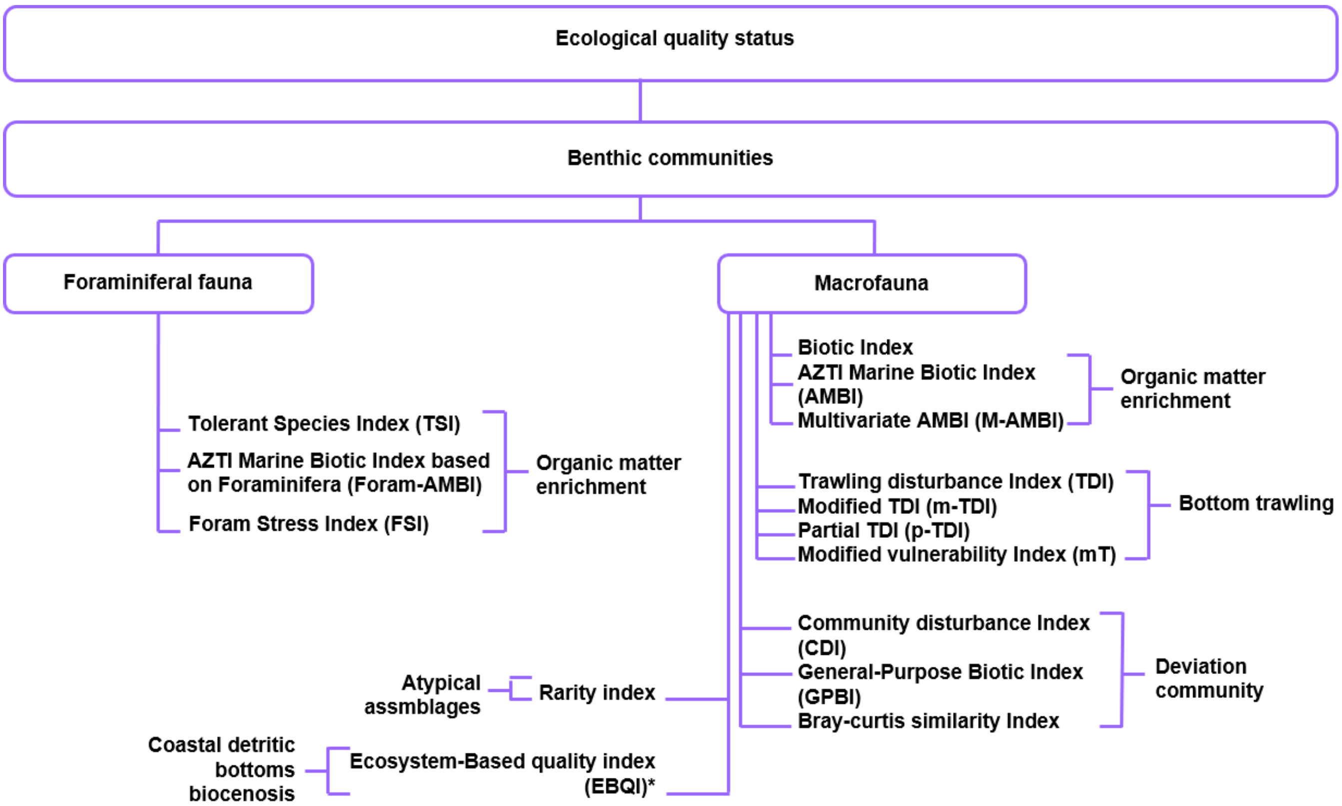

Figure 11: Benthic communities are used to assess ecological quality status of marine environments. Several indices have been developed over the last decades and are summarized here. Both foraminiferal fauna and macrofauna are used. *Only the Ecosystem-Based Quality Index (EBQI) integrates all the components of the ecosystem.

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Activities management

From the shore to the open sea, the Mediterranean Sea hosts a wide range of activities (e.g. exploitation of living and mineral resources, coastal development, tourism, Fig. 12) and is the source of a large economy. The economic value of ocean-related activities in the Mediterranean Sea, named the gross marine product, is estimated to be Euros 450 billion annually (Randone et al., 2017). The development of these activities exerts pressures on the marine environment and its ecosystems. These pressures, that express mainly as physical, chemical or biological pressures and that often overlap, cause impacts on marine ecosystems, degrading their state and eroding their resilience.

In the Gulf of Lions, these activities occur all year-round with variable temporalities and intensities. Activities are particularly intense during summertime and are regularly gathered in restricted areas (near the coastline or ports, for instance). Some of these activities depend on the health of the marine environment, like primary sector activities (e.g. fishing, aquaculture) and service sector activities (e.g. tourism, recreational fishing).

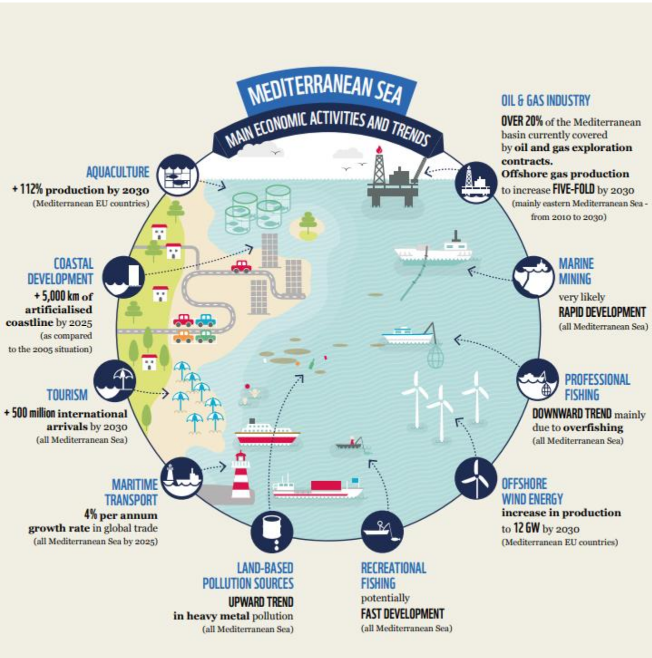

Figure 12: Main economic activities in the Mediterranean Sea and their foreseeable trends (Source: Randone et al., 2017).

To support the implementation of a Blue Economy and to develop management measures that secure biodiversity and ecosystem services, it is necessary to assess marine ecosystem condition and to have a comprehensive understanding of human pressures on the marine environment. During the last decades, several methods and indicators have been developed for marine condition assessments (see review of Smit et al. (2021)).

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In the following section, the main activities that exert pressures and impacts on soft sediment habitats, in the Gulf of Lions, are described. Methods and indicators used for condition assessments are also discussed.

Fishing activity

Fishing, and particularly bottom-trawl fishing, is known to be one of the main human disturbance in marine ecosystems (Halpern et al., 2008). It is a widespread and extensive source of physical to soft sediment habitats and has effects on the biomass, biodiversity, structure and functioning of benthic ecosystems (Thrush et al., 2015; Rijnsdorp et al., 2016; Eigaard et al., 2017). The increasing demand for marine resources and the development of fishing technologies have generated, in the Mediterranean Sea, an increase pressure on demersal fishery resources while selectivity (i.e. proportional exploitation of juveniles) has been deteriorating (Vasilakopoulos et al., 2014). Even if, for the first time in decades, the General Fisheries Commission for the Mediterranean (GFCM) report some positive trends (including the European hake due to management measures), most of the demersal fish stocks remain subject to overfishing (FAO, 2020).

Socio-economic context

In the Mediterranean Sea, the Gulf of Lions (Geographical Subarea (GSA) 7, defined by the GFCM) is a highly productive area due to its bottom morphology, the Rhone River inputs and the coastal upwelling activity (Raimbault and Durrieu de Madron, 2003). For decades, many demersal species of commercial interest have been intensively exploited on the continental shelf and the upper slope by the French and Spanish fleets using multi-gears (e.g. trawls, gillnets, dredges; Lleonart and Maynou, 2003). Spanish trawlers, 30 in number, are confined near the south-eastern edge of the Gulf of Lions. French trawlers are the main component of the fleet that exploits marine fish resources in the Gulf of Lions. In 2020, the French fleet was composed of 53 trawlers. 91% of the fleet is characterized by boat length of 18 to 25 m (Ifremer-SIH, 2022). It is noticed than, in 10 years, the number of French trawlers has been reduced by ca. 50%. Trawlers are mainly based in the French ports of Le Grau du Roi, Sète and Port-la-Nouvelle. Two main gears are used for trawling: the bottom otter trawl (OTB) and the otter twin trawl (OTT), with a 40 mm square mesh size or a 50 mm diamond mesh size. Most of the fishing effort is concentrated near the coast, in a strip located between the 3 and 12 nautical miles. This is directly linked to the French regulations which limit fishing trips to 12 to 15 hours in time. The volume of fish landed is estimated of ca. 10,000 tons per year and represents a capital gain of ca. 40 M€. Trawling activity forms the backbone of commercial fisheries and generates ca. 600 direct and indirect employment (Baranger et al., 2017). The largest species in the fish trade are the octopus, the hake, the mackerel, the capelin, the squid, the monkfish, the red mullet and the sole (Baranger et al., 2017; Ifremer-SIH, 2022).

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Management plan

In 2019, the EU established a multiannual plan for fisheries exploiting demersal stocks in the western Mediterranean Sea (Regulation 2019/1022). The regulation aims to ensure a sustainable exploitation of the main harvested species in order to restore and/or maintain their stock. It also aims to contribute to eliminate discards and to apply an ecosystem-based approach to fisheries management. In the Gulf of Lions, the regulation applies, firstly, to the hake and the red mullet. The regulation introduces a fishing effort regime and foresees a 10% reduction in 2020 and a 30% reduction by 2025. To reach these objectives, the French authorities had set up a national management plan that includes, a reduction of the number of hours spent for fishing per day and of the number of fishing days per year. It also includes spatial-temporal restrictions of fishing activities. In the Gulf of Lions, a Fisheries Restricted Area (FRA, Fig. 13) was established, in 2009, near the continental slope of the eastern Gulf of Lions (recommendation GFCM/33/2009/1).

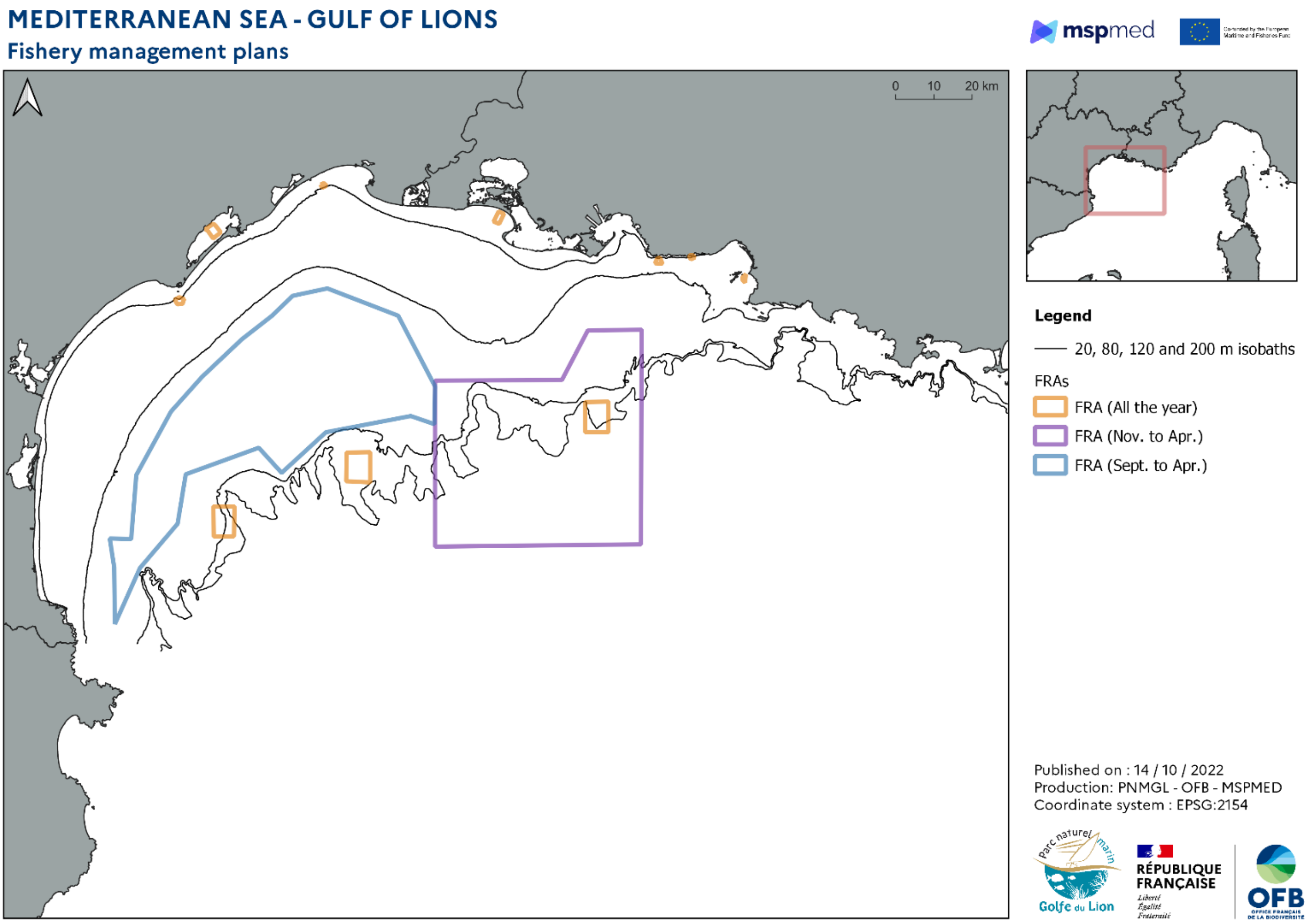

Figure 13: Spatial-temporal fishery closures in the Gulf of Lions to protect demersal fish stocks (hake and red mullet).

This FRA (3 468 km²) was established to protect the spawners in the area and is closed for a time period of six months (from November to April). Another area (3 368 km²) of temporal closure has been established at the western edge of the FRA described above, between the 90- and 100-metre isobaths (Fig. 13). Trawling is prohibited in this area during a time period of height months (from September to April). Since 2018, it is also noticed that trawling activity is prohibited throughout the year within three little areas (178 km² in total) located near the continental slope (Fig. 13) in order to protect the juveniles.
FRAs are also present along the coast. The FRA of the Gulf of Beauduc has been established in 2013. This FRA (4.5 km²) aims to protect soft-sediment bottom communities from trawling.

More details on French and Spanish fisheries are available (UNEP-MAP-RAC/SPA, 2013 and MEDFISH project; Tab. 4). The efficiency of the management plan described has been also assessed (Wendling et al., 2019; Leforestier et al., 2020) and its socio-economic impact on fisheries has been evaluated (Baranger et al., 2017; Tab. 4).

Project	Year(s)	Institution	Topic	Link
UNEP-MAP-RAC/SPA	2013	UNEP	Description of the fisheries in the Gulf of Lions	PDF
MEDFISH	2015 – Present day	WWF, Marine Stewardship council	Fisheries moving towards sustainability in the Mediterranean Sea	Outcomes and data
DISCARDLESS	2015-2019	EU project	Strategies for the gradual elimination of discards in European fisheries	PDF
GALION	2019	AMOP	Alternative management of trawl fisheries in the Gulf of Lions	PDF
PECHALO	2019	IFREMER	Assess the adaptation of fishing strategies in the Gulf of Lions	PDF
GEPAC MED	2017	AMOP	Socio-economic diagnosis of the French trawler in the Gulf of Lions	PDF

Table 4: Synthesis of the main projects describing the French and Spanish trawlers in the Gulf of Lions and assessing the efficiency of the management plan.

Impact of bottom trawl fisheries on soft sediment habitats

Seabed trawling affects a wide range of habitats, environmental components and characteristics specifically defined in the MSFD (Smith et al., 2016). The descriptor on biodiversity (D1) and the descriptor on seabed integrity (D6, which states that "the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected") require that the impact of bottom trawling on benthic habitats is regularly assessed. Therefore, indicators and threshold values have to be defined.

VMS data and surface abrasion pressure

Fishing data are based on the development of satellite-based vessel monitoring system (VMS) which provides, at regular intervals, large-scale high-resolution information of European fishing activity for largest fishing vessels (Eigaard et al., 2016). Launched in 2009 by the EU

(Council Regulation N°1224/2009), VMS data inform on the time spent to fish per area and time units. All European fishing vessels over 15 m in length are mandatorily required to equipped with VMS. Since 2012, fishing vessels over 12 m in length are also required to use satellite system to detect their location, course and speed. VMS data are used to estimate fishing effort. Fishing trajectories and fishing gear type are used and aggregated yearly to compute the abrasion induced by fishing vessels over the seabed (Jac and Vaz, 2018; Georges et al., 2021; Fig. 15). Abrasion is expressed as Swept Area Ratio (SAR).

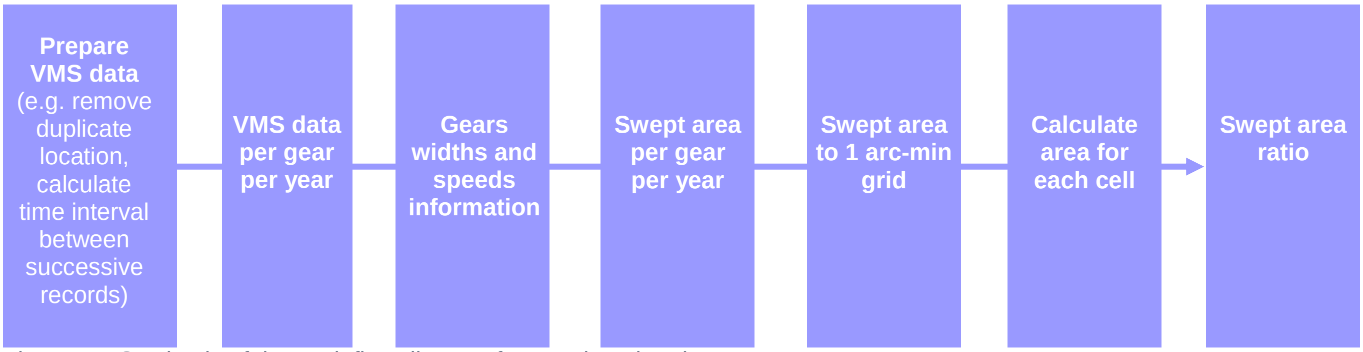

Figure 14: Synthesis of the work flow diagram for creating abrasion pressure.

In the Gulf of Lions, map of 90th inter-annual percentile of swept area ratio was used to determine the abrasion value at each sampled station during the 2009-2017 period (Fig. 16).

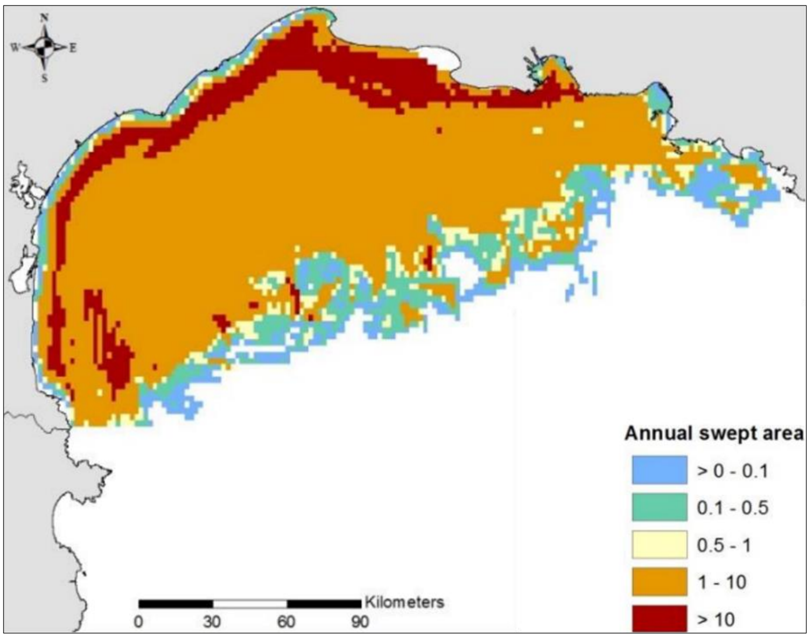

Figure 15: 90th inter-annual (2009-2017) percentile of the abrasion in the Gulf of Lions (Source: Jac et al., 2020). Abrasion data due to bottom trawling activity are available at the following link (14 gridded layers (2008-2020) of 1'x1' resolution).

Resolution of the map is 1’x1’ (Jac and Vaz, 2018). The calculation of abrasion using VMS data induces some uncertainties. At present, VMS pings occur only every 2 hours. Furthermore, fishing vessels smaller than 12 m in length are not mandatorily required to equipped with VMS. Thus, some areas, particularly near the coast, might be inaccurately considered as untrawled. The legal requirement for all vessels under 12 meters in length to have a VMS (like in the United Kingdom by late 2022), together with an increase frequency of VMS pings, could, in a near future, increase the accuracy and spatial resolution of abrasion values.

Trawling-induced physical alteration of the seabed

Demersal fishing gears used are designed to maximize their contact with the seabed. Bottom trawl gears penetrate the seafloor up to 35 cm deep for otter trawls (Eigaard et al., 2017). In general, penetration depth varies with sediment type. Penetration will be deeper on finer and softer sediments than on sandy sediments. The disturbance due to trawling is most significant in deeper shelf areas with softer sediments where the level of physical disturbance due to waves and tides is low (Duplisea et al., 2001).

In the Gulf of Lions, a dedicated trawling experiment was performed to assess the resuspension of particulate and dissolved matter triggered by trawling gears on soft sediments (Durrieu de Madron et al., 2005). Bottom-trawls induce, regularly throughout the year, significant resuspension and increase turbidity. The sediment clouds produce by trawls is estimated to be 3 to 6 m in high and 7 to 200 m in width, few hundred meters astern. Nutrients fluxes induce by trawling activities are estimated to be 2 to 5 orders of magnitude higher than the natural diffuse effluxes. The injection of new nutrients, particularly during summer, a period where the water column is depleted in nutrients, might locally affect the biological production in the Gulf of Lions (Durrieu de Madron et al., 2005). A large fraction of the resuspended sediment settles rapidly (within 1 to 2 hours according to Durrieu de Madron et al., 2005) but one-tenth remains in suspension. The bottom nepheloid layer is thought to be regularly supplied with suspended fine-grained sediment, particulate and dissolved elements.

The impact of natural (waves and currents) and anthropogenic processes (trawling) on the dispersal of shelf sediments in the Gulf of Lions was also assessed. Trawling-induced resuspension fluxes are on average several order lower than the wave- and current-induced resuspension fluxes (Ferré et al., 2008). During energetic years, where large flood, strong marine storm or dense water formation occurred, trawling activity contributed little to the total shelf export of fine sediment. During years where no significant events occurred, trawling is expected to contribute to one-third of the total shelf export in the Gulf of Lions (Ferré et al., 2008).

The tracks left by the trawl gears remain for a long period and are observed with acoustic mapping (e.g. Palanques et al., 2001).

Impact of bottom trawling on benthic communities

Several studies have shown that bottom trawling disturb seabed sediments, flatten the bottom topography and affect the structure, functioning and complexity of benthic communities.

Macrofauna and megafauna are particularly sensitive to physical disturbance and a depletion of these fauna is generally observed following trawling. Megafaunal species are vulnerable because they are long lived and take long time to reach a reproductive age (Munday, 1992). Benthic mega-epifauna represent the fauna the most directly affected by bottom trawling.

Most studies evaluating the impact of trawling activity on benthic communities use sampling methods such as dredges which are mainly focused on the infauna communities (Fig. 16). Sampling dredge are located relatively nearshore in a limited spatial coverage. Benthic data from scientific bottom trawl surveys (such as MEDITS survey) represent a good alternative. Nevertheless, this sampling method is considered destructive for benthic communities. Due to its non-destructive nature and its ability to focus on benthic macro-epifauna, towed video sampling appears to be a good alternative to monitor the impact of trawling on benthic communities (Jac et al., 2021; Fig. 16).

Many indices exist and detect changes in benthic fauna community in relation with anthropogenic pressure (see paragraph: ecological quality status). Not all of them are effective for physical disturbance like bottom trawling. Indices specific to trawling pressure and based on biological traits (mobility, fragility, position on substrate, average body and feeding mode) of benthic species (e.g. TDI, mTDI, p-TDI and mT) appear to be suitable to detect the impact of trawling (Jac et al., 2020; Fig. 16). In Mediterranean waters, these indices need to be systematically screened and the locally most suitable on chosen for impact assessment (Jac et al., 2020).

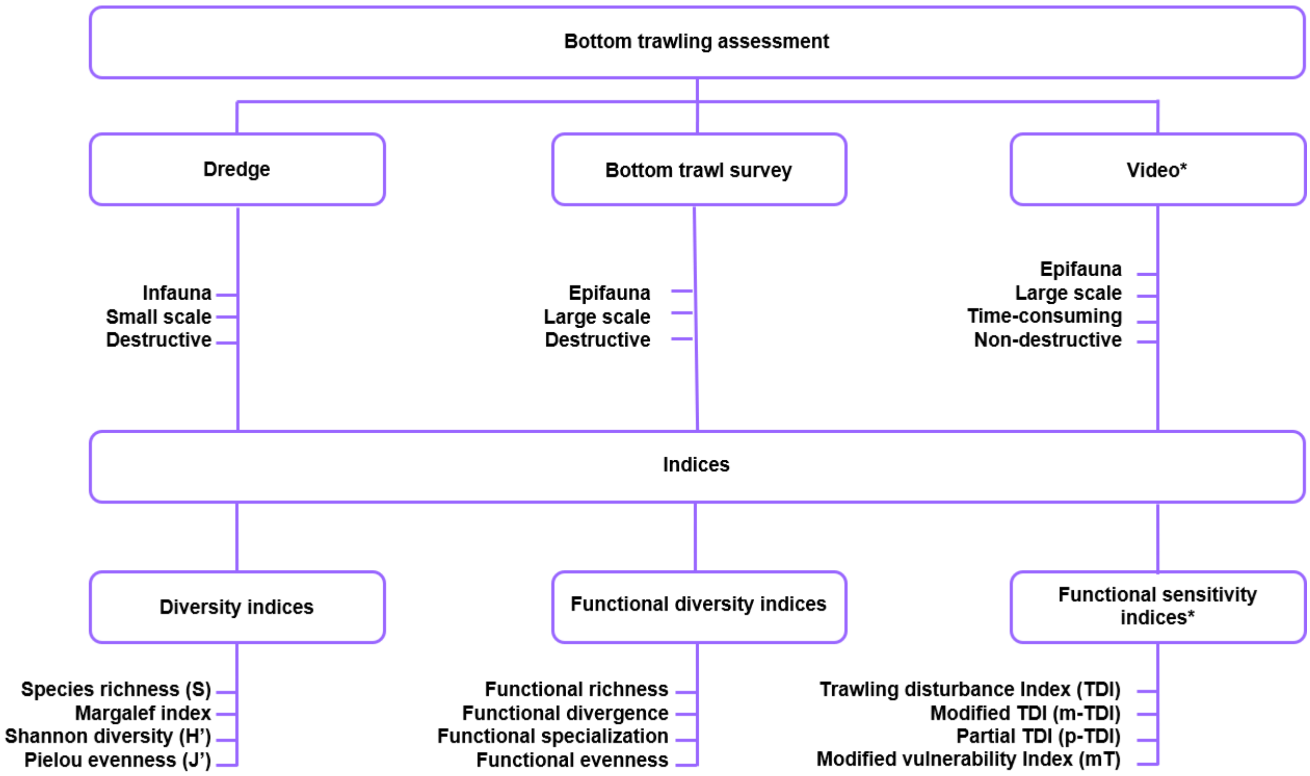

Figure 16: Sampling methods and indices used to assess the impact of bottom trawling on benthic communities. *indicates that towed video sampling and functional sensitivity indices are particularly suitable for bottom trawling assessment (information from Jac et al. (2020; 2021)).

Trawling is also recognized as a low-selective fishing activity. It can result in the removal of large parts of demersal and benthic communities including many species that play a key role in marine ecosystems (Hall et al., 2000). Identification of essential fish habitats is a key requirement for the development of spatial conservation planning in order to reduce adverse impact of bottom trawling.

In the Gulf of Lions, several projects aim to study the impact of bottom trawling on benthic communities. There are summarized in Table 5.

Project	Year(s)	Institution	Topic	Link
INTERPOL	2001-2003	EU project	Impact of natural and trawling events on the resuspension, dispersion and fate of pollutants	PDF
IDEM-VIDEO	2018	IFREMER	Benthic habitats in recently closed FRAs	Link (videos)
EPIBENGOL	2018	IFREMER	Impact of bottom trawling on various sedimentary hydrodynamic context	Link (videos)
IMPEC	2021-2024	IFREMER, University of Angers (LPG), University of Sorbonne (LECOB)	Impact of bottom trawling on benthic communities	N/A

Table 5: Synthesis of the main projects assessing the impact of bottom trawling in the Gulf of Lions.

Coastal management

The littoral is a fragile and mobile area. Its evolution depends on a combination of continental (geological structure), marine (variation in sea level) and atmospheric (subaerial agents) factors. Shoreline position and coast morphology change on various time and space scale, with phases of erosion/accretion.

The littoral is exposed to multiple and interlinked risks. Coastal erosion and submersion hazards are the main threats for coastal environment. Sea level rise in relation to climate change is expected to increase coastal risks (IPCC, 2018).
The concentration of population and activities on the coast contribute also to a greater vulnerability. At present, the population density on the French coast is 2.4 times higher than the national average, with an expected upward trend (Cerema, 2020). Since the 1960s, the littoral has been transformed for economic and coastal tourist development (mission Racine). Considering coastal hazards, the coastline has been equipped with hard defense structures such as dikes, seawalls, breakwaters and jetties. In France, more than 20% of the coastline is artificialized (Cerema, 2015). In the Gulf of Lions, the length of artificialized coastline was ca. 623 km in 2014 (Fig. 17).

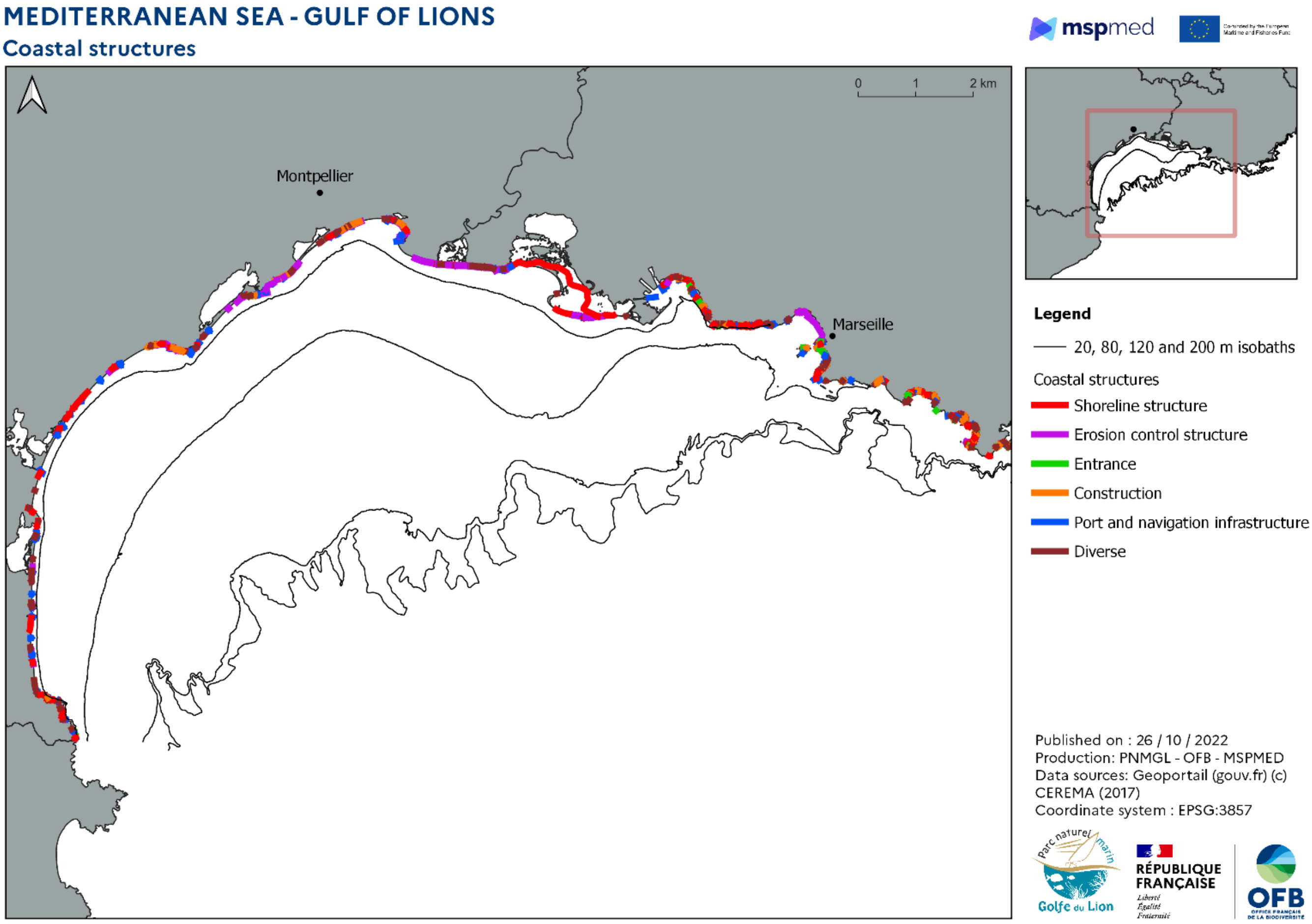

Figure 17: Coastal infrastructures in the Gulf of Lions (data from Cerema, 2017).

Hard engineering use to protect coasts by absorbing the energy of waves, preventing erosion and flooding. Hard structures lead to fix the shoreline. At the opposite, soft solutions are designed to “work with the nature” by integrating the natural dynamic of the littoral and the mobility of the shoreline. There are considered more ecological minded, have limited life span and are reversible. Many protections against beach erosion have been developed over the last decades. Among them, geotextile structures, hydraulic piling, by-passing, beach nourishment and revegetation are commonly used. Artificial reefs are also used to dissipate the energy of the swell and currents and then slow down the longshore drift (PEGASE project, Agde; Tab. 6). In the Gulf of Lions, experimental nets (1.1 m height, 1.5 m width) have also been set up in Sainte-Marie-la-Mer (S-ABLE project; Tab. 6). This new method aims like artificial reefs to dissipate swell energy.

Hard coastal protection solutions and soft coastal protection solutions have both limitations. If stakes (socio-economic, human and environmental) do not justify an intervention, a strategic-retreat or a non-intervention are considered. Strategic retreat is at present relatively complex, expensive and require major communication with local population and concerned users.

The National Strategy for Integrated Coastline Management[1] (SNGITC) adopted in 2012 shares the roadmap for the development of knowledge and the implementation of local strategies that better consider coastal dynamic. In a context of climate change, this strategy aims to better anticipate erosion and submersion phenomena and their consequence on coastal areas, particularly in terms of urban planning. At SNGITC is declined at regional scale (Regional Strategy of Integrated Coastline Management). The Region Occitanie where coastal management is a priority adopted a regional SNGITC[2] that aims to implement coastal management for a short- and long-term (2018-2050).

To support coastal management, observatories have been implemented at national and regional level. These observatories federate stakeholder responsible for monitoring coastlines and aim to centralize data and support information sharing. At a national level, the French national coastline observatories network[3] website was launched in 2008. In the Mediterranean Sea, three observatories have been developed:
- the integrated coastline management platform (Region PACA, website);
- the observatory of the Catalan sandy coast (Region Occitanie; website);
- the Occitanie littoral portal (Region Occitanie ; website).

In the framework of the SNGITC, a national coastal erosion index has been produced and highlight the evolution of the shoreline position over a period of 50 years (Cerema 2018; Fig. 18). In France, near 20% of the coastline is threatened by erosion. In the Mediterranean Sea, a long-term trend in shoreline retreat is also observed (Fig. 18). The disappearance of beaches due to an increase in erosion would be detrimental for the economy of the regions.

Locally, scientific studies aim to help local authorities to implement integrated coastal management. These studies highlight that sediment budget in the Gulf of Lions is characterized by an overall negative balance (Brunel et al., 2014). The management strategy developed over the last decades with the development of hard engineering might have caused adverse effects within the coastal zone on a long-term process. Natural longshore sedimentary redistribution is indeed strongly disturbed by these hard structures that generate the formation of artificial boundaries. The general alongshore erosion/accretion pattern is then disrupted. Sediment loads as a result of dam construction has also decreased significantly, increasing this phenomenon.

Negative balance induces a reduction of the shoreface volume and long-term sediment output. Shoreface contributes in a major way to the coastal sediment budget by acting either as a sink or a source of sediment and represents thus an important control on shoreline movement. Sedimentary balance and sand stock availability along the littoral system provide key information are proved to be an efficient way to evaluate beach trend in the Gulf of Lions. Consideration of changes in sand volume is particularly important, rather than looking at changes in bathymetry.

Today a variety of techniques is available and currently used by scientists and coastal managers for monitoring beach and shoreline change. It includes field surveys using DGPs, terrestrial scanning and/or UAV photogrammetry which offer the best accuracy but is time

[1] National Strategy for Integrated Coastline Management : PDF
[2] Regional SNGITC (Region Occitanie): PDF
[3] National coastline observatories network: website

consuming and restricted to small areas. Airborne surveys using LIDAR have the preference for larger areas. Satellite remote sensing can be also an alternative and affordable techniques for large-scale acquisition data and to target coastal erosion (e.g. the Space for Shore consortium).

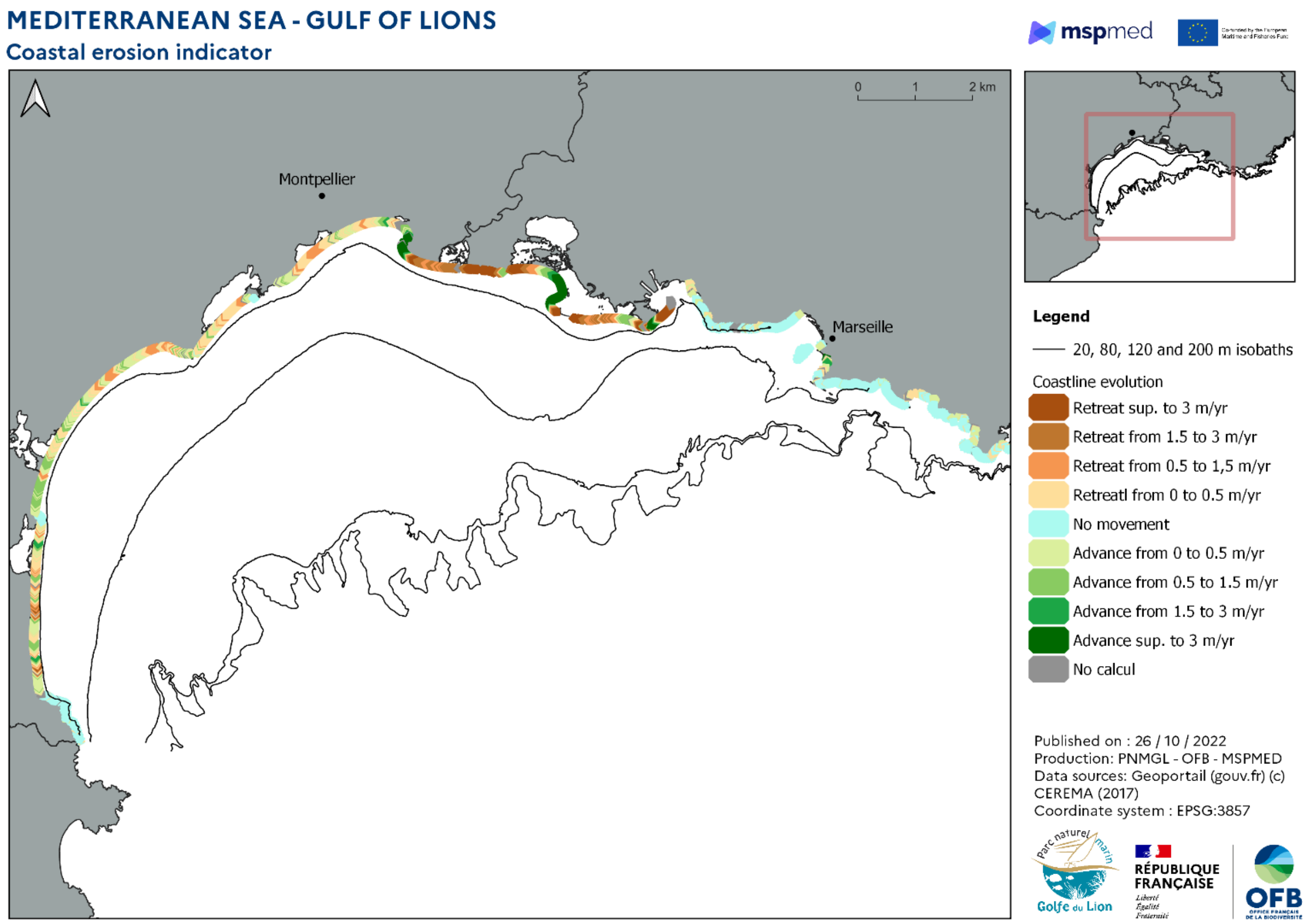

Figure 18: Evolution of the shoreline position over the last 50 years (Cerema, 2018).

Several projects have been carried out in the Gulf of Lions over the last decades in order to support local and national authorities in coastal management. These projects are summarized in Table 6.

Project	Year(s)	Institution	Topic	Link
S-ABLE	2022-2023	ABLE	Experimental nets for swell energy attenuation	N/A
PEGASE	2020-2023	Seaboost, University of Montpellier	Artificial reefs (mangrove type) for swell energy attenuation	N/A
DYNATC	2020-2023	University of Perpignan (CEFREM), OFB	Shoreline migration	N/A

Project	Year(s)	Institution	Topic	Link
PAUL		University of Perpignan (CEFREM), DREAL, CNRS	Sand transport offshore	PDF (Axe 1 and 4) PDF (Axe 2), PDF (Axe 3)
SIMILAR		University of Perpignan (CEFREM), DREAL	Infrastructures, morphology and shoreline dynamic	PDF (Theme 1), PDF (Theme 2), PDF (Theme 3), PDF (Theme 4)
SENSIVAT		University of Perpignan (CEFREM), EID, OFB	Satellite environment monitoring in the Natral Marine Park of the Gulf of Lions	PDF (Phase 1), PDF (Phase 2), PDF (Phase 3 and 5), PDF (Phase 4)
ESTER		University of Perpignan (CEFREM), OBSCAT	Sedimentary stock assessment	PDF
LITTOSIS	2015	University of Perpignan (CEFREM)	Sand stock	PDF
REVOLSED	2014	University of Perpignan (CEFREM), DREAL	Shoreline migration and sedimentary budget	PDF
REVOLSTOCK	2018	University of Perpignan (CEFREM), DREAL	Shoreline migration and sand stock	PDF

Table 6: Synthesis of the main projects assessing the impact of shoreline migration, erosion and sedimentary budget in the Gulf of Lions.

Dredging/Dredging disposal

In coastal environments, dredging involves the excavation and relocation of sediments from sea beds. Dredging methods include both mechanical and hydraulic processes. Hydraulic dredgers are commonly used in coastal marine waters. Uses are vast and include construction of ports, dykes, and other coastal development projects, land reclamation, flood and storm protection, beach nourishment and mineral extraction. Since ports and waterway authorities have a legal obligation to maintain navigation channels, most of sediment dumped at sea is locally-generated and results from the dredging of harbors and their approaches to ensure they are navigable. The new generation of large-capacity vessels combined with the development of offshore renewable energies will require, in a near future, an increase in dredging activity worldwide.

Sediments are sinks for some contaminants from anthropogenic sources such as sewage discharges, marine traffic, industrial wastewater that end up in waterways ports and seas. Since the 1970s, management of dredged material is regulated worldwide with the signings, in particular, of the London Convention (1972), the Barcelona Convention (known as the Convention for the Protection of the Mediterranean Sea against pollution, signed in 1976 and amended in 1995) or the OSPAR Convention (1998). European Directives, like the Water Framework Directive, the Waste Water Directive or the MSFD, establish a framework in the field of water and marine environmental policies and, alongside Conventions, set out guidelines for minimizing adverse impacts on marine environment resulting from placement of dredged materials and dumping. Dumping of certain hazardous materials, like sewage sludge and of vessels or aircraft, is therefore prohibited. Dumping of low-level radioactive wastes has also been banned. Sediments containing hazardous pollutants require to be transported on land, to be treated for cleaning and most of the time to be stored, resulting in additional operating costs.

In France, "Dredging and/or related discharge in the marine environment" are regulated by the French Environmental Code (Article R.214-1) and require notification and authorization. The type of procedure is based on the chemical composition of dredged sediments (i.e. threshold levels for trace elements (e.g. Cd, Hg, Pb), tributylin (TBT), polychlorinated biphenyl (PCB), polyaromatic hydrocarbon (PAH)), the distance of the project to aquaculture farms and the volume of dredged sediments over 12 consecutive months (Geode, 2015). An evaluation of the environmental situation prior to the dredging activity is mandatory and an environmental impact assessment might be required.

Since 2009, an annual survey on dredging activity in France is carried out by the CEREMA (Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning). These surveys are available for download at the following link. In the Mediterranean Sea, data for 2018, 2017 and 2016 are summarized in Table 7. National data have been reported for comparison (Cerema, 2019; Cerema, 2020; Cerema, 2021). In the Gulf of Lions, most of the dredging activity aims to deepen and maintain the navigation route of small ports. Most of the ports have a multi-year authorization (for 10 years).

Dredging activity		Mediterranean Sea			France		
		2016	2017	2018	2016	2017	2018
Dredged materials (million wet ton)	Total	<0.12	0.191	0.231	31.82	30.49	29.34
	Large ports	<0.02	0.001	0.011	29.26	27.96	26.84
	Small ports	<0.1	0.19	0.22	2.56	2.53	2.50
Uses of dredged materials		Mediterranean Sea			France		
		2016	2017	2018	2016	2017	2018
Dumping (million wet ton)		N/A	N/A	N/A	30.1	29.9	24.25
Beach nourishment (million wet ton)		0.041	0.036	0.073	0.19	0.17	0.51
Stored (waste; million wet ton)		0.004	N/A	N/A	1.5	0.35	4.57

Table 7: Synthesis of the dredging activity in the Mediterranean Sea and of the uses of dredged materials in 2016, 2017, 2018. National data for the same periods are reported for comparison. Data are from surveys carried out by the CEREMA.

Most of dredged material is dumped at sea. A part is also used to nourish beaches where erosion is occurring. In the Gulf of Lions, the location of the dumping sites and the beach nourishment sites is represented on Figure 19.

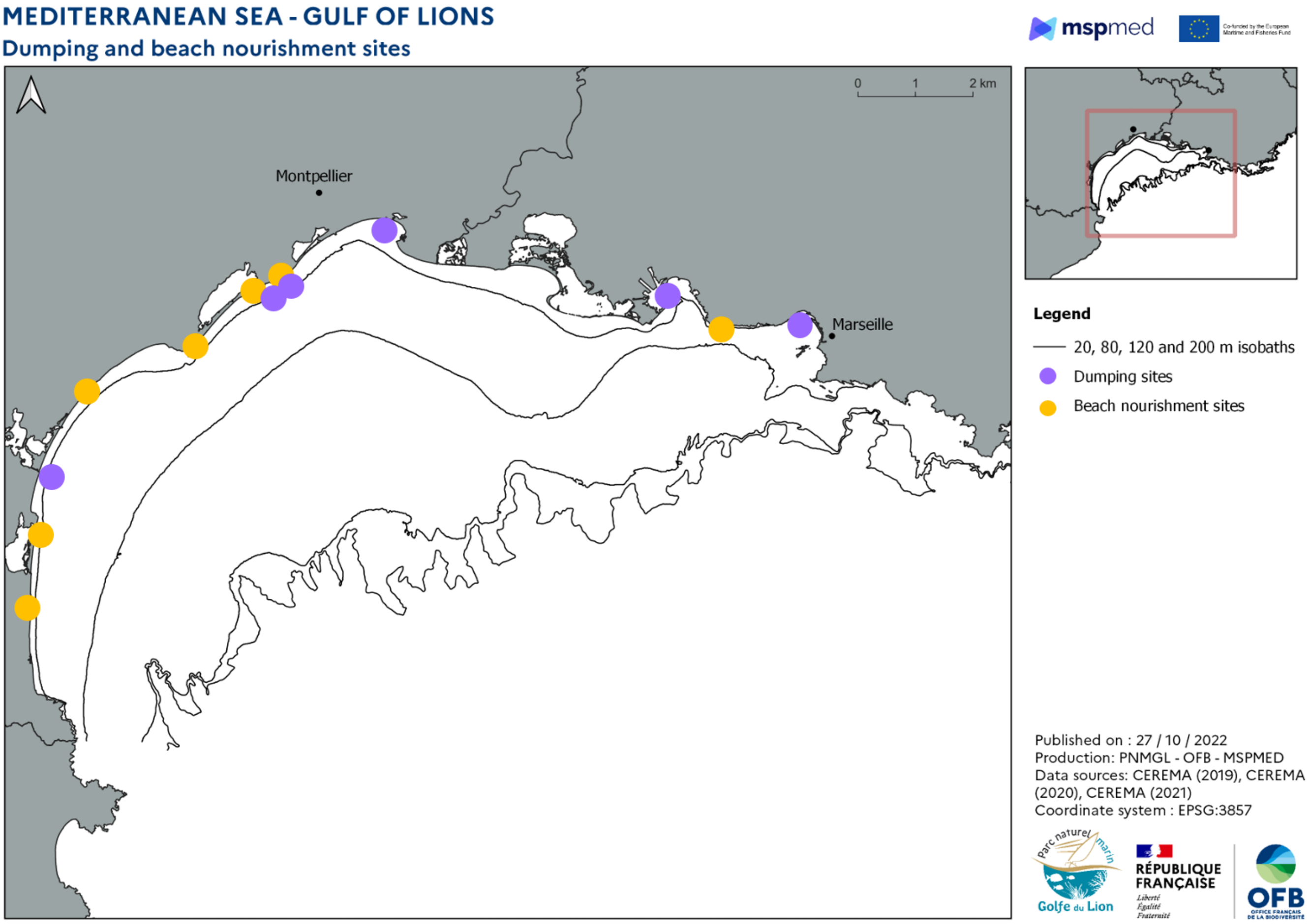

Figure 19: Dumping and beach nourishment sites in the Gulf of Lions (2016 to 2018). Data are from the surveys carried out by the CEREMA.

Dredging often has two main sites of operations; the dredge site and the dredge material disposal site. Dredging and dumping activities have direct impacts on the environment and require a sustainable management. Impacts can be physical, chemical and/or biological (Fig. 20) and depend on (1) the particle size of dredged material, (2) the dredging technique used, (3) the hydrodynamic characteristics of the dredged area, (4) the sensitivity of the habitat to disturbance, turbidity and sedimentation.

Dredging is known to modify the three-dimensional structure, topography and complexity of the seafloor (Eidam et al., 2020) and can induce local changes in hydrodynamic conditions (Geode, 2012). Seabed disturbance through extraction and disposal of sediments results in increased turbidity and the formation of sediment plumes. Dredging-related increases in turbidity may exceed turbidity levels induced by natural events. Sediment plumes can extend several kilometers from the dredging operations, depending on the particle size and the quantity of dredged material and local hydrodynamic conditions (Fisher et al., 2015).

Increased suspended sediment concentrations and the settlement of sediments smother benthic habitats and might suffocate bottom-dwelling organisms (Erftemeijer et al., 2012).

Impacts of increased suspended sediment concentrations are highly species-specific and depend on the ability of species to tolerate or escape burial (Wilber and Clarke, 2001). By decreasing the underwater light intensity, increased turbidity can also have effects on primary production. Regularly disturbed habitats characterized by fine sands and fast-growing opportunistic species are thought to be less affected than more stable habitats characterized by slow-growing sessile fauna (Tillin et al., 2011). Modelling sediment plumes can allow to avoid sensitive areas.

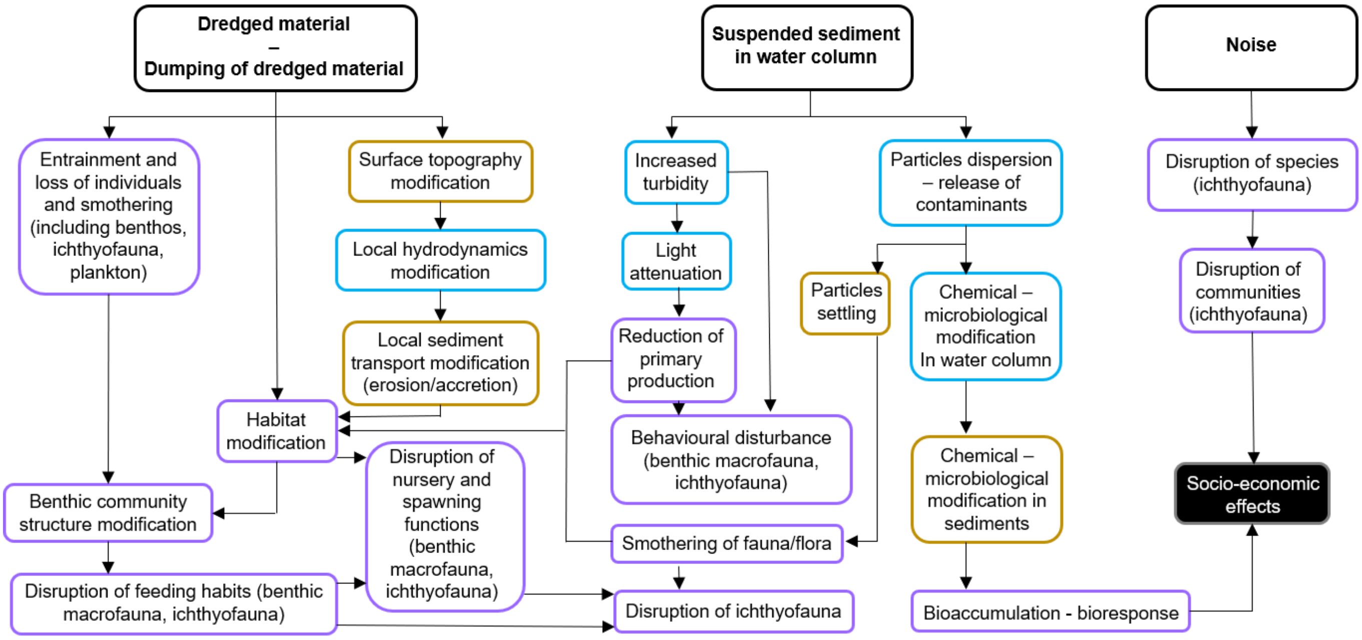

Figure 20: Impacts of dredging and dumping on marine ecosystems. Purple color indicates an effect on the biotic component, blue color indicates an effect on the water column and brown color indicates an effect on the sedimentary component (modified from Geode, 2018).

Dredging induces also a risk of entrainment for all marine organisms associated with the seabed. Suction field created by hydraulic dredgers is a threat for benthic fauna and demersal fish. Larvae, eggs and juveniles are particularly at risk since there are unable to avoid the suction field (Nightingale and Simenstad, 2001). Dredging in spawning and nursery areas can thus affect survival rate of organism to adulthood and modify the population structure and growth. Restrictions have to be implemented in these essential fish habitats (see Box 4.).

A remobilization of chemical contaminants accumulated within fine particles can be induce by dredging as well. Release of contaminants into the water column has the potential to reduce water quality at both dredge and dumping sites. Contaminants can become available to marine organisms and potentially accumulate up to the food chain. Contaminated sediments have thus to be strictly managed to minimize the effects on the environments.

Msp-Med
Towards the operational implementation
of MSP in our common Mediterranean Sea

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Box 4:
Seahorse population in the Gulf of Beauduc (Peau Bleue, Seaquarium's Marine Institute and Natural Regional Park of Camargue)

A new species of short-snouted seahorse, *Hippocampus hippocampus*, has been discovered near the Espiguette sandbank. The density of the short-snouted seahorse is exceptionally high and the population is considered as permanent since juveniles and adults are encountered at the same site.
The accretional Espiguette sandbank is a site of repeated dredging. Sand dredged is used for beach nourishments in the Gulf of Aigues-Mortes. A monitoring program have highlighted that sand-dredging operations have impact on this vulnerable short-snouted seahorse population. Dredging activity has been restricted in this area by authorities and a buffer zone has been defined.

The impacts of dredging and dumping have been investigated locally in the Gulf of Lions (Tab. X). Method for studying the post-disturbance recovery of soft sediment habitats involve analyses of large numbers of samples of macrofaunal and meiofaunal assemblages. This method is carried out near the port of Port-la-Nouvelle (CLAPI project). This area is particularly interesting since human pressures are well known and have been quantified over the years. Indices for ecological quality status assessment are developed and tested at present.

Project	Year(s)	Institution	Topic	Link
BEACHMED	2005-2008	IFREMER, BRGM	Dredging: assessment of offshore sand for dredging	Phase A, Phase B, Phase C
ESPEX	2007-2013	University of Perpignan (CEFREM), IFREMER, Egis Eau	Dredging: environmental stakes related to the potential sand area exploitation off the Gulf of Lions	Link to PDF
CLAPI	2021-2023	GIS Posidonie, University of Sorbonne (LECOB), Creocean, University of Angers (LPG)	Dumping: assessment of detritical	N/A

Table 8: Dredging and dumping projects in the Gulf of Lions.

The efficiency of beach nourishment has also been evaluated locally (Gulf of Aigues-Mortes) over a ten-years period. This study highlights the spatio-temporal redistribution of sediments and the existing relationships in between the emerged beach and the shoreface. A certain stability has been reached four years after the beach nourishment and ca. 30% of the sand initially deposited has been lost. Strong disparities are observed between the beaches. This study aims to support coastal management decisions.

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Marine renewable energy

France has defined its objective and the means to implement the Paris Agreement on Climate Change (21st Conference of the Parties, COP 21), signed in December 2015, in adopting the Energy Transition for Green Grow Act (Law N° 2015-992). The Act, implemented in August 2015, prior to COP 21, sets out the roadmap to mitigate climate change and diversify the energy mix. The multiannual energy plan (MEP or *Programmation Pluriannuelle de l'Energie*, PPE), established by the Act, defines the priorities of the government in terms of energy policy and sets a target of 40% renewable electricity by 2030. It is consistent with the National Low-Carbon Strategy (NLCS or *Stratégie Nationale Bas-Carbone*, SNBC) adopted in October 2015. This strategy provides guidelines for implementing the transition to a low-carbon, circular and sustainable economy in all sectors of activity. To respond to climate emergency, the Law on Climate and Energy (Law N° 2019-1147), adopted in November 2019, updated the energy policy objectives and revised the NLCS, with the objective of achieving carbon neutrality by 2050. Law N° 2019-1147 sets a target of 40% reduction in fossil fuel consumption by 2030 – compared to 2012. It also includes a target of achieving 33% of energy consumption from renewable sources, all energies combined (including hydrogen, photovoltaic, geothermal energy and wind energy), by 2030. For information, in 2020, renewable energy accounted for ca. 23% of the total gross national electricity production (RTE, electricity report 2020)[1].

Renewable marine energies will be a key component for meeting the ambitious objectives set by the Energy Transition for Green Growth Act and the Law on Climate and Energy. Over the past 10 years, France has supported the development of offshore wind energy by launching three competitive bidding procedures, which were completed in 2011, 2013 and 2016, in the Eastern Channel – North Sea Basin and the North Atlantic – Western Channel Basin (for a total of 3.6 GW divided into seven projects)[2].

In the Mediterranean Basin, sea characteristics (bathymetry) and conditions (currents, swells) are considered suitable for the development of offshore floating wind technology. From August 2015 to April 2016, the ADEME (French Agency for Ecological Transition) launched a call for tenders (named EOLFLO) for the installation of pilot floating offshore wind farms. Three pilot farms will emerge in the Mediterranean Sea:

(1) EFGL (*Eoliennes Flottantes du Golfe du Lion*) off the coast of Leucate – Le Barcarès,
(2) EOLMED (*Eolien en Méditerranée*) off the coast of Gruissan – Port-la-Nouvelle,
(3) PGL (*Provence Grand Large*) off the coast of Faraman – Port-Saint-Louis-du-Rhône.

Each pilot farm will be composed by three wind turbines and produce a total of 30 MW for EFGL and EOLMED and a total of 24 MW for PGL. These farms will enable performance and reliability testing and provide feedback prior to the development of commercial farms. Their commissioning is scheduled for 2023.

The MEP states that two commercial floating offshore wind farms of 250 MW each will emerge in the Mediterranean Sea. The two projects will be later supplemented by two extensions of 500 MW each, leading to build a total of 1.5 GW of floating offshore wind farms. Four pre-selected areas in the Gulf of Lions have been designated for the development of these two farms (Fig. 21). From

[1] https://bilan-electrique-2020.rte-france.com/total-generation/?lang=en
[2] Further information can be found at the following address: https://www.eoliennesenmer.fr/presentation

July 12 to October 31, 2021, these farms and their connection were subject of a public debate commissioned by the Ministry of Ecological Transition and the Transmission System Operator (*Réseau du Transport d'Electricité*, RTE), and orchestrated by the National Commission for Public Debate (CNDP). The public debate aims to (1) identify from the available data and the expertise of the citizens the main stakes of the selected areas, (2) define at least three preferential zones for the installation of the two farms, and (3) ensure the proper integration of the farms in the environment.
Following the debate and the report published in December 31, 2021, the Minister of Ecological Transition announced the three selected zone in April 2022 (Fig. 21).

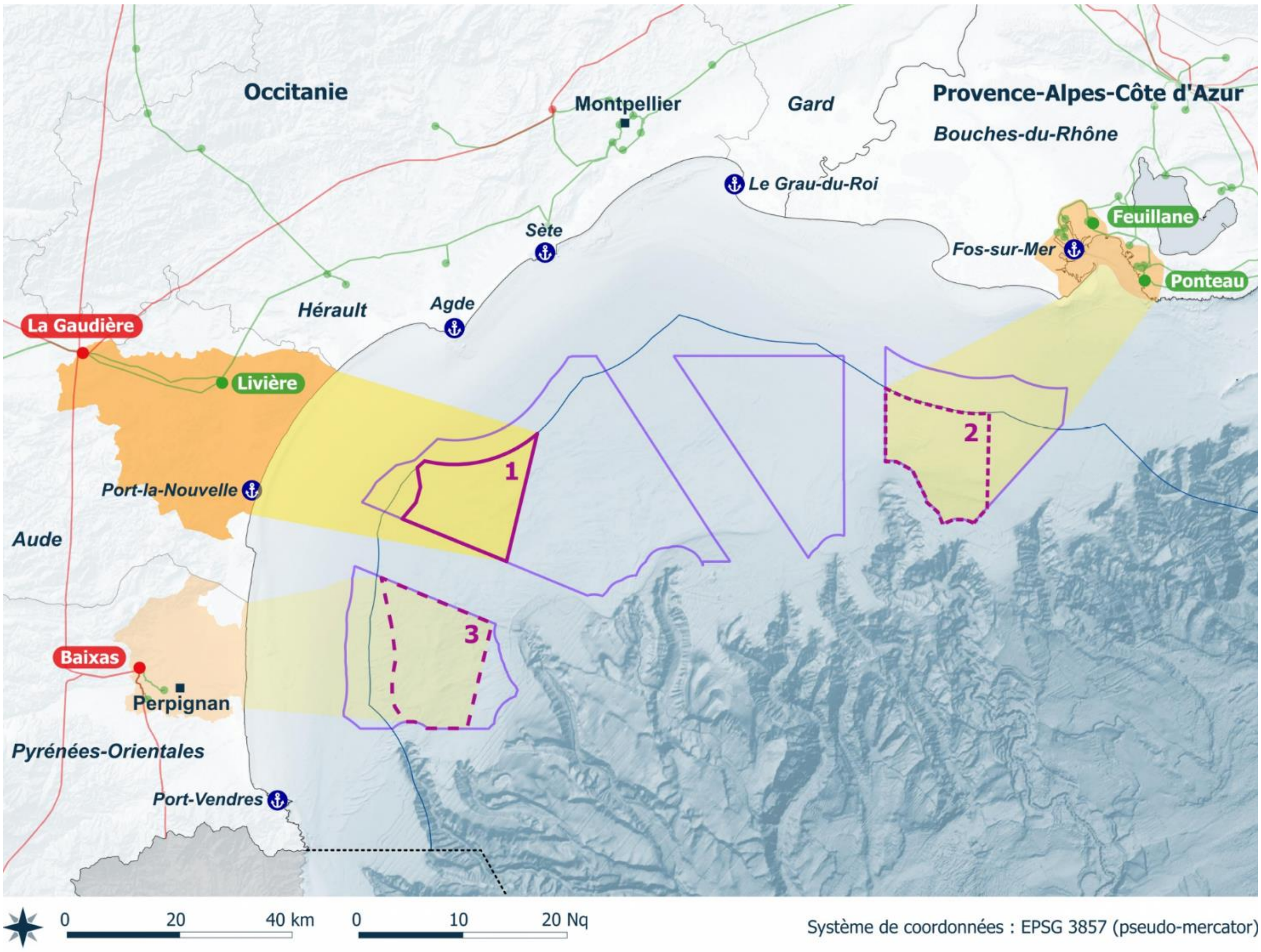

Figure 21: Map highlighting the areas selected for the development of two commercial offshore floating windfarms in the Gulf of Lions. Zone 1 is a zone selected for competitive bidding procedures and further technical and environmental studies while zone 2 and zone 3 correspond to preferential area and optional area, respectively (source: Ministry of Ecological Transition).

Prior the installation of pilot or commercial farms, geophysical and geotechnical studies are required. The initial state of environment has also to be described. Knowledge studies have been carried out recently within the implementation areas of floating offshore wind farms (Tab. 9). The DGEC (Directorate General for Energy and Climate) is in charge of carrying out studies on project areas (Tab. 9).

Within the MSP-MED project, a deliverable has been dedicated to provide knowledge about interactions between Mediterranean ecosystems and wind farms development in the Gulf of Lions (Henry et al., 2022). Development of floating offshore wind farms might exert pressure on benthic communities that are not well identified and quantified. Among these pressures, loss of habitat, changes in habitat, changes in hydrodynamic conditions and turbidity can have significant impact on benthic communities. Readers will find more information in consulting the available documents that are referred in Table 9.

Project	Year(s)	Institution	Topic	Link
APPEAL	2018-2022	IFREMER, University of Sorbonne (LECOB)	Towards an ecosystem approach to assess the impacts of offshore windfarms	N/A
FISHOWF	2021-2024	FEM, IFREMER, Ecocean	Identify and assess the impacts of offshore wind farms on fish populations	N/A
MSPMED (D8-1)	2020-2022	FEM, OFB	Interactions between Mediterranean ecosystems and wind farms development	PDF
-	2021	CREOCEAN	Environmental bibliographic study	PDF
-	2021	IFREMER	Identify and assess the impacts of offshore wind farms on fish populations	PDF

Table 9: Projects related to the development of offshore wind farms in the Gulf of Lions.

Synthesize and recommendation

The work conducted within the Gulf of Lions case study (task 2.2.1) aims to provide an updated synthesis of ecological stakes related to soft sediment habitats in the Gulf of Lions. It allowed to identify data sources, methods and main results in regards with soft substratum habitats. Scientific knowledge gaps still exist and scientists have proposed some recommendations.

The continental shelf of the Gulf of Lions comprises a variety of seabed habitats that are not well constrained. The mapping of seabed habitats has to be improved in a near future. Some areas, particularly near the canyon heads, are poorly mapped. These areas are characterized by the presence of morphological structures that are not fully identified. Priority is to map these areas and to better characterized and understand the formation of these structures and their evolution. Furthermore, in assessing the impact of human pressures on benthic communities, scientists have to ensure that samples are taken within the same habitats. At present, seabed habitats mapping is not precise enough to ensure that.

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Understanding the pattern distribution of demersal fish communities is a critical consideration in the development of effective management and conservation strategies. For marine populations of highly mobile species, this exercise can be difficult since relevant shifts in habitat appear through life cycle. Identifying essential fish habitats, and particularly nursery and spawning areas, is thus particularly important. In the Gulf of Lions, these essential fish habitats are not fully identified. Essential nursery habitats have been studied during two years. Not enough data have been collected and a long-time series data is necessary.
Functional connectivity at multidimensional levels and spatio-seasonal patterns of demersal fish communities have to be also better constrained. At present, only few information exists.

Assessing ecological quality status of benthic communities is required by European directives. Many indices have been developed over the last decades. Some indices are relatively new and have to be tested in different habitats to ensure there are able to detect pressures inducing changes in benthic communities. Furthermore, to move towards an ecosystem approach, we need to improve available data on human activities and how they spatially accumulate. It has been highlighted that it is fundamental to quantify key pressures.

The absence of pressure free areas (pristine conditions) for most habitats prevents the use of a method based on an observed reference state to monitor human disturbance. Resilience of the ecosystem is at present unknown. Determining resilience of benthic habitats is particularly important for the management of marine ecosystem. Restoration and complete recovery might be a long process (from months to decades). FRAs could be potential good target areas to study the resilience o benthic communities.

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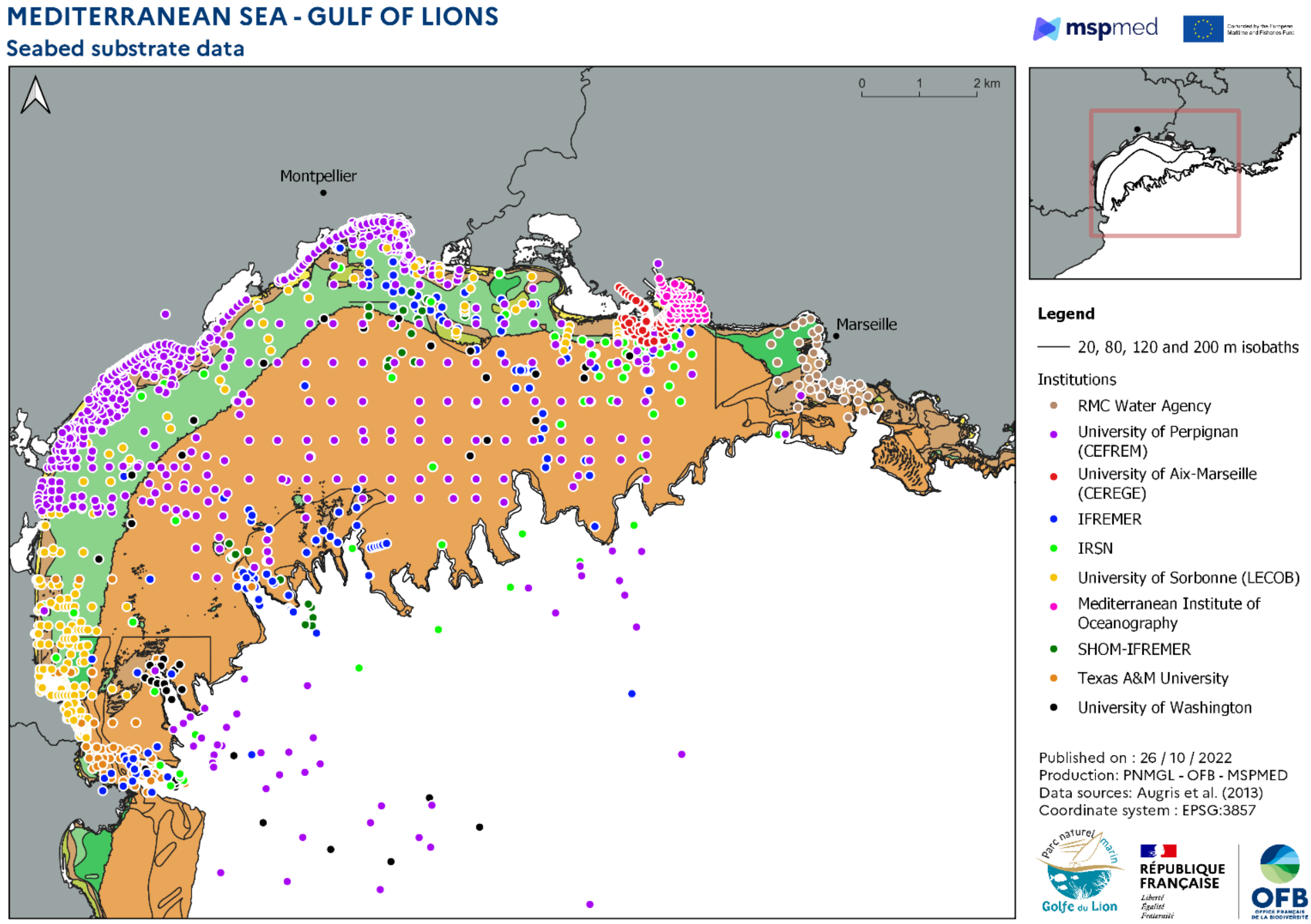
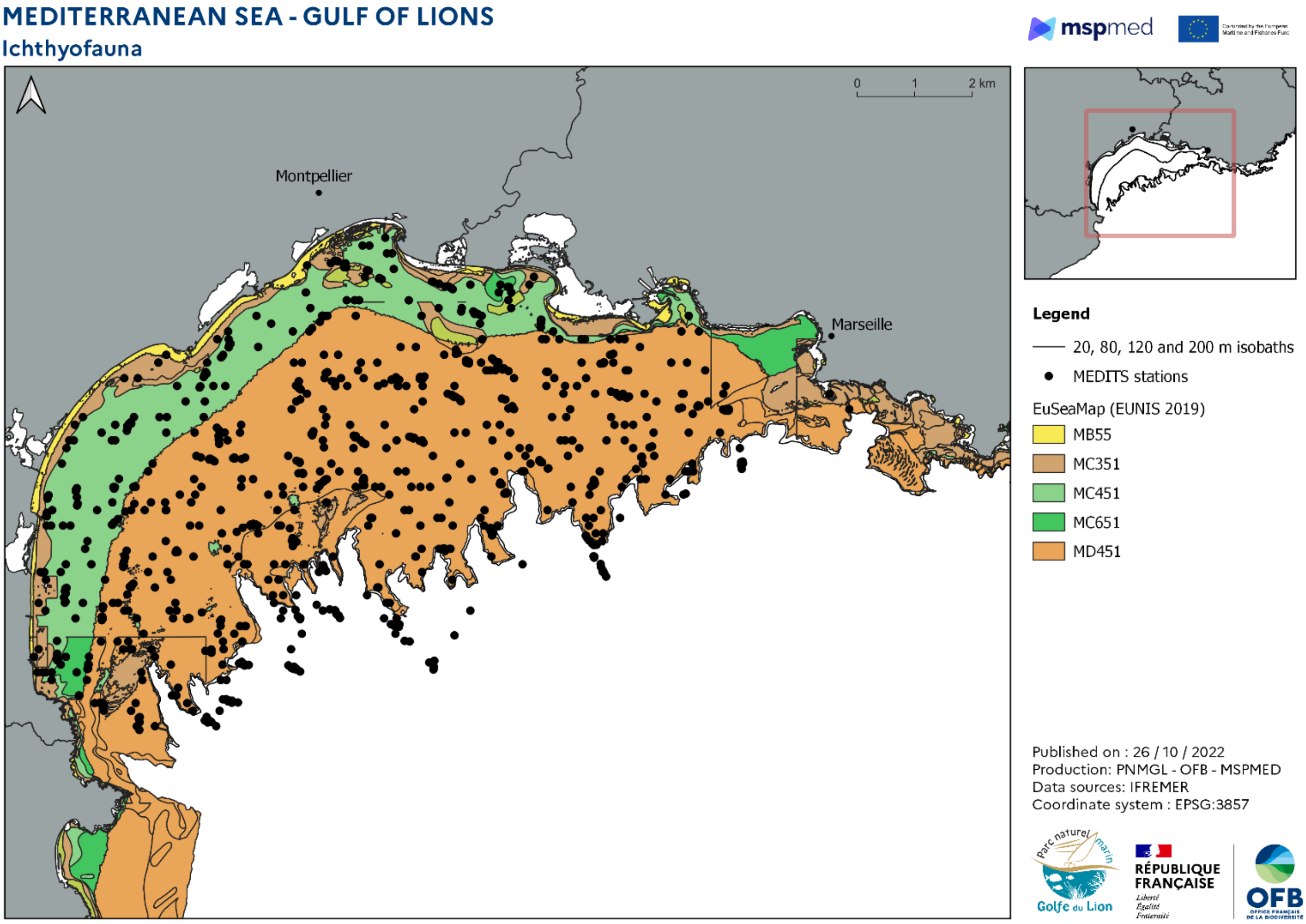
Annex

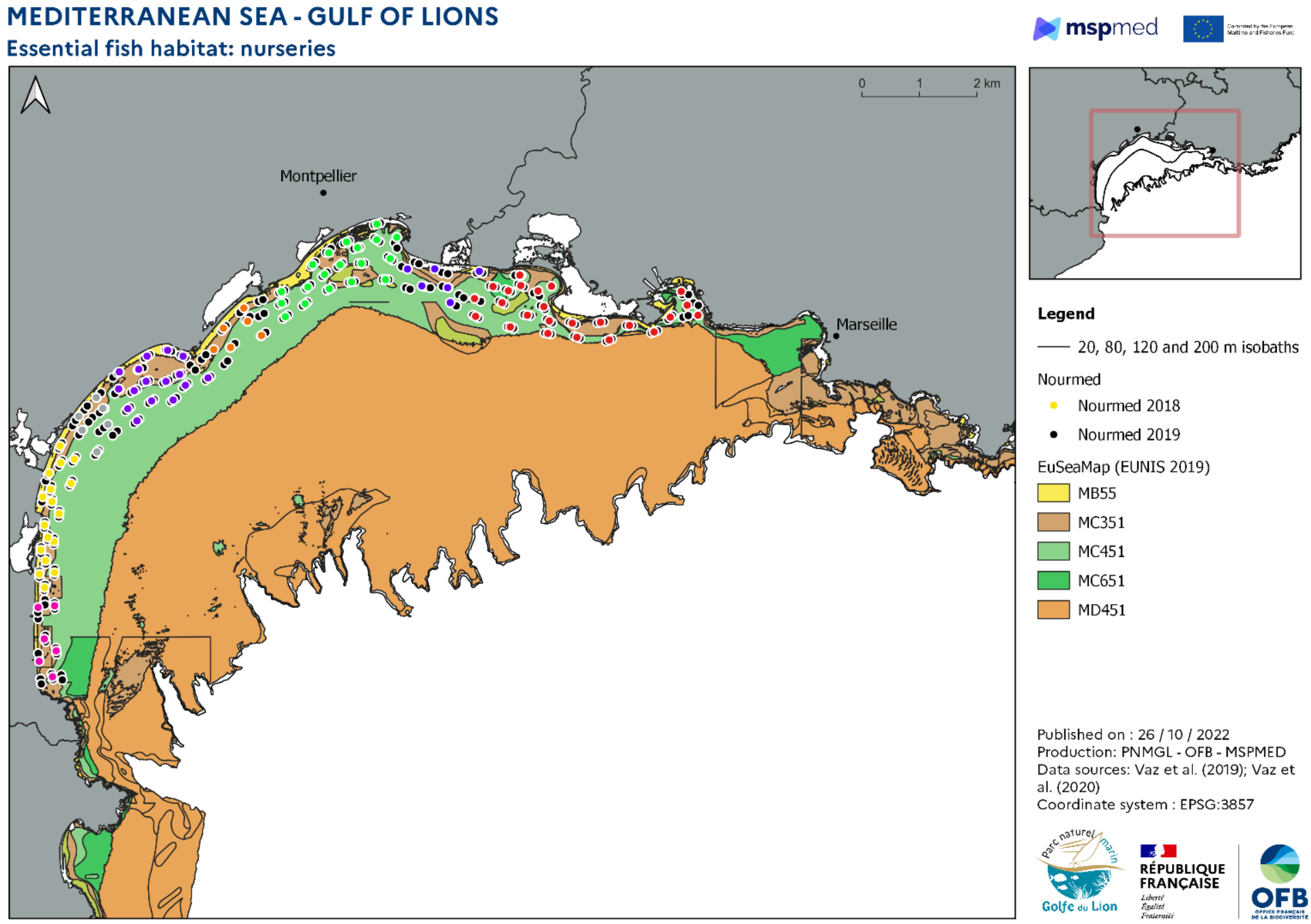
Annexes presented here aim to illustrate data availabilty in the Gulf of Lions. Maps higlight the location of data and owners are mentionned.



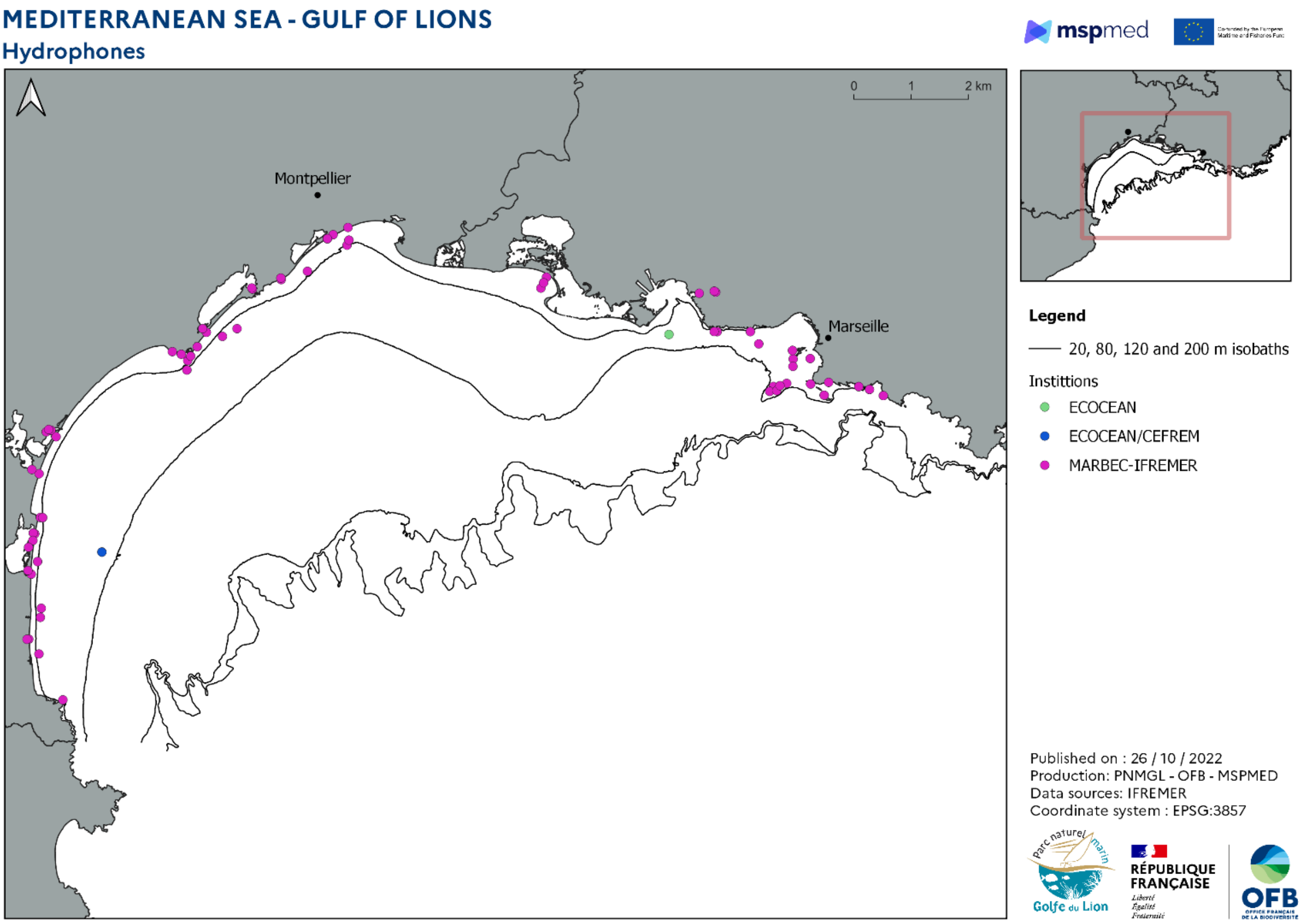
Annex 1: Seabed substrate data in the Gulf of Lions (Source: Augris et al. (2013)).



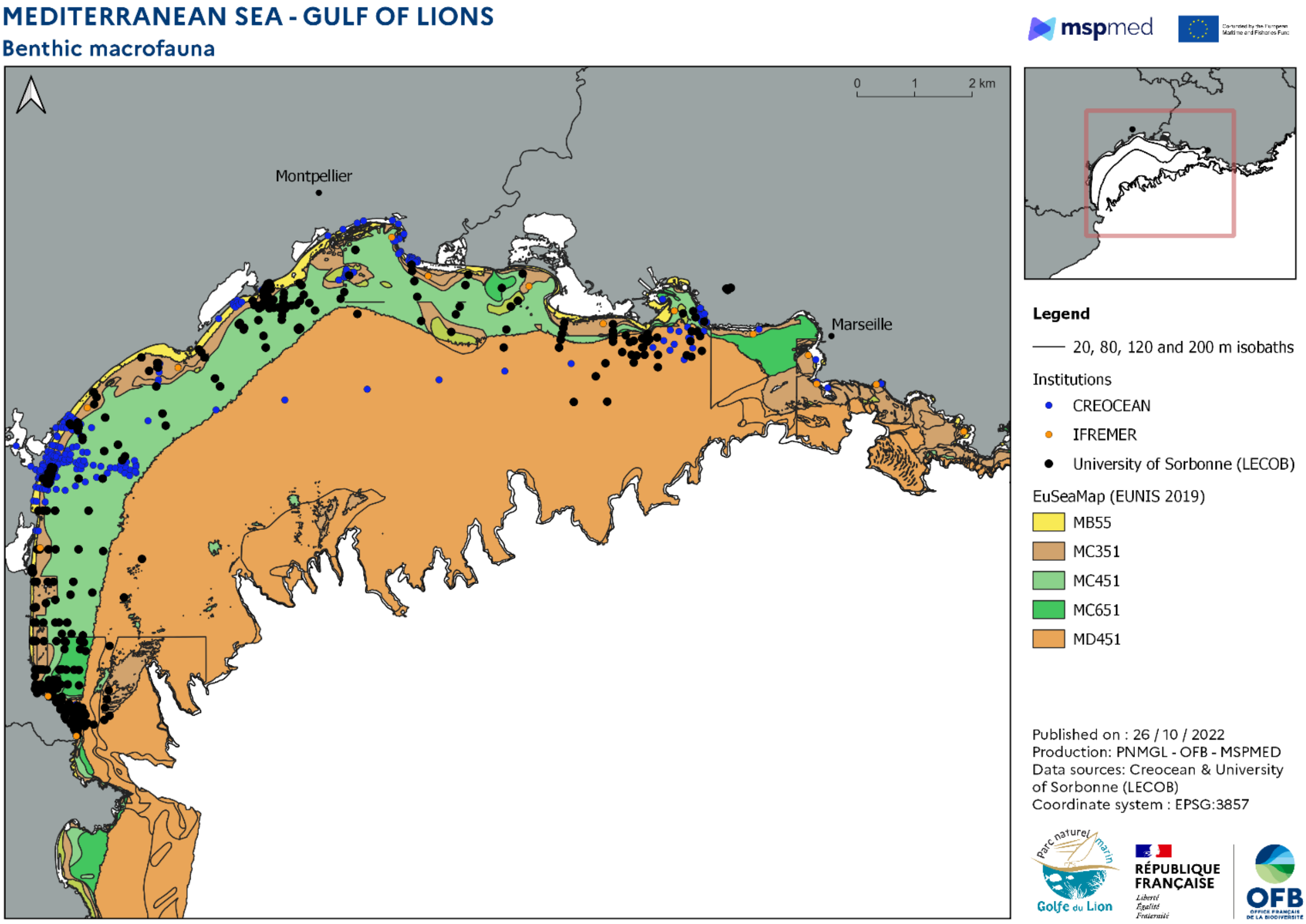
Annex 2: Bottom-trawling stations (MEDITS) in the Gulf of Lions (Source: IFREMER).



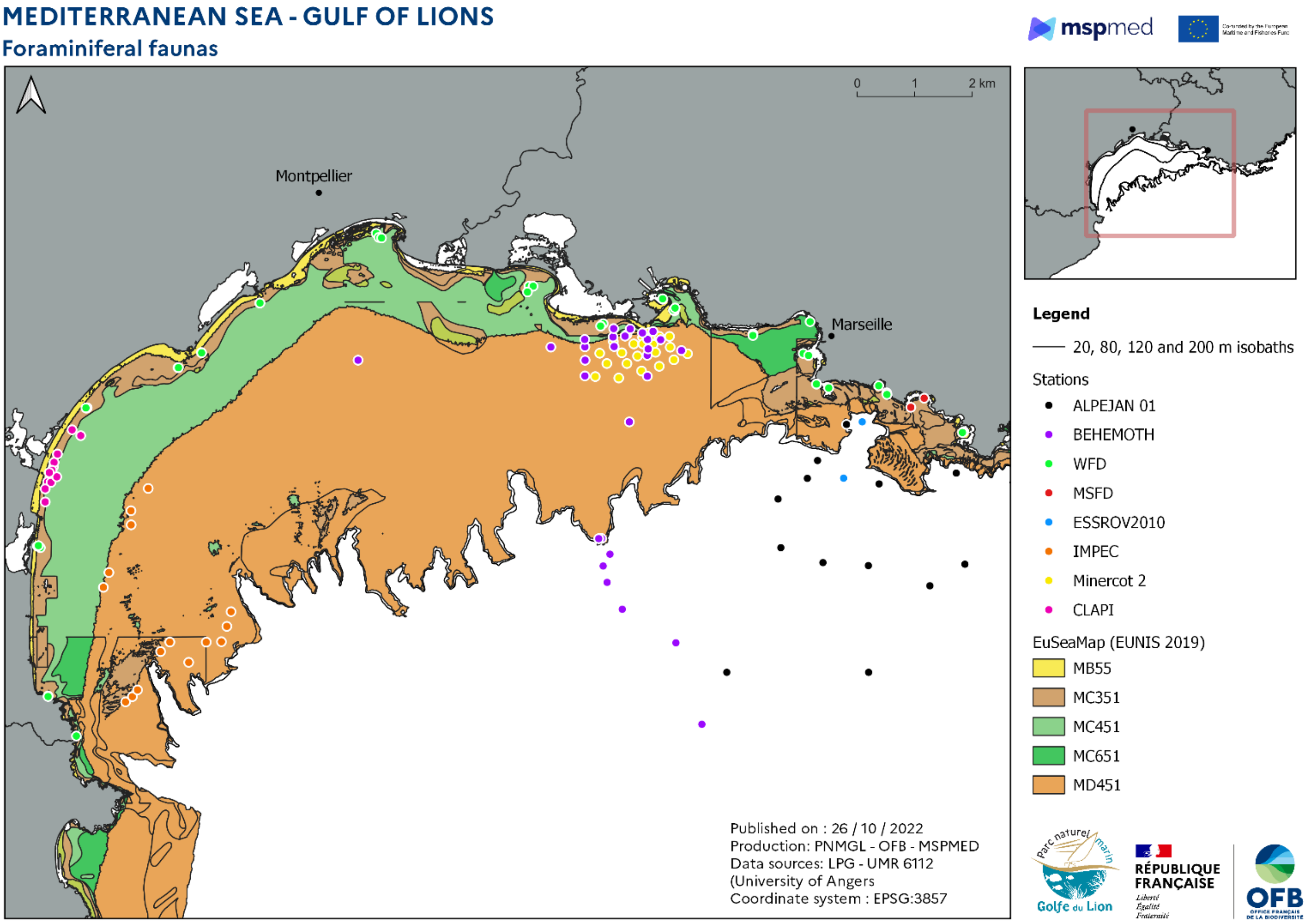
Annex 3: Bottom trawling stations (NOURMED) linked to nursery habitats in the Gulf of Lions (Source: Vaz et al. (2019; 2020)).



Annex 4: Location of hydrophones in the Gulf of Lions (Source: IFREMER).



Annex 5: Benthic macrofauna data in the Gulf of Lions (Source: Creocean and University of Sorbonne (LECOB)).



Annex 6: Foraminiferal fauna data in the Gulf of Lions (Source: University of Angers (LPG)).