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BRIDGING RISK ASSESSMENT OF HUMAN PRESSURE AND ECOSYSTEM STATUS

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ENVIRONMENTAL RISK ASSESSMENT
ANTHROPOGENIC PRESSURES
STATUS – PRESSURE LINK
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ABSTRACT. – Within the frame of a natural environment impacted by anthropogenic activities, assessing and quantifying their related pressures are essential to its management and are linked to its status. However, there are no, or very few, geographical areas where thorough knowledge of human uses and sources of impact is available as a basis to quantify these pressures. For this reason, we propose to grade impact sources based on risk assessment index using semi-quantitative rating grids. The impact source is defined as the environmental factor responsible for the impact (*e.g.*, sewage, fishing activity or coastal development). The environmental Risk Assessment of Marine Ecosystems (RAME) is based on several combined rating criteria in order to obtain a criticality score. These semi-quantitative criteria are: (S) the sensitivity of the environment, the ecosystem or the species; (I) the importance of the impact source; (D) the distance from the impact source, and (O) the frequency of occurrence of the pressure. Thereafter, the index is weighted by a criterion of control that is related to the environmental management (M). This method can be adapted to all types of pressure and is not specific to any situation.

INTRODUCTION

To confront strong anthropogenic pressures and conservation efforts, management procedures are necessary but must be tailored to the environmental risks. Effective management of the natural environment and human pressure requires assessment of the ecological status of the ecosystem. In the European Union (EU), within the framework of the Habitats Directive (HD, 92/43/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC), measures related to the marine environment are meant to enhance its conservation, in the context of sustainable use of ecosystem services. Ecosystem services form a basis for the recognition and the economic valuation of environmental processes that have beneficial consequences for human wellbeing (Millennium Ecosystem Assessment 2005). The ecosystem approach offers the best response possible for the assessment of the ecological status, taking into account the functioning of the ecosystem as a whole on based on several functional compartments (Laffoley *et al.* 2004, Boudouresque *et al.* 2020b). For the northwestern Mediterranean Sea, the Ecosystem Based Quality Index (EBQI) is representative of this approach (Personnic *et al.* 2014, Ruitton *et al.* 2014, Rastorgueff *et al.* 2015, Thibault *et al.* 2017). The management and the conservation of the marine environment require a good understanding of the scope and the intensity of human activities. The prerequisite for linking ecological status and anthropogenic pressures is proper assessment of the extent and intensity of human threats to the environment.

How to assess anthropogenic pressures in the marine realm?

The choice of the working scale is essential to properly consider the pressure and its point source or widespread nature as well as its local or global scope. A global approach involves the use of extensive spatial data and their overlap onto the status of marine ecosystems. This analytical process provides tools allowing for a global-scale approach to allocate conservation resources or implement broad ecosystem-based management (Halpern *et al.* 2008). But to act locally, more specific information on the pressures are needed. In the marine realm, precise information on pressures in terms of importance, location and field of influence is scarce. Among the existing sources, Medtrix (Andromède Océanologie 2016) and Medam (Meinesz *et al.* 2013) provide a basis for locating a range of pressures such as coastal development or sewage outfalls in coastal areas. Holon *et al.* (2018) have proposed a spatial statistical approach based on a predictive model of multiple coastal anthropogenic pressures which was compared to maps of living and dead *Posidonia oceanica* (Linnaeus) Delile beds but not with their ecological status. In contrast, Giakoumi *et al.* (2015), who took into account the state of the food web to assess the cumulative effect of human impacts on the *P. oceanica* meadows, reached very different conclusions. It emerges that the choice of the working scale and the indicators of the ecological status are essential factors for understanding the relationships between status and pressure. In the terrestrial realm, data on anthropic pressures are more readily available despite uncertainty regarding the carrying capacity of ecosystems and their ability to tolerate a given level of pressure (Fanelli *et al*. 2006, Bartalev *et al*. 2007, Di Bitetti *et al*. 2013, Maraux *et al*. 2013).

Existing indicators or assessment methods are generally specific to one case study. The LUSI is based on terrestrial uses that are not clearly linked to the environmental status (Gardi *et al*. 2010), the HAPI is based on a few human terrestrial and marine pressures related only to the subtidal rocky shore (Blanfuné *et al*. 2017), while the pressure index of Ar Grall *et al*. (2016) only concerns intertidal communities. AFB *et al*. (2019) focused on the impacts on the physical integrity of habitats resulting from professional fishing activities. The 'cocktail effect' is another difficult aspect to consider (human activities can overlap and their impacts on marine ecosystems can be more harmful when combined). Furthermore, global change issues also contribute to this 'cocktail effect', in combination with direct human pressure, making it even harder to assess (Boudouresque *et al*. 2017).

Risk assessment methods

Risk assessment involves various methods, which provide a basis for assessment of pressures and even anticipation of their effects in many technical fields. Assessment methods of this type are already used to consider the environmental risk in the industrial field, when dealing with genetically modified organisms and even with public health. These methods can be adapted to all types of pressure and are not specific to a particular situation. The principles and methods of risk assessment provide the means to conceptualize and assess the risk in the purpose of its management (Aven 2016). Its implementation within the framework of the assessment of the risk for a natural environment exposed to human activities provides a basis for environment assessment, prediction, and management.

The aim of the present work is to adapt the risk assessment approach to marine coastal ecosystems in a Mediterranean context and to define a suitable new indicator. Hitherto, in the marine realm, human pressures have generally been managed with hindsight once the deleterious effects are felt. Even if we try to embed the tripartite 'avoid-reduce-compensate' approach in an environmental management system, certain pressures still persist, gradually intensify and go beyond what the environment can tolerate (Treweek *et al*. 2005, Michelot & Aseeva 2017). Adopting a risk assessment approach makes it possible firstly to connect pressures with the status of the environment and above all provide the means to predict any potential future effects and to plan ahead in order to develop good management decisions.

MATERIALS AND METHODS

A source of impact is any form of human activity that can interact with the natural environment. These sources are human activities with a negative effect (*e.g.*, sewage, fishing activity and coastal development). One impact source can be responsible for one or several impacts. For example, coastal development may lead to the destruction of a natural area but also to the release of substances into the environment that will affect organisms. An impact source can act directly or indirectly on the environment and its effect can be rapid or delayed over time. Conversely, when pressures stop or management measures are implemented, the benefit may take time to become apparent. In the marine realm, it is very complicated to quantify the impacts while it is much more easily achievable to identify the sources. For all these reasons, we propose here to address the issue of pressure from the angle of risk assessment.

Any source of impact can affect the environment depending on its sensitivity, as well as the importance, the distance, and the occurrence of the phenomena. The environmental Risk Assessment of Marine Ecosystems (RAME), by considering several rating grids, combines semi-quantitative criteria that will enable us to obtain a criticality score. These criteria are: (S the sensitivity of the environment, ecosystem or species; (I) the importance of the impact source; (D) the distance from the impact source and (O) the occurrence of the pressure. Thereafter, the index is weighted by a criterion of control that is related to the environmental management system (*e.g.*, level of protection, sewage treatment, regulation). Each criterion is assessed by means of semi-quantitative rating grids with scores ranging from 1 to 4. A score of 1 corresponds to low sensitivity, importance, or occurrence and a significant distance, and good environmental management. A score of 4 highlights a high sensitivity, importance, or occurrence over a short distance, with an ineffective management.

The sources of impact that will be considered here are as exhaustive as possible and include discharges, global change, physical destruction and degradation, noise and vibration, fishing and all other activities not explicitly mentioned but generating pressure which can be compared to that from other activities.

Sensitivity (S): Sensitivity refers to the combination of the ability to tolerate the pressure (resistance) and to recover from a disturbance (resilience) (Holling 1973). The sensitivity (S) of the environment towards a source of impact depends on the species, the community or the ecosystem, but also on specific conditions of the environment, or geographical area, such as exposure of the environment, current, depth, slope, etc. Sensitivity offers groundwork in a local context. For example, a *Posidonia oceanica* seagrass meadow will be more sensitive to the anchorage pressure than a soft bottom while cetaceans will be more impacted by underwater noise than macrophytes. The rating grids (Table I to VIII) attempt to be as exhaustive as possible while retaining a general focus so that each scenario can fall into a category without being based on in-depth knowledge of the biology of the species or the technical details of the sources. The choice of the score for the sensitivity of the species and / or the

Table I. – Rating grid of sensitivity to a discharge altering the salinity or the temperature of the environment.

Score	Characteristics of species or ecosystems concerned by a discharge altering the salinity or the temperature of the environment
4	– Fixed species or ecosystem sensitive to variation in salinity and / or temperature and exposed directly to the plume of water that is desalinated or hypersaline or with different temperature – Fixed species with very slow dynamics: low growth rate for example
3	– Fixed species but tolerant to a range of variations in salinity and / or temperature. The risk being that occasional variations may exceed the tolerance range – Fixed species sensitive to variations in salinity and / or temperature but not directly under the influence of discharge. For example, a species attached to the bottom subjected to a layer of freshwater which is usually to be found near the sea surface and conversely a species of shallow habitats subjected to brine which is generally to be found on the bottom (*e.g.*, discharge from a desalination plant). The risk being that the species is occasionally in contact with the modified water plume
2	– Mobile species but with low mobility, for example not swimming – Stenohaline and / or stenothermal mobile species. These species will be able to flee the impacted area but will not be able to survive there because of the modification of the specific composition of the community
1	– Very mobile, migratory, and swimming species – Species very tolerant to variations in temperature and salinity, euryhaline and eurytherm

Table II. – Rating grid of sensitivity to discharge containing nutrients and/ or organic matter and / or contaminants.

Score	Characteristics of species or ecosystems concerned by a discharge containing nutrients and / or organic matter and / or contaminants
4	– Fixed species / ecosystem, characteristic of clean water, sensitive to eutrophication and contamination even if occasionally – Not competing species and with slow growth rate
3	– Fixed species / ecosystem of clean water, sensitive to eutrophication and contamination but resistant if occasionally exposed to the discharge
2	– Fixed species / ecosystem tolerant to contamination and to an increase in nutrient exposure – Mobile species but with low mobility, for example not swimming, tolerant to pollution – Mobile species sensitive to contamination
1	– Fixed or mobile species tolerant to eutrophication and contamination, or even favored by them – Ecosystem tolerant to contamination

Table III. – Rating grid of sensitivity to discharge containing suspended terrigenous and mineral matter.

Score	Characteristics of species or ecosystems concerned by a discharge containing suspended terrigenous and mineral matter
4	Substratum with slope < 45° and/or calm water conditions with little or no current – Photophilic photosynthetic species at a depth > 10 m – Fixed heterotrophic species with very low dynamics: for example, low growth rate (less than 1 cm/year)
3	Substratum with slope < 45° and/or calm water conditions with little or no current – Photophilic species at a depth < 10 m – Fixed heterotrophic species, with low tolerance to sedimentation – Heterotrophic species with low mobility and sensitive to sedimentation Substratum with slope > 45° and/or exposed, open environment, strong current – Photophilic photosynthetic species at a depth > 10 m – Fixed heterotrophic species with very low dynamics: for example, low growth rate (less than 1 cm/year)
2	Substratum with slope < 45° and/or calm water conditions with little or no current – Sciaphilous photosynthetic species with high growth rate – Heterotrophic fixed species with high growth rate, tolerant to sedimentation – Heterotrophic mobile species Substratum with slope > 45° and/or exposed, open environment, strong current – Photophilic photosynthetic species at a depth < 10 m – Fixed heterotrophic species, with low tolerance to sedimentation – Heterotrophic species with low mobility and sensitive to sedimentation
1	Substratum with slope > 45° and/or exposed, open environment, strong current – Sciaphilous photosynthetic species with high growth rate – Heterotrophic fixed species with high growth rate, tolerant to sedimentation – Heterotrophic mobile species

Table IV. – Rating grid of sensitivity to global change (especially increase in temperature, decrease in pH, rise in sea level, spread of invasive species).

Score	Characteristics of species or ecosystems concerned by global change
4	– Ecosystem / ecosystem engineer species at the limit of its thermo-tolerance range – Calcified fixed species playing the role of ecosystem engineer, sensitive to low pH variation – Engineer species with a very limited range of distribution and/or living at a depth level overwhelmingly impacted by the rise in sea level (*e.g.*, mediolittoral species – sensu Pérès & Picard 1964). The sensitivity increases if the species is slow growing – Specialized species, low tolerance for environmental changes including invasion
3	– Ecosystem / ecosystem engineer species not at the limit of its thermo-tolerance range – Fixed species (non-ecosystem engineer) at the limit of its thermo-tolerance range – Calcified fixed (non-ecosystem engineer) species sensitive to low pH variations – Non-ecosystem engineer species with a very limited distribution area and living at a depth level overwhelmingly impacted by the rise in sea level – Species / ecosystem in competition with invasive species for space but not for trophic, pathological, or physiological interactions
2	– Mobile species at the limit of its thermo-tolerance range – Calcified mobile species sensitive to low pH – Species whose range is limited to a sea level which is partially impacted by the rise in sea level
1	– Thermophilic species / ecosystem – Species not sensitive to decrease in pH – Species with wide range and not affected by the rise in sea level – Competitive species (high growth rate and generalist strategy in life history traits)

Table V. – Rating grid of sensitivity to physical destruction and degradation (burial by coastal development, dredging discharge, anchorage, use of fishing gear, etc.).

Score	Characteristics of species or ecosystems concerned by physical destruction and degradation
4	– Physical destruction of an ecosystem engineer species – Very slow ecosystem recovery (> 10 years) – Ecosystem very sensitive to the use (*e.g.*, trawling) or loss of fishing gear (abrasion, fixed species removed) (*e.g.*, *Posidonia oceanica* seagrass meadows and coralligenous habitat, respectively)
3	– Physical damage of an ecosystem engineer species – Fixed species, non-ecosystem engineer, with low growth rate – Slow ecosystem recovery (5 to 10 years) – Ecosystem moderately sensitive to the use (*e.g.*, nets) or loss of fishing gear (e.g. *Cymodocea nodosa* meadows and coastal detritic bottoms)
2	– Fixed species, non-ecosystem engineer, with high growth rate – Slow moving and fast-growing species – Moderately fast ecosystem recovery (1 to 5 years) – Ecosystem weakly sensitive to the use (*e.g.*, nets, trawling) or loss of fishing gear (*e.g.*, sandy bottom)
1	– Very mobile species (swimming) – Ecosystem relatively insensitive to physical destruction and degradation – Fast ecosystem recovery (< 1 year) – Ecosystem non-sensitive (physically) to the use of fishing gear (*e.g.*, muddy bottom, open water column)

Table VI. – Rating grid of sensitivity to acoustic pollution.

Score	Characteristics of species or ecosystems concerned by acoustic pollution
4	– Species using communication systems for the social organization of the population and echolocation (*e.g.*, cetaceans)
3	– Noise-sensitive species showing behavioral changes (*e.g.*, fish)
2	– Species impacted through physiological or other mechanisms at the individual level that could have long-term consequences
1	– Acoustic pollution-tolerant species

ecosystem towards a source of impact will be made based on the most damaging rating.

A discharge that alters the salinity or the temperature of the environment (Table I) implies that there is no contaminant in the effluent. Only salinity or temperature values can be modified. The salinity of the receiving environment can be altered by a freshwater discharge (*e.g.*, stormwater drainage) or a hyper-saline outfall (*e.g.*, desalination plant). The temperature of the receiving environment can be altered by warmer water (*e.g.*, from a water-cooling system) or a cold effluent (*e.g.*, water effluent from a methane gas terminal).

A discharge containing an excess (compared to the 'natural' content of the habitat) of nutrients, organic matter or contaminants (Table II) corresponds for example to untreated sewage,

Table VII. – Rating grid of sensitivity of the resource in relation to fishing pressure.

Score	Characteristics of the resource in relation to fishing pressure	
	One species or a small number	Fish assemblage
4	– Long life expectancy species > 50 years (*e.g.*, *Epinephelus marginatus*) – Later age at first spawning > 5 years (*e.g.*, *Anguilla Anguilla*) – Slow growth rate species – Target species for fishing – Commercially exploited marine species – Piscivorous species	– Fish assemblage of ultra-oligotrophic waters (*e.g.*, south-eastern Mediterranean) – Deep ecosystem – High mean trophic level of the fish assemblage based on biomass
3	– High life expectancy species (10 to 50 years) – First spawning between 3 to 5 years old (*e.g.*, *Diplodus sargus, Thunnus thynnus*) – Macrocarnivorous species	– Fish assemblage of oligotrophic waters (*e.g.*, Gulf of Lions, north-western Mediterranean)
2	– Medium life expectancy species (2 to 10 years) – First spawning between 1 and 2 years old (*e.g.*, *Symphodus ocellatus*, *S. tinca, Sardina pilchardus*) – Non-target fish but often caught incidentally – Mesocarnivorous species	– Fish assemblage of mesotrophic waters (*e.g.*, Bay of Biscay, north-eastern Atlantic) – Estuarine areas – Medium mean trophic level of the fish assemblage based on biomass
1	– Short life expectancy species usually < 2 years (*e.g.*, *Atherina* spp.) – Early age at first spawning < 1 year (*e.g.*, *Octopus vulgaris*) – High growth rate species – High level of reproduction – Non-target species – Non-commercial species – Planktivorous and herbivorous species – Low trophic level species	– Fish assemblage of eutrophic zone – Upwelling systems fish assemblage (*e.g.*, Peruvian coast) – Low mean trophic level of the fish assemblage based on biomass

wastewater from treatment plant outfalls or industrial discharge. The sensitivity of organisms and ecosystem depends on their tolerance to contaminants, nutrient enrichment, and their mobility.

A discharge containing suspended terrigenous and mineral matter (Table III) implies that no significant quantities of contaminant or organic matter or nutrient are present in the effluent. This discharge may be remarkable for the quantity of mineral suspended matter, such as during coastal work generating a lot of fine particles in the environment or an estuary carrying a man-induced excess load in sediments (*e.g.*, linked to soil erosion following deforestation). The sensitivity of organisms and ecosystems to suspended terrigenous matter depends on their light requirements and their ability to resist burial and therefore in particular their growth rate and the substratum slope.

Global change (Table IV) corresponds to the current climate change, including effects on pH (acidification), oxygen concentration, temperature, as well as biological invasions, rise in sea level, increase in extreme event frequency, etc.

The sensitivity to physical destruction and degradation includes all physical damage, reversible or not, such as anchorage, trawling and the use and loss of fishing gears (Table V). Physical destruction such as burial occurs for example during coastal development, inclusion within a port basin, and the discharge of dredging material. Full recovery is a return to the former state of the habitat, prior to the impact, *i.e.*, to a structurally and functionally recognizable habitat with its associated biological community (La Rivière *et al*. 2018). The assessment of habitat sensitivity to physical pressures is essentially based on expert judgment; the study led by La Rivière *et al*. (2018) can constitute a reference document for coastal habitats. A description of the sensitivity of ecosystems to the loss of fishing gear is available following completion of the methodological guide on the impact of fishing gear (Belloni *et al*. 2019).

Anthropogenic underwater noise is now recognized as a worldwide issue (Williams *et al*. 2015). Most human activities generate noise. Many species of fish and cetaceans are sensitive to sounds because they use them to orient themselves, to communicate with each other, to avoid predators and to feed. Some noises can disorient these species, change their behavior, and even kill or deafen cetaceans. For fish assemblages, several studies have shown that intense noise can have negative effects on certain species such as habitat abandonment, reduced reproductive capacity and increased susceptibility to disease. For example, noise generated by underwater oil exploration that generates powerful sound sources, particularly when using air cannon, shows that fish exposed have sustained significant damage to their auditory sensory epithelium (McCauley *et al*. 2003). The sensitivity toward anthropogenic noise depends on the species and particularly the use of sounds and vibrations in its biology and physiology and its ability to perceive noise (Table VI).

The sensitivity of resources to fishing pressure concerns all marine phyla (*e.g.*, fishes, crustaceans, mollusks). The sensitivity of the resource depends on whether a single or a small number of species or the whole assemblage is considered. Table VII therefore presents the two cases. On the one hand, if we consider only a small number of species, it will be the biological characteristics of the species and its life history traits that will be important. On the other hand, if we consider the fish assemblage, it will be the productivity of the area (*e.g.*, inputs in nutrients, primary production) and the interspecific relationships

Table VIII. – Rating grid of sensitivity to other activities not cited above.

Score	Characteristics of species or ecosystems concerned by other activities
4	– Species/ecosystem whose presence is incompatible with disturbance caused by these other activities
3	– Species/ecosystem highly sensitive to these other activities, human presence, disturbance
2	– Species/ecosystem not very sensitive to these other activities, human presence, disturbance
1	– Species/communities not sensitive to these other activities, human presence, indifferent to disturbance

Table IX. – Rating grid of importance of a discharge.

Score	Characteristics of the importance of a discharge
4	– Discharge of toxic substances known to be dangerous, toxic, which can lead to mortality at the doses contained in the effluent – Discharge containing radioelements – Industrial discharge obtained with derogation and from an ICPE (Installation Classified for the Protection of the Environment) – Discharge from untreated sewage outfall
3	– Discharge of CMR (Carcinogenic, Mutagenic and Reprotoxic), proven endocrine disruptors – Trace elements and persistent organic pollutants that can be biomagnified – Sewage treated by a sewage treatment plant but with high flow rate (> 10 000 population equivalent) – Presence of macro-waste altering the natural habitat – Industrial release to ICPE standards – Organic matter and / or suspended matter in high quantity
2	– Discharge of substances without proven toxicity but potentially biomagnified – Sewage treated by a sewage treatment plant but with low flow (< 10 000 population equivalent) – Presence of macro-waste that does not alter the functioning of the natural habitat – Industrial discharge compliant with standards and not concerning an ICPE – Discharge containing no pollutant substance but with a different temperature or salinity from the environment – Organic matter and / or suspended matter in low quantity
1	– Water discharge without pollutant, organic matter, or nutrient, in very low quantity that cannot cause variation in salinity or temperature of the receiving environment

(trophic, mutualistic, etc.), which will influence this sensitivity to the exploitation of the resource. The ratio fish production/primary production takes into account the nutrient richness (Cresson *et al.* 2020), while the fish production is also linked to the length of the food web (Sommer *et al.* 2002). In the Mediterranean, we can distinguish two zones according to their richness in nutrients, the southeast with ultra-oligotrophic waters, and the northwest with oligotrophic waters (Moutin *et al.* 2012).

Other impacts can result from human activities such as scuba diving, snorkeling, or other recreational activities (Table VIII). Note that most of these activities can be included among the activities cited above (Tables I through VII). For example, sensitivity to boat anchorages is dealt with in the rating grid of sensitivity to physical destruction (Table V). Sensitivity to yachting activities will be concerned both in the noise grid (Table II and in the discharge grid (Table VI) for pollution generated by grey and black water effluents and hydrocarbons.

Importance (I): The importance (I) of an impact source reflects the harmfulness of the source for a species or an ecosystem (Tables IX through XV). It is linked to its nature (*e.g.,* toxicity), its flow and intensity (*e.g.,* quantity, level). For example, information on wastewater treatment plant discharges in France is available on the website of the French Ministry of the Environment (*Ministère de l'Écologie et de la Transition Solidaire)* (http://assainissement.developpement-durable.gouv.fr/index.php). It should be noted that even at a relatively low levels of importance when compared to other anthropogenic sources, it could still lead to long-term exposure to sessile marine organisms and cause significant damage. This is accounted for by the sensitivity (Tables I to III) and occurrence criteria (Table XVII).

Global change includes several phenomena such as increase in temperature, decrease in pH, rise in sea level, invasive species. For the Mediterranean Sea, T-Mednet, an observation network on climate change impact in marine coastal ecosystems, collects seawater temperature and mass mortality events data from scientific observers all around the Mediterranean (Garrabou *et al.* 2018, 2019). The rating grid of the importance of global change is based on the RCP (Representative Concentration Pathway) climate scenario (Guiot & Cramer 2016). The baselines for the Mediterranean, reference status and predictions are to be found in Shaltout & Omstedt (2014) for sea surface temperature, in Jackson & Jevrejeva (2016) for the sea level and in Zunino *et al.* (2017) for acidification. For the NIS (Non-Indigenous Species), UNEP/MAP-RAC/SPA (2008) gives examples of impact of NIS on ecosystems under consideration.

Coastal areas play an essential economic, social, and political role in most countries that are conducive to extensive artificialization of the shoreline at the expense of littoral underwater ecosystems. Coastal development damage may be direct (*e.g.,* burial, destruction) or indirect (*e.g.,* sedimentation, contaminant input, erosion, and increased turbidity). Moreover, other activities can cause physical destruction and degradation of ecosystems such as dumping of dredged material, sand replenishment

Table X. – Rating grid of the importance of global change (increase in temperature, decrease in pH, rise in sea level, Non-indigenous/invasive species - NIS).

Score	Characteristics of the importance of global change
4	– Non-indigenous species (NIS) profoundly altering the functioning of the ecosystems in the area – Increase in mean temperature > RCP8.5 climate scenario – Frequent (more than 1 every 5 years) and intense thermal anomalies and related mass mortality events in invertebrate communities – Decrease in pH > 0.2 compared to the baseline – Rise in sea level > RCP8.5 climate scenario
3	– NIS modifying several interactions between species within the ecosystem – Increase in mean temperature between RCP8.5 and RCP2.6 climate scenario – Thermal anomalies (frequency from 1 every 5 years to 1 every 10 years) and related mass mortality events in invertebrate communities – Decrease in pH between 0.1 and 0.2 compared to the baseline – Rise in sea level between RCP8.5 and RCP2.6 climate scenarios
2	– NIS modifying some interactions between species within the ecosystem – Increase in mean temperature close to RCP2.6 climate scenario – Rare thermal anomalies (less than 1 every 10 years) – Decrease in pH close to 0.1 compared to the baseline – Rise in sea level close to RCP2.6 climate scenario
1	– No significant changes in the ecosystems due to NIS – Increase in mean temperature < RCP2.6 climate scenario – No significant decrease in pH – Rise in sea level < RCP2.6 climate scenario

Table XI. – Rating grid of the importance of coastal development, burial (dredging discharge) and physical destruction and degradation.

Score	Characteristics of the importance of physical destruction and degradation
4	– Irreversible destruction (on the scale of a human life) by coastal development, burial, etc. and affected area ≥ 10 m^2 – Reversible degradation and affected area ≥ 100 m^2; reversible degradation is for example, temporary abrasion of the substrate or a rearrangement of a sandy bottom
3	– Irreversible destruction (on the scale of a human life) by coastal development, burial, etc. and affected area from 1 to 10 m^2 – Reversible degradation and affected area from 10 to 100 m^2
2	– Irreversible destruction (on the scale of a human life) by coastal development, burial, etc. and affected area < 1 m^2 – Reversible degradation and affected area from 1 to 10 m^2
1	– No direct destruction by coastal development – Reversible degradation and affected area < 1 m^2

of beaches, and low-crested structures. The importance of coastal development, burial and all physical destructions depends on the affected surface and whether it is reversible or not.

The importance of anchorage pressure can be based on the daily mean number of anchorages during the peak frequentation period and the size of the boat's anchorage in the studied area (Abadie *et al.* 2016, 2017). To collect such information, it is necessary to monitor the boats frequentation, which has been rarely attempted. In other studies, it is only the number of boats per day and surface unit that is considered to quantify the anchorage pressure (Francour *et al.* 1999, Boudouresque *et al.* 2012, Frachon *et al.* 2013, Rouanet *et al.* 2013, Claeys *et al.* 2017) or the use of AIS data (Automatic Identification System; Deter *et al.* 2017). Thresholds have been proposed by Boudouresque *et al.* (2012) such as a maximum density of 10 anchorages per day and per hectare during the peak period and a mean of 2 anchorages per day and per hectare (annual mean). This threshold does not consider the boat size and is only suitable for small and medium size boats (less than 24 m-80 feet in length). The rating grid for the importance of anchorage is therefore based on criteria for which we can easily provide answers based on occasional observations or field knowledge by managers and based on the studies cited above.

Ambient ocean noise is generated by a variety of sources of both natural (biological and ambient ocean noise) and anthropogenic origin. Ambient noise levels in the open ocean increased approximately by 3.3 dB per decade during the period 1950-2007 and can be attributed primarily to commercial shipping activity (Frisk 2012). It is estimated to be ~ 90 dB in 2007 in the open ocean (55 % from natural noise and 45 % from shipping noise; Frisk 2012). In coastal areas, noise can locally increase above this ambient noise, depending on the anthropogenic activities. Hermannsen *et al* (2019) underline that small recreational motorized vessels dominate the anthropogenic noise in the shallow water soundscape especially in coastal areas. In the framework of the MSFD, the noise is considered in terms of intensity but also according to its duration. A distinction must be made between impulsive emissions (energetic noise emissions of very short duration) and continuous emissions (permanent noise emissions), and this is examined within the occurrence grid (Table XVII). The importance of noise pollution is therefore assessed considering the noise source level (decibels; Table

Table XII. – Rating grid of the importance of anchorage. The numbers given in the table represent the mean number of boats anchored/day/km² during the peak frequentation period (July and August for the Mediterranean).

Score	Characteristics of the importance of anchorage	
	Monitoring of anchorage during the peak frequentation period	No monitoring of the anchorage, occasional observations or managers' field knowledge
4	– Boats ≥ 200 m long, ≥ 2/day/km² (mainly cruise vessels) – Boats 21-200 m long, ≥ 7/day/km² – Boats 10-20 m long, ≥ 16/day/km² – Boats <10 m long, ≥ 60/day/km² – Total number of boats ≥ 50/day/km² (mainly small boats but of unknown length)	– Boats > 200 m long are regularly in the area – Boats 21–200 m long are frequent in the area – Boats 10-20 m long are numerous during the peak season – Boats < 10 m long are very abundant during the peak season – The whole area is occupied by moored boats, anchorage carrying capacity reaches its limits during the peak season
3	– Boats ≥ 200 m long, 1/day/km² – Boats 21-200 long, 2 to 7/day/km² – Boats 10-20 m long, 8 to 16/day/km² – Boats < 10 m long, 30 to 60/day/km² – Total number of boats 20-50/day/km² (mainly small boats but of unknown length)	– Boats > 200 m long are occasional in the area – Boats 21-200 m long are occasional – Boats 10-20 m long are frequent – Boats < 10 m long are numerous – Anchorage carrying capacity occasionally reaches its limits
2	– Boats 21-200 m long, ≤ 2/day/km² – Boats 10-20 m long, 3 to 8/day/km² – Boats < 10 m long, 10 to 30/day/km² – Total number of boats 8 to 20/day/km² (mainly small boats but of unknown length)	– Boats 21-200 m long are very occasional in the area – Boats 10-20 m long are occasional – Boats < 10 m long are frequent – Anchorage carrying capacity never reaches its limits
1	– Boats 10-21 m long, ≤ 2/day/km² – Boats < 10 m long, maximum 10/day/km² – Total number of boats ≤ 8/day/km² (mainly small boats but of unknown length)	– Boats 10-20 m long are very occasional – Boats < 10 m long are occasional

Table XIII. – Rating grid of the importance of noise pollution.

Score	Characteristics of the importance of acoustic pollution
4	– Sound level above 180 dB (*e.g.*, supertanker, more than 200 dB for active sonar or seismic airgun array)
3	– Sound level from 150 to 180 dB (*e.g.*, frigate, dredger, echo sounder)
2	– Sound level from 110 to 150 dB (*e.g.*, sidescan, small motorized vessels at speed > 9 km/h)
1	– Sound level below 110 dB (*e.g.*, equivalent to sailing, submarine, small motorized vessels at speed < 9 km/h)

Table XIV. – Rating grid of the importance of fishing activities.

Score	Characteristics of the importance of fishing activities
4	– Industrial fishing activities using bottom-contact fishing gear (*e.g.*, trawling, dredging) – Extensive artisanal fishing activities, using active bottom-contact fishing gear (*e.g.*, coastal trawling, 'gangui' in the fisher's local dialect of Provence) – Extensive recreational fishing activities, spearfishing, and jig fishing – Fishing techniques with high level of by-catch – Fishing activity that causes disturbances greater than the population's renewal capacity (over-exploitation of a fish stock)
3	– Industrial fishing activities using fishing gear in the water column – Artisanal fishing using passive and selective fishing gear (*e.g.*, fixed net and bottom longline) – Intensive recreational fishing activities: angling on the bottom
2	– Occasional artisanal and recreational fishing activities; the occasional nature of the practices will be judged according to the frequentation of the area as reported by observations made in the field either by the managers or by people used to frequenting the area – Recreational fishing activities: trolling fishing
1	– Rare fishing activities

XIII; Boyd *et al* 2008). The frequencies of the noises are not considered even if this parameter is important for the effects and for the propagation of the signal, but this information is generally absent not available.

To assess the importance of fishing activities, we distinguish recreational, artisanal (*i.e.*, small scale) and industrial fishing and the type of fishing gear (Table XIV). A study by IFREMER (2008) lists the impacts of professional fishing gears on habitats and species. The degree of impact depends on the gear and the type of habitat, therefore fishing techniques can be classified according to the potential damage they can have on the habitat. Fishing gear in contact with the bottom can disturb it. Substrate shifts, destruction of carrying capacity and reduction of the complexity of habitats (uniformization of the bottoms) can be induced. Among biological impacts, fishing gear can destroy organisms fixed on the bottom (*e.g.*, the giant mollusk *Pinna*

Table XV. – Rating grid of the importance of other activities or pressures not cited above.

Score	Characteristics of the importance of other activities
4	– Activity that causes disturbances going beyond the population's renewal capacity (*e.g.*, permanent trampling of an area) – Activity that creates a continuous and permanent disturbance of the species – Disturbances going beyond the resilience capacity of the ecosystem
3	– Activity that creates frequent disturbances of the species – Effect on the population (recruitment, abundance, sex-ratio, demographic structure, etc.)
2	– Activity that creates a temporary disturbance – Physiological effects on certain individuals without endangering the population – Vital needs of species disturbed but reversible, less than resilience
1	– Activity that does not create any disturbance for the communities – Neutral activity for populations or the ecosystem – No impact on the vital needs of individuals (O_2, light, nutrient, etc.)

Table XVI. – Rating grid of distance from impact source.

Score	Distance between a point-source pressure and a point impact (see Fig. 1C)	Distance between a point-source pressure and a diffuse impact (see Fig. 1A)	Distance between a diffuse-source pressure and a diffuse impact (see Fig. 1B)
4	0	0 to 1 km	0 to 1 km
3	0 to 0.1 km	1 to 3 km	1 to 3 km
2	0.1 to 1 km	3 to 6 km	3 to 6 km
1	> 1 km	> 6 km	> 6 km

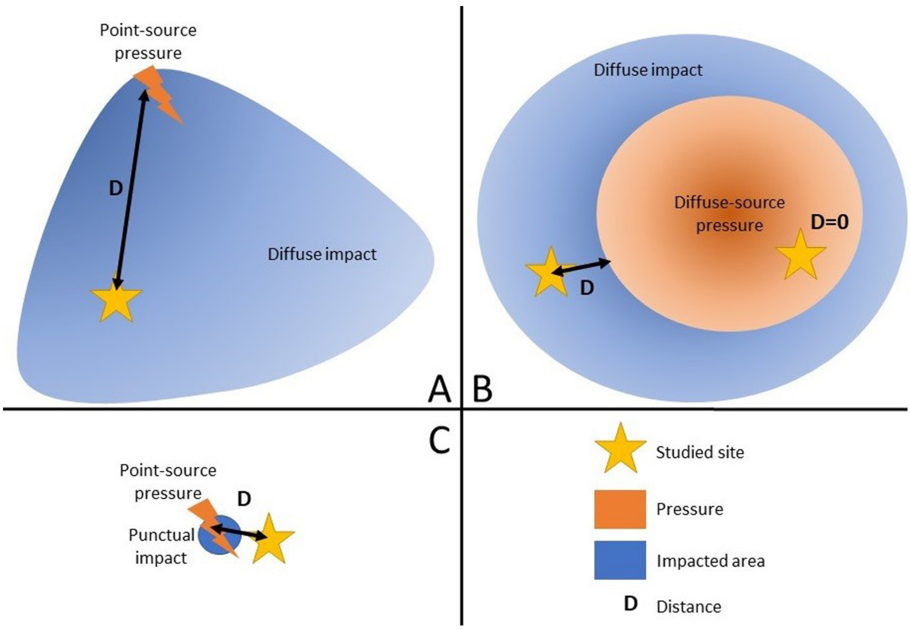

Fig. 1. - Distance measurement between pressure and the impacted studied site. **A**: Distance between a point-source pressure and a diffuse impact; **B**: Distance between a diffuse-source pressure and a diffuse impact; **C**: Distance between a point-source pressure and a point impact.

nobilis Linnaeus, 1758), move animals outside of their natural habitat, dig up individuals, contribute to the dissemination of invasive species and exhaust resources. Physical and chemical effects are also possible with the physical contact of the fishing gear with the substrate, which can induce a resuspension of the sediment, turbidity, and chemical effects (impact on biogeochemical

Other impacting activities, including scuba diving, snorkeling, or other recreational activities, are important in coastal areas of the Mediterranean Sea (Rouanet *et al*. 2017). New activities are also regularly created, can establish a trend, and be practiced for a few years along the coast. Table XV sum up the importance of all activities, which could not be taken into account in the other table.

Distance (D): The distance (D) concerns the distance between the source and the impacted environment (Fig. 1). A point-source pressure is in a limited area unlike a diffuse-source pressure, which cannot be located precisely, and which concerns a large area; however, both can have widespread effect. The distance is easy to measure if it is related to a point-source pressure with a geographically limited impact (*e.g.*, dredging, anchorage; Fig. 1C), but more difficult to estimate if the impact is diffuse. The origin of diffuse impact can be both diffuse-source pressure

Table XVII. – Rating grid of occurrence of an activity, discharge, or coastal development.

Score	Occurrence of activity / discharge / development works
4	Activity/discharge: – Daily activity – Continuous or daily discharge or activity (*e.g.*, sewage outfall, commercial shipping) – Noise emissions more than half the time (*e.g.*, > 12 h/day or 15 days/month) Coastal development: – Development works: ≥ 2 events every year
3	Activity/discharge: – Seasonal activity but frequent in the season concerned – Discharge less than 1 time per week – Noise emissions between half the time and 1/10th of the time (*e.g.*, between 2.4 h to 12 h/day or between 3 to 15 days/month) Coastal development: – Development works: 1 event every year
2	Activity/discharge: – Activity ≤ 1 time per month – Discharge less than 1 time per month – Noise emissions of short duration, between 1/10th to 1/30th of the time (*e.g.*, between 0.8 h to 2.4 h/day or between 1 to 3 days/month) Coastal development: – Development works: 1 event every 2 to 5 years
1	Activity/discharge: – Activity ≤ 1 time per year – Discharge occur less than once a year – Noise emissions of short duration, less than 1/30th of the time (*e.g.*, less than 0.8 h/day or 1 day/month) Coastal development: – Development works: < 1 event every 5 years

Table XVIII. – Rating grid of environmental management.

Score	Characteristics of environmental management
4	– No management measures exist – No specific regulations for uses and discharges – Unsuitable actions for the protection of the environment – No fishing quota, fishing regulation and fishing labor regulations
3	– A few management measures have been introduced but are insufficient, no policing or field inspections – Management based on mitigation – Only fishing effort regulation or fishing quotas
2	– Species-centered management actions with policing and field inspections – Management based on reducing the importance of impact sources or control – Local fishing regulation (*e.g.*, ban on spear fishing and trawling, artisanal and recreational fishing regulations, fishing charter more restrictive that national and local regulations)
1	– Management measures have been introduced and seem to be effective, with policing and field inspections – Ecosystem-based management with field monitoring to survey the effectiveness of the management – Prevention measures to limit further impact – No-Take-Zone (artisanal and recreational fishing are banned)

(Fig. 1B) or point-source pressure (Fig. 1A). In the case of diffuse-source pressure such as shipping or global change (Table XVI), the distance is measured between the studied site and the closest point of the diffuse-source (*e.g.*, the border of the shipping lane). If the studied area is within the pressure area, the distance is then equal to zero. A discharge is a point-source when the outfall can be located precisely but can be diffuse-source when the discharge affects a large area (runoff water and greywater/blackwater discharges from vessels in a mooring area).

Occurrence (O): To estimate the occurrence of a phenomenon, it is essential to adopt different scales depending on the source related to an activity, a discharge or a coastal development (Table XVII). Coastal development includes all coastal development works such as deployment of coastal constructions (*e.g.*, harbor, dikes, piers), strengthening and extension of external seawalls, rehabilitation of wharfs, public access, roads, and offshore wind turbine arrangements. The rise in sea level, flooding and coastal erosion represent serious threats that could, in the future, increase the need for coastal structure reinforcement. Obviously, depending on the nature of the work, the impact will differ in extent and this notion is taken into account by the importance criterion (Table XI).

Environmental management (M): Environmental management (M) corresponds to all the management measures already existing at the time of the analysis. Management measures can be of several kinds depending on the status of the area (*e.g.*,

Table XIX. – List of the XIII groups of sources of impact, the corresponding DCSMM descriptor, tables to use for the RAME calculation and the name of the RAME.

Sources of impact	Corresponding DCSMM descriptor	Tables					RAME name
		S	I	D	O	M	
Suspended matter (SM) discharge	Sea-floor integrity	III	IX	XVI	XVII	XVIII	SM
Anchorage	Sea-floor integrity	V	XII	XVI	XVII	XVIII	Anchorage
Physical destruction and degradation	Sea-floor integrity	V	XI	XVI	XVII	XVIII	Degradation
Use of fishing gear	Sea-floor integrity	V	XV	XVI	XVII	XVIII	Fishing gear
Discharge of water with different salinity or temperature than the environment	Hydrography	I	IX	XVI	XVII	XVIII	Hydrography
Contaminant discharge	Contaminants	II	IX	XVI	XVII	XVIII	Contaminant
Nutrients and organic matter discharge	Eutrophication	II	IX	XVI	XVII	XVIII	Eutrophication
Waste discharge	Waste	V	IX	XVI	XVII	XVIII	Waste
Acoustic pollution	Energy input	VI	XIII	XVI	XVII	XVIII	Acoustic
Non-indigenous species	Invasions	IV	X	XVI	XVII	XVIII	Invasion
Temperature increase, pH decrease, and sea level rise		IV	X	XVI	XVII	XVIII	Global change
Marine resources	Fishing	VII	XIV	XVI	XVII	XVIII	Fishing
Other activities		VIII	XV	XVI	XVII	XVIII	Other

marine protected area, EU Natura 2000 site, national park) and the ecological status of the ecosystem. The management measures may relate to (i) prevention; (ii) decreasing the importance of impact sources or control and (iii) mitigation measures.

Species-centered management actions can be considered today as inappropriate (Boudouresque *et al.* 2020a, b) as an ecosystem is a complex system of species interactions and the consideration of only one species or a group of species cannot solve ecosystem issues. Consequently, the management actions that can have applicability in the context of ecosystem-based management are of particular relevance. The risk assessment of a marine ecosystem is therefore weighted by a criterion of control that is related to the environmental management (Table XVIII).

Calculation of the Risk Assessment of Marine Ecosystem (RAME): The Risk Assessment of Marine Ecosystem (RAME) for an impact source and an area is calculated by the multiplication of the score for each criterion.

$$RAME = S \times I \times D \times O \times M / 1024$$

The result of the multiplication of the five criteria varies from 1 to 1024. The value obtained is then divided by 1024 to give a score on a scale of 0 to 1. A value close to 0 corresponds to a weak impact of the source and a value close to 1 corresponds to a huge impact.

The different types of pressure exerted in the marine environment could be grouped in 13 sources of impact (Table XIX). The scores of the cumulative value of RAME for each pressure at one site ($RAME_{total}$) range from 0 to 13.

RESULTS

In a given area, generally several anthropogenic pressures are exerted and the RAME must be estimated for each related impact source. For example, for an area subject to sewage outfall, fishing activities and anchorage, a RAME must be estimated for those three pressures. We obtain 3 RAME values: $RAME_{contaminant}$, $RAME_{fishing}$, $RAME_{anchorage}$. For the considered area, we can aggregate the 3 values or use them separately to analyze more precisely the relationships between ecological status and pressures. This approach is particularly relevant if an Ecosystem-Based Quality Index (EBQI) is used allowing assessment of the status of multiple functioning compartments (Personnic *et al.* 2014; Ruitton *et al.* 2014; Rastorgueff *et al.* 2015; Thibaut *et al.* 2017).

In the Bay of Marseille, which is under pressure from multiple sources, the ecological status of three *Posidonia oceanica* seagrass meadows has been assessed using the EBQI method in 2019. The first site located on the 'Plateau des Chèvres' is affected by fishing activities and is located next to the sewage outfall of the Marseille sewage treatment plant. The second site, 'Moyade', is in the core of the Calanques National Park, in a no-take zone since 2012. The third site in the Marseille Prado Bay is subject to various discharges from the city, in particular runoff urban wastewater and occasionally bypass sewage water after a severe storm, and to fairly intensive fishing and boating activities and anchorages.

The results of the EBQI assessments (Personnic *et al.* 2014) give five ecological status classes, from Bad to High: (i) Bad (EBQI < 3.5); (ii) Poor (3.5 ≥ EBQI < 4.5); (iii) Moderate (4.5 ≥ EBQI < 6); (iv) Good (6.0 ≥ EBQI < 7.5) and (v) High (EBQI ≥ 7.5) (Table XX). The ecological status for the 3 sites 'Plateau des Chèvres', 'Moyade' and 'Prado Bay' are respectively poor, good and moderate (Table XX).

The RAME is assessed for each pressure taking into account its importance, its distance, its occurrence, its environmental management and the sensitivity of the ecosystem (Table XX to Table XXII).

The total RAME (cumulative value of RAME for each pressure, $RAME_{total}$ in (Table XXII) for the 3 sites 'Plateau des Chèvres', 'Moyade' and Prado Bay' are respectively 3.14, 1.48 and 3.51. The lowest value of risk corresponds to the site of Moyade with the best EBQI status (Table XX and Table XXII). The total RAME values for the other two sites are similar but the contribution of each pressure is rather different (Fig. 2).

The RAME for each human pressure reflects the fishing pressure at both the 'Plateau des Chèvres' and the 'Prado Bay' (Fig. 2). The low fishing pressure observed since 2012 at 'Moyade' explains the good status of the fish assemblage (Fig. 3). This assemblage is not yet at its optimum but is gradually improving as shown by the fish censuses conducted over the last few years at this site (GIS Posidonie, comm pers).

Another major difference between sites is the extent of waste waters discharges at the Plateau des Chèvres site, linked to contaminant inputs

Table XX. – Ecological status assessment by the EBQI method of the *Posidonia oceanica* meadows at the 3 sites. Each functional compartment is assessed according to the ecological status from 0 to 4. HOM: High level of organic matter in the water filter feeders' indicators. LOM: Low level of organic matter in the water filter feeders' indicators. SRDI: Specific Relative Diversity Index is the mean number of species of teleosts observed per transect. Compartments 10 to 12 concern teleosts. EBQI: Ecosystem-Based Quality Index (0 through 10). CI: confidence index. For more details on the method, see Personnic *et al*. (2014).

		Ecological status of functional compartment		
N°	**Functional compartment**	**Plateau des Chèvres**	**Moyade**	**Prado Bay**
1	Rhizomes	4.0	4.0	4.0
2	*Posidonia* leaves	2.5	3.0	3.0
3-4	Leaf epibiota	1.0	3.0	3.0
5	*Pinna nobilis*	1.0	0.0	0.0
6	HOM/LOM	1.0	3.0	1.5
7	Litter	3.0	2.0	4.0
8	*Holothuria* spp.	2.0	3.0	4.0
9	Herbivorous	1.5	1.5	2.5
10	Predators	1.0	2.0	0.0
11	Piscivorous	0.0	2.0	0.0
12	Planktivorous	2.0	2.5	2.0
10-12	SRDI	1.0	3.0	2.0
13	Sea birds	1.5	2.0	2.0
	EBQI	3.9	6.0	5.0
	CI (%)	99	97	100
	Ecological status class	Poor	Good	Moderate
	$RAME_{total}$	3.14	1.48	3.51

Table XXI. – Related sources of pressure in each site and information about human pressures. SM: Suspended Matter. NC: Not concerned. See Fig. 2 for values.

RAME	Plateau des Chèvres	Moyade	Prado Bay
SM	Suspended matter from the outfall and the Huveaune River	Suspended matter by runoff during storms	Rhone River diluted water intrusion in Marseille's Bay, runoff from Hubeauve
Anchorage	Small boats, occasionally	Small boats, frequent from spring to autumn for diving activity	Small boats, occasionally
Degradation	NC	NC	Coastal development at 2 km from the site
Fishing gear	Net fishing, spear fishing and angling	NC: No-take zone since 2012	Net fishing, spear fishing and angling
Hydrography	Fresh water from the sewage outfall in surface	NC	Intrusion of the Rhône River fresh water in surface
Contaminant	Sewage outfall at 2900 m	Sewage outfall at 4 700 m	Runoff urban wastewater and occasionally bypass sewage water
Eutrophication	Sewage outfall at 2900 m	Sewage outfall at 4 700 m	Runoff urban wastewater and occasionally bypass sewage water
Waste	Some macro-waste from the outfall	No macro-waste observed underwater	Some macro-waste from the city
Acoustic	Small motorized vessels, no limited speed	Small motorized vessels at limited speed	Small motorized vessels at limited speed, big ships daily traffic (cruise and commercial)
Invasion	Scarce patches of *Caulerpa cylindracea*	Scarce patches of *Caulerpa cylindracea*	Scarce patches of *Caulerpa cylindracea*
Global change	Thermal anomalies	Thermal anomalies	Thermal anomalies
Fishing	Net fishing, spear fishing and angling	NC: No take zone since 2012	Net fishing, spear fishing and angling
Other	NC	Diving	NC

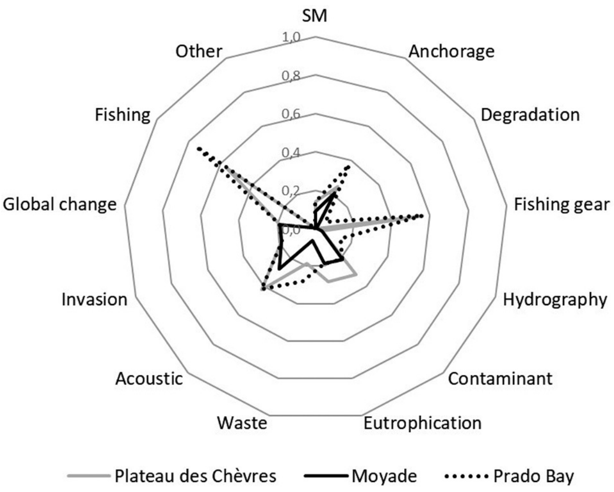

Fig. 2. – Example of RAME assessment (Risk Assessment of Marine Ecosystems) for each human pressure at three sites in the Bay of Marseille. SM: Suspended Matter.

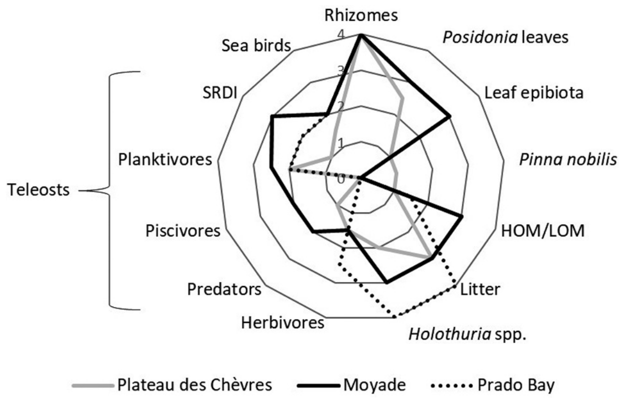

Fig. 3. – EBQI (Ecosystem Based Quality Index) assessment for each functional compartment, at three sites in the Bay of Marseille. HOM: High level of organic matter in the water filter feeders' indicators. LOM: Low level of organic matter in the water filter feeders' indicators. SRDI: Specific Relative Diversity Index is the mean number of species of teleosts observed per transect.

and eutrophication. These inputs are long-standing in the area and certainly explain the important high level of organic matter in the filter feeders' indicators of filter-feeder invertebrates ('bad' status of the LOM/HOM). The low status of the *Posidonia oceanica* leaf compartment at this site (density of shoots and cover) is however a consequence of the local degradation of the seawater quality.

Acoustic pollution and anchorage are present at all sites, although to a lesser extent at 'Moyade'. Global change as well as invasions is similar at all sites as they are within the same water body and habitat. The 'bad' status of *Pinna nobilis* is due to mass mortality events since 2018 due to the unicellular parasite *Haplosporidium pinnae* (Catanese *et al*. 2018).

Table XXII. – RAME value for each source of pressure and $\text{RAME}_{\text{total}}$ and EBQI for each site.

RAME	Plateau des Chèvres	Moyade	Prado Bay
SM	0.141	0.094	0.141
Anchorage	0.250	0.211	0.375
Degradation	0.004	0.004	0.063
Fishing gear	0.563	0.008	0.563
Hydrography	0.035	0.035	0.141
Contaminant	0.316	0.211	0.211
Eutrophication	0.281	0.188	0.188
Waste	0.188	0.063	0.281
Acoustic	0.422	0.281	0.422
Invasion	0.188	0.188	0.188
Global change	0.188	0.188	0.188
Fishing	0.563	0.012	0.750
Other	0.002	0.002	0.003
$\text{RAME}_{\text{total}}$	**3.139**	**1.482**	**3.511**
EBQI	**3.9**	**6.0**	**5.0**

DISCUSSION AND CONCLUSIONS

The presented methodology may apply to all type of pressures and environments, by simply adapting rating grids and topics. Several sources of human pressures can be assessed in an independent or combined manner and the results can be presented in an integrative way ($\text{RAME}_{\text{total}}$) or as single values for each pressure (RAME_{SM}, $\text{RAME}_{\text{anchorage}}$, $\text{RAME}_{\text{fishing}}$, etc.). In the framework of an ecosystem-based approach for the assessment of the ecological status of a given environment, this method allows a multifactorial analysis.

The field of research on ocean impacts has been growing rapidly over the last decades, but in the meantime the ocean environment has been becoming increasingly degraded. Our scientific knowledge based on the good ecological status of an ecosystem is often far from the pristine state. So, we must work on how to choose a relatively good ecological status so that our analyses on the status – pressure link could be accurate and not underestimated. Furthermore, the relationships between the intensity of the anthropogenic pressures and the ecosystem response is often not linear but features tipping points (*i.e.,* thresholds) that involve dramatic changes from a healthy to a degraded ecosystem or from one status to an intermediate one (Conversi *et al* 2010, Lejeusne *et al* 2010).

This regime shift generally implies a rupture in the resilience of an ecosystem. A non-linear relationship between human threats and the structural status of the *P. oceanica* meadows was detected by Holon *et al* (2018) which add complexity for establishing comprehensive models on relationships between human pressure and ecological status.

How can we take into account the time lag in the response of an ecosystem to a pressure?

The response time is defined as the time it takes for an indicator to record changes (degradation or recovery) in ecosystem health (Contamin & Ellison 2009). The environmental response to a pressure or ecological restoration is generally delayed in function of its intensity, the delay in biochemical and physiological processes and the resilience of the ecosystem (Hamilton 2012, Morales *et al*. 2012). Moreover, studies showing non-injurious effects at the population or the ecosystem level do not mean that there is no impact mediated through physiological or other mechanisms at the individual level that could have long-term consequences (Moore *et al*. 2004). The implications of such time lags in response to degradation or ecosystem restoration are difficult to estimate accurately. Risk assessment methods can overcome this difficulty in ecosystem-based management systems. A major challenge in impact and risk assessment is to link ecological consequences and the impact of pressures. Only the analysis of multiple datasets will be able to provide the means to bridge the ecological status of the ecosystem and the pressures estimated by the RAME. Following the pattern of risk assessment enabling preventive measures when human health is at stake, we could establish preventive rules for environmental management to prevent its degradation and to secure the sustainability of the environment.

How can the impacts be managed?

Finally, the purpose of these analyses is to identify the main sources of impact at a given location and to determine whether their level is bearable by the environment (carrying capacity), and then mitigate the effect with appropriate management measures (Guarnieri *et al* 2016). These answers can be threefold. Firstly, in some cases, countervailing or offset measures may be considered (Hrabanski 2015). Secondly, only the reduction of the source of impact can allow a return to good ecological status. And finally, management aims to continue activities but with preventive measures to mitigate the effects.

Ecosystem-based management of marine ecosystems considers impacts caused by complex interactions between environmental and human pressures (*i.e*.,, oceanographic, climatic, socio-economic) and marine ecosystems. Understanding ecosystem responses to multiple human threats is a major challenge for the implementation of sustainable natural resource management. Risk assessment is a preventive approach allowing the management of human pressures upstream of the damage they could cause. Even more effective ecosystem-based management methods should anticipate the impacts and only a risk assessment approach can make this possible to achieve.

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