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OVERSEAS CORAL REEFS AND SEAGRASSES - Developing WFD bioassessment tools

Onema
MEETINGS

Recap

Overseas coral reefs and seagrasses
Developing WFD bioassessment tools

CONCLUSIONS OF THE SYMPOSIA AND MISSIONS OF THE SEAGRASS AND REEF BENTHOS NATIONAL WORK GROUP. 2012-2014

Morgane Le Moal, Annabelle Aish and Olivier Monnier

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Conclusions of the symposia and missions of the Seagrass and reef benthos national work group.
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Foreword

In the year 2000, the European water framework directive (WFD) profoundly modified water-management policies by placing ecological considerations at the heart of the decision-making process. Since then, the development of bioassessment tools to inform on the ecological status of littoral and continental surface waters has been a major objective for the European scientific community. In continental France, an array of tools are already operational. In the overseas territories (OST, the *Départements d'outremer* in French), a number of tools have been validated and legally approved for rivers.

For the coastal waters of the island OSTs (Guadeloupe, Martinique, Mayotte and Réunion Island), the idea was to develop similar methods for coral reefs and beds of phanerogams (seagrass) that often lie just off the coasts of tropical islands. Major issues are involved in the conservation and protection of these emblematic ecosystems that serve as the basis for many economic and social activities. But in terms of the specific WFD needs, can coral reefs and seagrasses serve as indicators suited to assessing the ecological status of water bodies? The development of such tools represents a scientific challenge given the paucity of available knowledge on the ecology and functioning of these tropical ecosystems, and the relative lack of experience in their assessment.

The Seagrass and reef benthos national work group was set up in 2011 to collectively provide science advice on the topic. This document sums up the discussions and work of the group from 2011 to 2014, during three symposia and two missions in the field. Following a presentation of the context (Chapter 1), the discussion turns to the main topics addressed, namely an evaluation of the relevance of seagrasses and reef benthos in terms of WFD monitoring and assessment of water bodies (Chapter 2), identification of the parameters best suited to informing on the ecological status of coastal water bodies (Chapter 3), the protocols required to acquire the data (Chapter 4) and, finally, the work required to define the quality criteria (Chapter 5).

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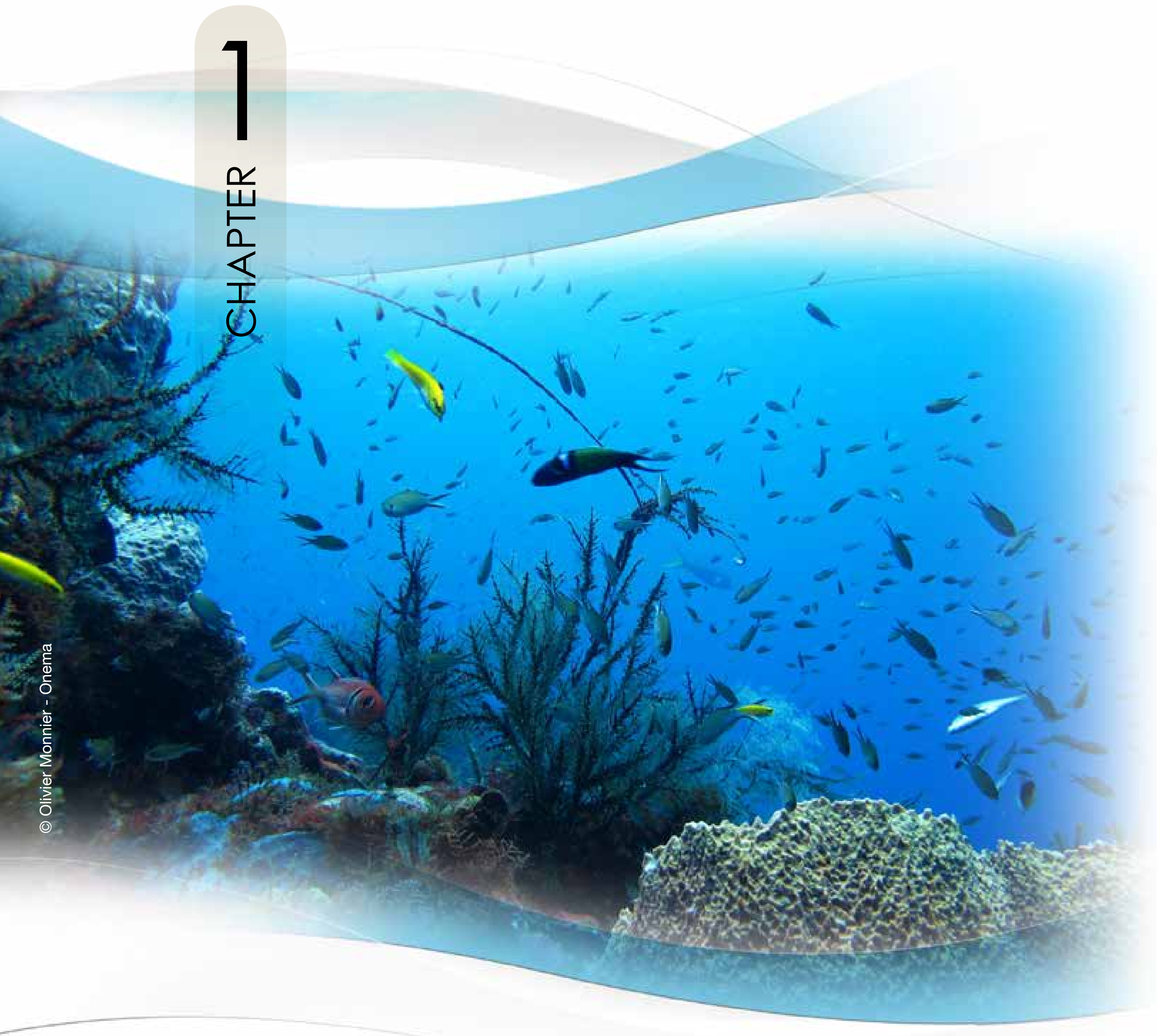


The context

1.1 - Assessing the ecological status of overseas waters in the WFD framework

Biological communities as sentinels for water quality

The European water framework directive (WFD) was adopted in 2000 and aims to maintain or restore water to good status throughout Europe, including littoral and continental surface waters, as well as groundwater. The WFD profoundly modified the water-management policies of the Member States in the European Union by placing aquatic ecology at the heart of the decision-making process. The status assessment of surface waters is now based essentially on monitoring various biological communities that live in the water, i.e. it no longer consists solely of the chemical status. Living communities have the great advantage of integrating over time all the disturbances occurring in their environment, both acute and chronic. They act as true sentinels in that they reflect the status of the water in which they live and develop. In compliance with the WFD, when an ecological status is deemed insufficient, action is taken to restore the environment to good status

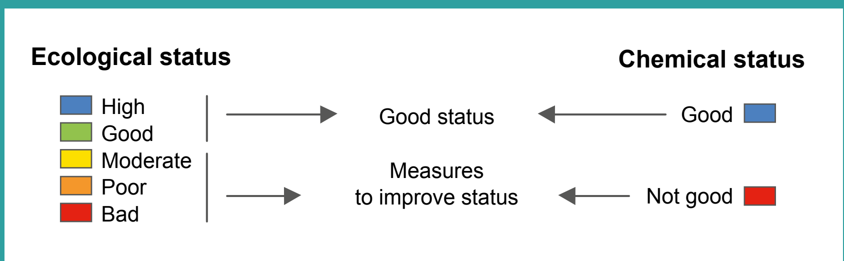
(Figure 1). For waters with high or good status, measures can be taken to ensure that the level of quality is maintained.

In general, a WFD bioassessment tool should 1) accurately reflect the status of an environment based on the characteristics of the communities living there (a biocenotic indicator), 2) inform on the causes (anthropogenic pressures) of any alterations in the status of the environment. It is also important that 3) the assessment of alterations indicate all the biological impacts related to the pressures weighing on the environment and 4) the assessment be calibrated with respect to a reference state based on a typology of water bodies. A WFD assessment tool for the ecological status of water should also take into account the natural spatial and temporal variability of environments as well as the impacts of different anthropogenic pressures. For the above reasons, the tools developed for the WFD are generally "multimetric" (Monnier *et al.*, 2016).

The biological parameters specified by the WFD and the development of bioassessment tools

In assessing the ecological status of a water body, the basic spatial unit for status assessments, the WFD recommends the use of biological quality elements (BQE) such as phytoplankton, phytobenthos, macrophytes, macroalgae, angiosperms, benthic invertebrates and fish (*European Commission*, 2000). The idea, for a given monitoring point, is to compare the observed characteristics of biological communities to the characteristics under reference conditions, i.e. the characteristics of the same communities in an equivalent environment not subjected to anthropogenic disturbances. Identification of the anthropogenic pressures and of the relationship between the pressures and the ecological status is a key aspect

Figure 1. The system behind the assessment of surface-water status.



of the WFD approach. It offers the possibility of taking precisely targeted restoration action if water status has been negatively impacted. For each BQE, one or more indices can be developed and each index is based on the measurement and integration of parameters used to describe the characteristics of the biological community (Table 1).

Bioassessment tools suited to the particularities of tropical islands

Beyond continental Europe, the WFD applies to the ultra-peripheral regions (UPR) of the EU, namely the French OSTs, the Azores and Madeira of Portugal and the Canary Islands of Spain (Figure 2). In continental France, most of the assessment tools for continental waters have already been validated and are operational (Reyjol *et al.*, 2013). The widespread establishment of biological monitoring of rivers in the 1980s, significant work to acquire biological and pressure data on water bodies and the new developments in the effort to meet the stipulations of the WFD made it possible to provide robust tools based on statistical data for the

Table 1. Biological parameters required by the WFD for the assessment of the ecological status of littoral waters. *Source: European Commission 2000, Annex V.*

	Transitional waters	Coastal waters
Composition, abundance and biomass of phytoplankton	X	X
Composition and abundance of aquatic flora (other than phytoplankton)	X	X
Composition and abundance of benthic invertebrates	X	X
Composition, abundance and age structure of fish communities	X	Not required

Figure 2. The WFD applies in the EU countries and in the ultra-peripheral regions.

second WFD management cycle. The project is more complex for littoral waters due to smaller quantities of available information and the difficulties in identifying pressures in some cases. Littoral waters are on the receiving end of the river basins and often subjected to vast mixtures of pressures that are not easy to identify once in the ocean waters. For these reasons, approaches based on expert opinion are often used to select the suitable metrics and define quality thresholds. A remaining task for certain tools is to precisely determine the relationships between pressures and ecological status (MEDDE, 2013).

In the OSTs, implementation of water policies is much more recent than in continental France, notably in Mayotte, an island that has been an OST only since 2011. The biodiversity and specific functioning of tropical eco-systems are often poorly understood and the anthropogenic pressures are frequently quite different and less well analysed than those encountered in continental France. In spite of these difficulties, a truly dynamic development effort for bioassessment tools was launched during the first WFD management cycle (2010-2015) and several tools, particularly those for rivers, have been validated and included in the applicable regulations (Monnier *et al.*, 2016).

In the island OSTs, a significant proportion of coastal water bodies contain reefs, often found in conjunction with beds of phanerogams[1] (seagrasses) (Figure 3). It was deemed essential to develop bioassessment tools adapted to these ecosystems, i.e. corresponding to the benthic[2] invertebrate and angiosperm[3] BQEs (Table 1, p. 9). The development of such tools nonetheless represents a scientific challenge for WFD implementation in that it combines the difficulties involved in working in a marine environment and in the OSTs. The available knowledge on the ecology and functioning of tropical ecosystems and that on pressures is far less advanced and much more recent than the knowledge acquired on the Atlantic and Mediterranean coasts of continental France. The difficulties inherent in the task are made even more daunting for reef benthos on hard substrates due to the absence of equivalent work elsewhere in the EU.

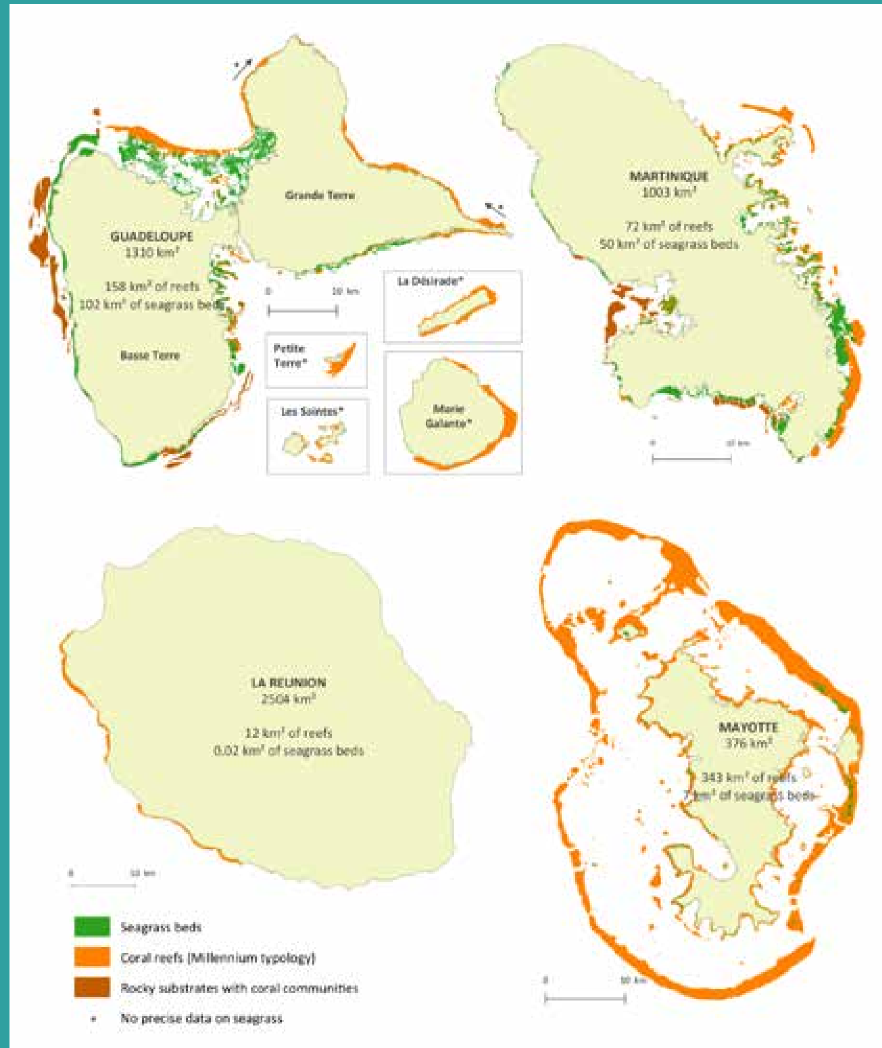


Figure 3. Map of coral reefs and seagrass beds in the island OSTs.
The data on the reefs (in orange) are drawn from the Millennium Coral Reef Mapping project to characterise and map all the reefs on the planet using a consistent set of methods and data, using an identical classification scheme worldwide (Andréfouët et al., *2008). The western and southern sides of the Caribbean islands do not have coral structures strictly speaking, but they do have coral communities (in brown) that develop on rocky substrates (for Guadeloupe, Boutry, 2001; for Martinique, Legrand, 2010). Sources for seagrasses are, for Martinique, Legrand, 2010; for Guadeloupe, Boutry, 2001; Morancy* et al., *2001; Diaz, 2005; Chauvaud* et al., *2005; for Mayotte, Loricourt, 2005.*

[1] *Phanerogams are plants whose reproductive organs are visible.*
[2] *Benthic organisms live on or near the bottom of aquatic environments.*
[3] *Angiosperms are flowering plants that produce fruit.*

1.2 - Setting up the collective effort

Given this context, the decision in favour of a collective approach was seen as the most effective solution in attempting to overcome the lack of data and knowledge. In 2011, the MNHN, with support from Onema, launched the Seagrass and reef benthos national work group by contacting coral-reef and seagrass experts in the academic and research fields, as well as local operators in charge of WFD monitoring.

The various participants initiated a true collaborative effort, laying the groundwork for a rigorous scientific approach taking into account the operational constraints.

A programme combining an assessment of the situation and work in the field

In 2011, the first step was to learn about the work already undertaken in the OSTs. WFD monitoring had been launched five years earlier in the Caribbean. On Réunion, work had concentrated on gathering data ("good status" and "bioindication" projects), whereas on Mayotte, the job consisted of setting up the monitoring network. An analysis of these efforts (Vandel *et al.*, 2012) provided a basis for discussion and guided the work within the group in the years 2012 to 2014, during the three symposia (GT DCE « Herbiers & benthos récifal », 2012, 2014a, 2014b) and two field missions (Le Moal *et al.*, 2015; Le Moal & Payri, 2015). This document presents the discussions engaged and the work done during that period.

1.3 - Coral and seagrass ecosystems

Key ecosystems degraded worldwide

Coral reefs are, by definition, bioconstructed, three-dimensional structures, characteristic of tropical waters, and dominated by the Scleractinia[4] corals. Seagrasses constitute ecosystems dominated by marine phanerogams capable of developing in subpolar, temperate and tropical waters. These two coastal ecosystems constitute an excellent habitat and a source of food for many marine species, in addition to constituting the basis for numerous ecosystem services and an array of economic and social activities.

Unfortunately, they have undergone severe degradation worldwide and over the past decades, the surface areas originally occupied by coral reefs and beds of seagrass have decreased in size by 19% and 29% respectively (Wilkinson, 2008; Waycott *et al.*, 2009). This degradation has been attributed to the synergistic effects of both natural and anthropogenic factors. In the Caribbean, where the fragility of ecosystems is increased by their geographic isolation and highly specific fauna, the decline of coral reefs has been particularly worrisome with average coral cover having been reduced by 70% over the past three decades (Gardner *et al.*, 2003).

Ecosystems under close scrutiny

These observations led to numerous initiatives and programmes to protect coral reefs and seagrass, on the international level as well as on the regional (Caribbean, etc.), national and local levels. The objectives are generally to acquire greater knowledge to understand the trends and to identify the different factors causing the degradation, to raise the awareness of the public and to assist the decision-making of managers and authorities in view of proposing sustainable ecological and economic solutions.

On the international level, the International coral reed initiative (ICRI) established in 1995 the world monitoring network for coral reefs, called the Global coral reef monitoring network (GCRMN), and a citizen-science programme, the Reef Check, was launched in 1996. For the seagrass (phanerogam) beds, two international monitoring programmes, Seagrass Watch and Seagrass Net, were set up in 1998 and 2001 respectively. A number of programmes were also established on the regional level, for example the Atlantic and Gulf rapid reef assessment (AGRRA) and Caribbean coastal marine productivity programme (CARICOMP) in the tropical Atlantic, and the Indian Ocean commission (COI), Coral reef degradation in the Indian Ocean (CORDIO) and the Western Indian Ocean marine sciences association (WIOMSA) in the Indian Ocean.

In 1999, France founded Ifrecor, the French initiative for coral reefs, the national branch of ICRI, with the objective of protecting and sustainably managing coral reefs and the linked ecosystems in the OSTs. Monitoring systems were set up at the end of the 1990s in each OST. The collected data are analysed on the local level, but are also fed into the various research strategies on the mentioned national, regional and international levels.

[4] *Scleractinia corals are also known as the hard corals*

Coral reefs and seagrass in the OSTs

There are a number of similarities in the fauna and flora of the marine ecosystems in Martinique and Guadeloupe, which may be considered a single ecoregion (*European Commission* 2000, Annex 11). The ecosystems of Réunion and Mayotte differ significantly from those in the Caribbean as well as from each other. In this document, Martinique and Guadeloupe will often be discussed together, whereas Réunion and Mayotte will be handled separately. The beds of seagrass in Martinique and Guadeloupe are the largest in the OSTs, with surface areas of 50 and 102 square kilometres respectively, and reefs covering 72 and 158 sq. km respectively (Andréfouët *et al.*, 2008; Legrand, 2010; Vaslet *et al.*, 2013; Figure 3, p. 11). Whereas the Atlantic and southern coasts of the islands are surrounded by fringing reefs (Box and Figure 4), the steep slopes of the leeward coasts to the west are the site of non-bioconstructed coral bottoms. A barrier reef closes the Grand-Cul-de-Sac-Marin to the north of Guadeloupe, whereas in Martinique, an old barrier reef consisting of the skeletons of *Acropora palmata* is being progressively colonised by algae on the windward side (Bouchon *et al.*, 2008). The Caribbean corals comprise 66 Scleractinia species (Table 2,

The different types of reef formations

Fringing reefs constitute the initial development stage of a reef. They generally consist of a horizontal platform, the reef flat, i.e. the area along the coast which can be a few metres up to a few dozen metres wide, and the steep fore reef, i.e. the outer reef facing the ocean.

Barrier reefs form a belt that is separated from the coast by a lagoon of variable depth. The width of the lagoon can range from a few hundred metres up to several dozen kilometres. Barrier reefs are what fringing reefs become when the island subsides into the ocean or when the sea level rises. In the final, third stage, the reef becomes an atoll once the island has completely sunk below the water surface.

Within a lagoon, **inner reefs** consist of coral pinnacles and patch reefs, more or less large, that rest on the sediment bottom.

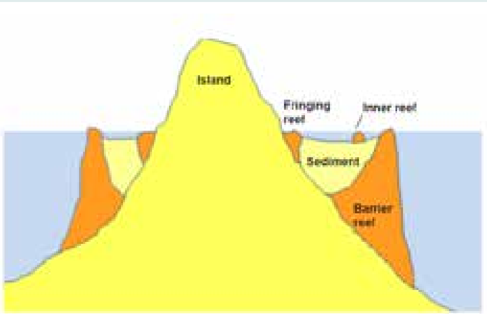


Figure 4.
Coral formations.

Table 2. Scleractinia (hard coral) genera and numbers of species in each OST. *Source: Gargominy* et al., *2014.*

	Number of species					Number of species			
Genus	**Martinique**	**Guadeloupe**	**Mayotte**	**Réunion**	**Genus**	**Martinique**	**Guadeloupe**	**Mayotte**	**Réunion**
Acanthastrea			3	2	*Lithophyllon*			3	1
Acropora	2	3	52	38	*Lobactis*			1	1
Agaricia	5	4			*Lobophyllia*			4	3
Alveopora			3	1	*Madracis*	5	5	2	1
Astrangia	1	1			*Madrepora*		1		
Astreopora			2	3	*Manicina*	1	1		
Balanophyllia		2			*Meandrina*	1	1		
Barabattoia			1		*Merulina*			2	
Blastomussa			2	2	*Montastraea*	1	1		
Caryophyllia	1	2			*Montipora*			10	12
Catalaphyllia			1		*Mussa*	1	1		
Caulastraea			1	1	*Mycedium*			1	1
Cladocora	1	1			*Mycetophyllia*	5	4		
Colpophyllia	1	1			*Oculina*	1	2		
Coscinaraea			3	1	*Orbicella*	3	3		
Craterastrea			1		*Oulophyllia*			1	1
Cycloseris			6	3	*Oxypora*			1	1
Cynarina			1		*Oxysmilia*		1		
Cyphastrea			3	3	*Pachyseris*			1	2
Danafungia			2	2	*Paracyathus*		1		
Deltocyathus	1	2			*Paragoniastrea*			1	
Dendrogyra	1	1			*Parascolymia*			1	1
Dendrophyllia	1			1	*Pavona*			10	12
Dichocoenia	1	1			*Pectinia*			2	
Diploastrea			1		*Phyllangia*	1	1		
Diploria	3	3			*Phymastrea*			3	2
Dipsastraea			10	6	*Physogyra*			1	
Echinophyllia			2	1	*Platygyra*			4	3
Echinopora			3	1	*Plerogyra*			1	
Euphyllia			1		*Plesiastrea*			2	1
Eusmilia	1	1			*Pleuractis*			2	2
Favia	1	1			*Pocillopora*			6	5
Favites			8	6	*Podabacia*			1	1
Fungia			1	1	*Polyphyllia*			1	
Fungiacyathus	1				*Porites*	4	5	11	6
Galaxea			2	1	*Psammocora*			6	4
Gadineria		1			*Rhizosmilia*	1			
Gardineroseris			1	1	*Schizocyathus*	1			
Goniastrea			7	4	*Scolymia*	3	2		
Goniopora			5	5	*Seriatopora*			2	
Guynia	1	1			*Siderastrea*	2	3	1	1
Gyrosmilia			1	1	*Solenastrea*	2	1		
Halomitra			1		*Solenosmilia*	1			
Herpolitha			1	1	*Stephanocoenia*	1	1		
Heterocyathus			1	1	*Stephanocyathus*	2	1		
Heteropsammia			1	1	*Stylocoeniella*			2	2
Horastrea			1	1	*Stylophora*			2	3
Hydnophora			3	2	*Symphyllia*			4	1
Isophyllia	2	2			*Tethocyathus*		1		
Isopora			1	1	*Thalamophyllia*	1	1		
Javania	1				*Trachyphyllia*			1	
Leptastrea			4	3	*Trochocyathus*	1			
Leptoria			1	1	*Tubastraea*	1	1	2	
Leptoseris	2	1	6	6	*Turbinaria*			4	3

Gargominy *et al.*, 2014) that are completely different than the corals in the Indo-Pacific region. Concerning seagrasses, on the basis of the currently available information, the presence of only five or six species has been confirmed in Martinique and Guadeloupe (Figure 5), namely *Thalassia testudinum, Syringodium filiforme*, *Halophila decipiens, Halodule wrightii* and *Halophila stipulacea*, the latter being an invasive species that arrived in the Caribbean around the year 2000. It would seem that *Halodule beaudettei*, a species mentioned in the past, is now considered synonymous with *Halodule wrightii* and that the use (only one time in the past) of the name *Halophila baillonis* in Martinique was probably an error (Kuo & Wilson, 2008; Ito & Tanaka, 2011). In Guadeloupe, the presence of *Halophila baillonis* has not yet been clearly determined (Le Moal *et al.*, 2015).

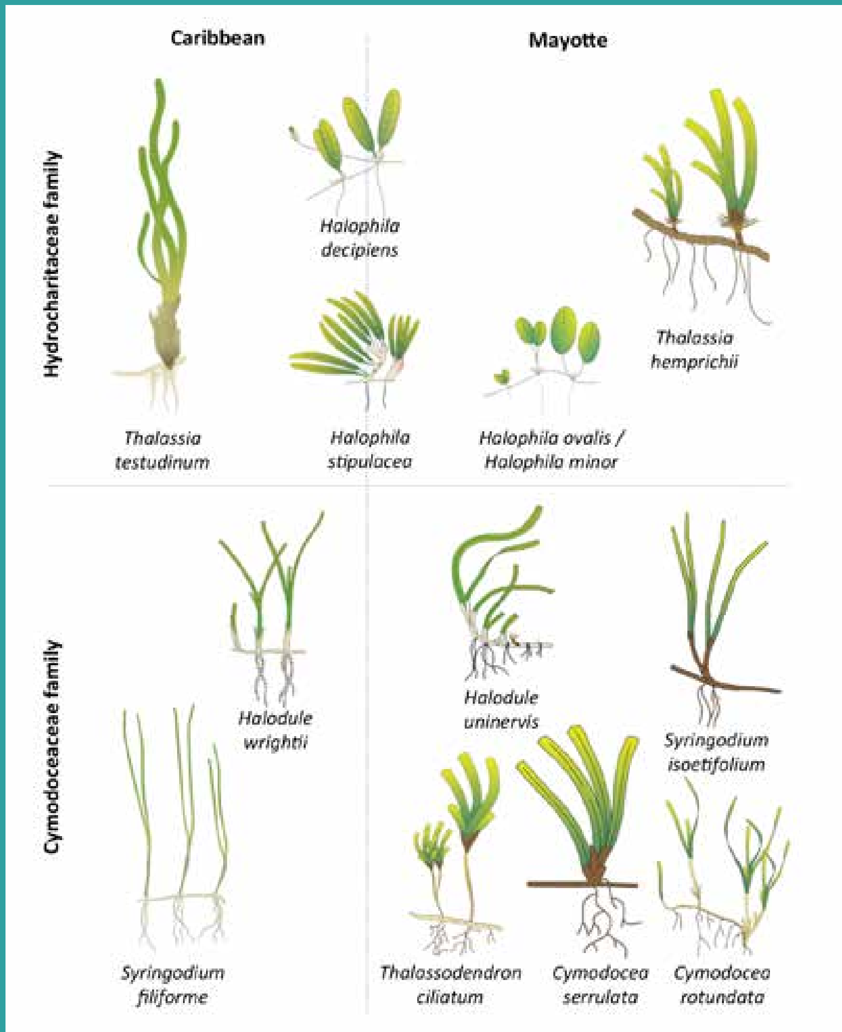


Figure 5. Marine phanerogams in the Caribbean and Mayotte.
In Réunion, only the Syringodium isoetifolium *species is present. Images: T. Saxby & C. Collier, IAN Image Library (ian.umces.edu).*

Réunion is a massive island with a fairly linear coasts. The island is still young, which explains why the coral reefs have not developed significantly and are present only on the western side of the island where they cover a surface area of approximately 12 square kilometres (Andréfouët *et al.*, 2008). The reefs are of the fringing type with a total of 171 species of Scleractinia (Table 2, p. 15, Gargominy *et al.*, 2014). Concerning seagrass, Réunion currently has only two hectares consisting of the *Syringodium isoetifolium* species (P. Frouin, per. com.). Though the beds of seagrass are currently growing, for the moment they are not included in the WFD monitoring programme.

Mayotte is the smallest of the island OSTs, with a surface area of only 376 sq. km, however it is completely surrounded by reefs that cover a surface area of 343 km² (Andréfouët *et al.*, 2008). Three main types of reef structures are on hand, namely fringing reefs around Grande Terre and the smaller islands (54 km²), the inner reefs (reef flats) in the lagoon (14 km²) and the barrier reef (275 km²) (Andréfouët *et al.*, 2008). Inventories have revealed 239 species of Scleractinia (Table 2, p. 15, Gargominy *et al.*, 2014). The beds of seagrass cover a surface area of 7 km² (Loricourt, 2005) and nine or ten marine species of phanerogams have been observed (Figure 5, Ballorain & Dedeken, oral communication, 2014), namely the *Halophila ovalis – H. minor* complex, *H. cf. decipiens, H. stipulacea, Halodule uninervis, Syringodium isoetifolium, Thalassia hemprichii, Thalassodendron ciliatum, Cymodocea rotundata* and *C. serrulata.*

CHAPTER 2

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Relevance of seagrasses and reef benthos for WFD biological-quality assessments

In a tropical context and even more so for biological compartments such as corals that have no equivalent elsewhere in the European Union, it was deemed indispensable to start by presenting the scientific data justifying the decisions made by the group of experts concerning the development of WFD coral-reef and seagrass assessment tools. Outside of the WFD context, these ecosystems are already the topic of numerous monitoring programmes in the OSTs, e.g. the projects run by Ifrecor (GCRMN) and by the marine protected areas (Guadeloupe national park and reserve, Réunion marine reserve, Mayotte marine nature park).

That is why the experts started their work by breaking down the operating principles and objectives of each of the above monitoring programmes, including the WFD, and comparing them all to each other. This was necessary because current WFD monitoring programmes are often more or less based on earlier programmes that had their own set of objectives. The goal was therefore to determine whether the approaches and the protocols for data acquisition and the formulation of the resulting assessment tools are compatible with WFD needs and whether WFD requirements in terms of general methods and management objectives are correctly taken into account. These considerations also led the experts to question the relevance of the coral-reef and seagrass ecosystems in meeting WFD objectives and in restoring water and aquatic environments to good status.

2.1 - Synergy between WFD monitoring and the other monitoring programmes

WFD objectives fall under a regulatory framework (*European Commission*, 2000) and target either maintaining the good or high status of water or restoring water of lesser quality to good status. In coastal waters, the purpose of monitoring of seagrasses and reef benthos is to assess the ecological status of the corresponding water bodies. To fully achieve the objectives, the characterisation of the impacts of local, anthropogenic pressures affecting the living communities is an essential component in monitoring the effectiveness of measures to restore the quality of water and environments (Figure 6). Ifrecor and the marine protected areas, on the other hand, study the status of the ecosystems themselves in order to monitor and understand their evolution on the local, regional and global levels, and to assess the effectiveness of management measures for these environments (Figure 6).

Though the spatial and temporal scales and the assessment approaches differ between the WFD on the one hand and Ifrecor/marine protected areas on the other (Figure 6), in both cases monitoring is part of a conservation effort to protect the ecosystems and resources, and to sustainably manage their ecological functions and the related services. The differences in management objectives in fact produce complementary approaches in that they target different pressures exerting their effects on different temporal and spatial scales. For example, a reduction in local alterations achieved by the WFD can enhance the resilience of ecosystems when confronted with cyclones or the effects of global change.

However, we must still determine the usefulness of reef benthos and seagrasses for WFD monitoring and assessment before thinking about possibly implementing the methods used in other monitoring programmes.

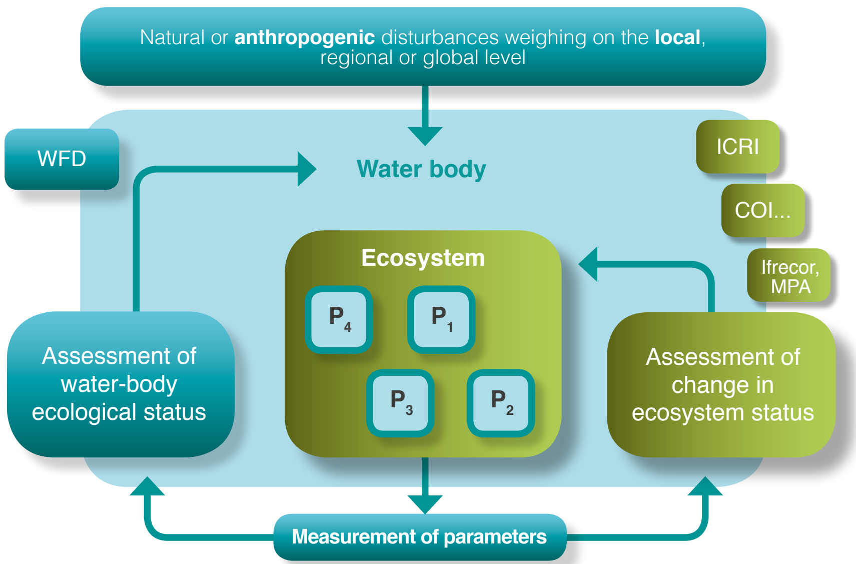

Figure 6. Monitoring the ecological status of water bodies and the status of ecosystems. *P1-P4: Measured parameters. ICRI: International coral reef initiative; COI: Indian Ocean commission; Ifrecor: French initiative for coral reefs; MPA: marine protected areas.*

2.2 - Reef benthos, a useful biological quality element in spite of difficult work conditions

Complex ecosystems...

Coral reefs are very complex ecosystems with a high degree of natural variability. They are frequently subjected to extreme natural disturbances, such as cyclones, coral bleaching events and massive invasions of predators, e.g. *Acanthaster* (Box, p. 25). In addition to these natural disturbances, amplified in some cases by global warming, are a number of local, anthropogenic disturbances. Coral reefs are sensitive to all these disturbances which can result in changes in the composition of living communities and in the structure and functioning of the ecosystem. Following these types of changes, a return to the *status quo ante* (resilience) can take several years or even decades depending on type and the intensity of the disturbances.

...requiring an assessment over the long term

Compared to other WFD biological quality elements (BQE) with high resilience levels, e.g. the microphytobenthos and benthic invertebrates on soft substrates, these specific aspects raise a number of technical and design issues concerning the development of bioassessment tools for the directive (Figure 7).

Technically speaking, the questions deal above all with how to integrate the extreme disturbances and the high degree of natural variability of coral reefs in the assessment. This is due to the fact that for the WFD, characterisation of ecological status takes place in six-year cycles. This time step may be insufficient for a valid assessment of the ecological status based on reef benthos if an extreme event occurred during that time or somewhat before.

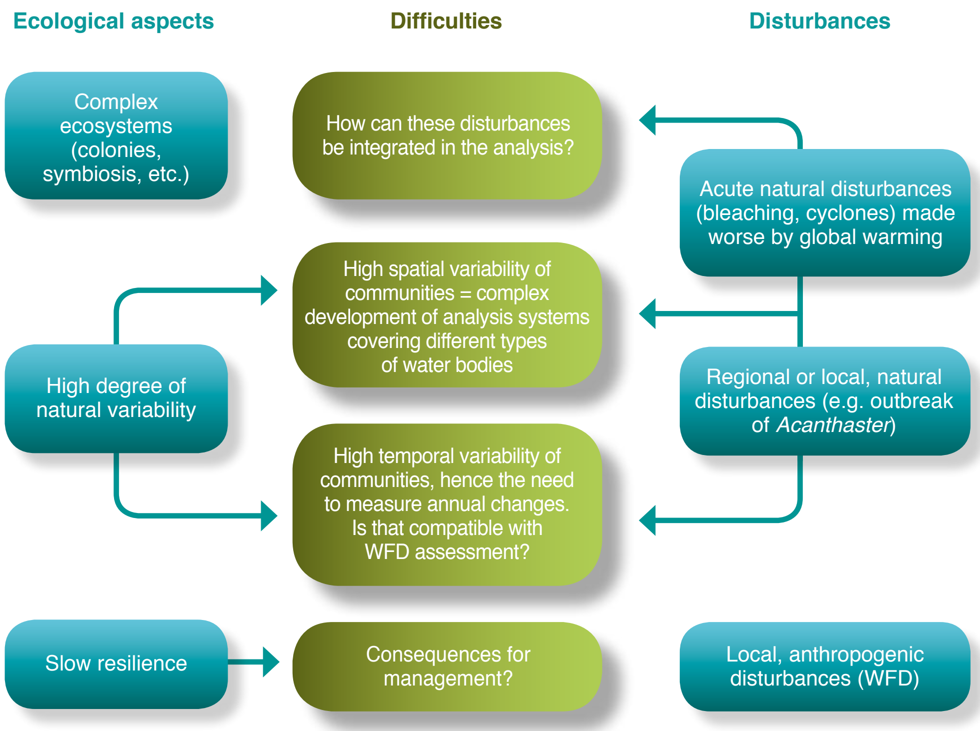

Figure 7. Specific ecological aspects of coral reefs, pressures weighing on these ecosystems and difficulties in their potential use in assessing the ecological status for WFD purposes.

From the design point of view, the main question focusses on the consequences, in terms of launching measures to restore the ecological status and the corresponding funding, if assessment results remained below the "good status" level over an entire six-year management cycle. As noted, following a natural or anthropogenic disturbance, the return to the *status quo ante* may be very long or may never occur, even if the disturbance ceases to exist. A new equilibrium may intervene, for example via a shift from an ecosystem dominated by Scleractinia to one dominated by macroalgae (called a phase shift, Hughes, 1994).

In spite of the difficulties involved in this work, it would be premature to abandon the development of a bioassessment tool based on coral reefs. The fact that they represent one of the main ecosystems in tropical coastal waters and that they are sensitive to local, anthropogenic pressures constitutes a serious argument in favour of their value in assessing the ecological status of tropical waters. If possible, reef benthos should be exempted from the "one out, all out" rule and not be included in the WFD assessment during a cycle in which an extreme event occurs. It should be seen as an element in addition to the other BQEs that can be used over the long term. In the current context of global change, it will be necessary to verify their relevance over time.

The barrier reef in Mayotte.

Extreme events affecting coral reefs

Coral reefs are frequently subject to extreme, natural disturbances, some of which are amplified by global warming.

Table 3. The main natural causes of damage to coral reefs in the island OSTs.
Source: Ifrecor secretariat, 2003.

	Caribbean	Reunion Island	Mayotte
Cyclones	Major impact	Major impact	Moderate impact
Bleaching	Moderate impact	Major impact (local)	Major impact
Acanthaster			Major impact

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Corals broken by waves

Cyclones have a direct impact in the form of large swells and waves, in addition to massive discharges of fresh water carrying quantities of alluvium, that result in significant coral mortalities and reduce the architectural complexity of the reef. In the French OSTs in the Caribbean, a cyclone occurs once every ten years on average. Over the past decades, five large cyclones affected the coral reefs in Guadeloupe (Hugo, 1989; Luis and Marilyn, 1995; Lenny, 1999; Omar, 2008) and three hit Martinique (David, 1979; Allen, 1980; Dean, 2007). In the Indian Ocean, the western coast of Réunion is generally protected, but the cyclones Firinga, Dina and Gamède (1989, 2002 and 2007 respectively) nonetheless hit both the southern and western coasts. Due to its latitude, Mayotte is less frequently hit by cyclones than the other OSTs (Ifrecor, 2003).

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Massive bleaching

Coral bleaching is caused by the expulsion of the zooxanthellae, the symbiotic microalgae living inside the coral, following an environmental stress, e.g. an increase in the water temperature. Massive bleaching was observed worldwide in 1982-83, 1987-88, 1998, 2005 and 2010, during El Niño sequences characterised by particularly high water temperatures (Olivier *et al.*, 2008). The reefs in Mayotte were particularly hard hit by the 1998 event, when coral mortalities reached 75 to 99% (Deschamps, 1999). The 2010 event also resulted in massive mortality, however the events in 1982-83 and 1987-88 were less severe and the results less serious. In comparison, the reefs in Réunion were relatively unaffected by the worldwide bleaching events, however they have suffered more local bleaching phenomena (Tourrand *et al.*, 2013). In the Atlantic, the most significant bleaching event occurred in 2005 during the hottest year ever recorded in the northern hemisphere. The corals in Guadeloupe and Martinique suffered mortality rates of 30 to 40% (Bouchon *et al.*, 2008).

Proliferations of *Acanthaster planci* are one of the most destructive among the natural disturbances for coral reefs in the Indo-Pacific region. Also know as the crown-of-thorns starfish, it feeds on the polyps of the coral communities and grows in cycles alternating long periods of low population densities and brief periods of very high densities. The causes of the proliferations are still debated. In Mayotte, approximately 15 short-lived population explosions have occurred since 1977 (Gigou, 2011). To date in Réunion, the local populations of *Acanthaster* have never been observed to proliferate and damage coral reefs (Tourrand *et al.*, 2013).

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An attack by an *Acanthaster planci*

2.3 - Seagrass, a useful biological quality element after defining a typology

Filtering out natural variability for better assessments

Beds of seagrass (an angiosperm BQE for the WFD) are useful factors in assessing the ecological status of water. Even though no definitive data is currently available on their full range of reactions to pressures, it is possible within these ecosystems to identify trends, balances and imbalances that provide information on the ecological status of water. The general knowledge on marine phanerogams in tropical environments makes it theoretically possible to differentiate between changes linked to natural population dynamics and anthropogenic effects linked to eutrophication, hypersedimentation or physical destruction. Compared to the reef benthos, seagrass beds are relatively unaffected by extreme, natural events.

However, in order to filter out natural variability as much as possible, it was deemed essential to create a typology of seagrasses, i.e. identify the different types of seagrasses and then select the type(s) of seagrass best suited to monitoring for WFD purposes.

This is necessary because depending on the environmental factors influencing their development, their composition and structure can vary over time and space, as can their ecological response to an anthropogenic disturbance. By concentrating on one type or a limited number of seagrass types, it is possible to monitor the plants under relatively consistent, natural conditions, an important factor for an accurate assessment of the ecological status of different water bodies.

In the Caribbean, the development of a typology was seen as necessary to clarify the link between the groups of species in seagrass assemblages and the use of this parameter as an indicator of the ecological status of water. This is because, in the past in the French OSTs in the Caribbean, species composition has been used as a metric in assessing the status of seagrass beds in the framework of monitoring the marine protected areas (Bouchon *et al.*, 2003). When WFD implementation was started in the OSTs in 2006, this indicator of the health status was adapted to the specific requirements of the directive. However, questions have been raised concerning this adaptation for WFD monitoring dealing with the environmental factors defining the maximum and optimum ecological range of each species of phanerogam.

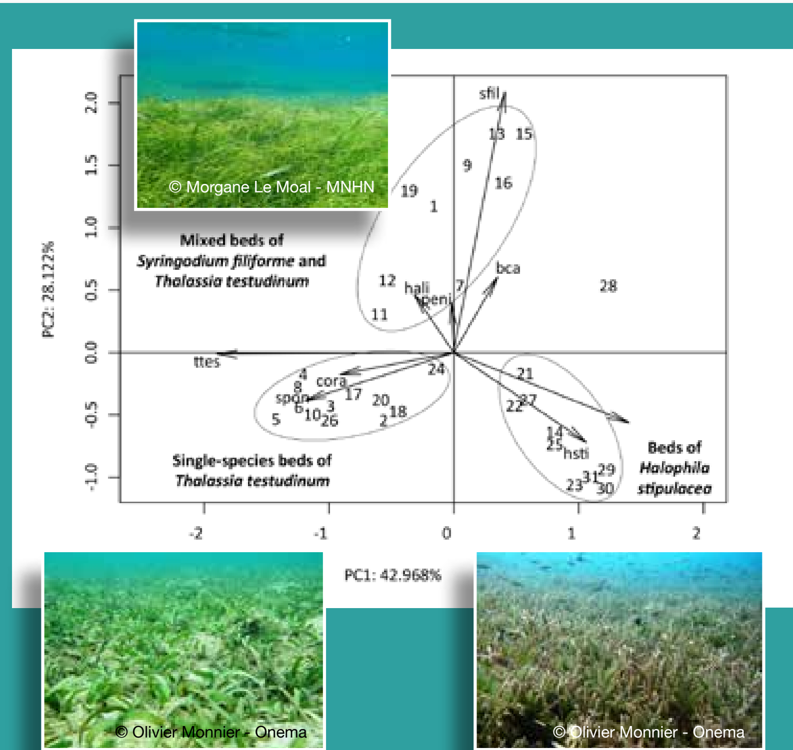
Martinique as an experimental site

In April-May 2013, a field study was carried out (Le Moal *et al.*, 2015). Martinique was selected as the pilot site given the small amount of quantitative data available and the absence of monitoring networks (other that WFD networks), compared to Guadeloupe which has benefited from different monitoring programmes since 2005 in the nature reserves and the Guadeloupe national park. Samples were taken from 31 monitoring points spread over all the seagrass beds around the island. The monitoring points were located in the centre of the beds, at depths from 1 to 6.5 metres, the bathymetric range in which the largest beds around Martinique grow (Laborel-Deguen, 1984; Legrand, 2010) and where most of the WFD points are located.

At each monitoring point, 35 parameters were measured, dealing with the biotic characteristics of the phanerogams, the fauna and flora living in conjunction with the beds, and the abiotic environment (Figure 8). The measurements were taken in accordance with the protocol developed by Hily and Kerninon (2013) for Ifrecor, with certain modifications to meet WFD needs. The next step was statistical analysis to characterise the 31 sampled points using the most significant biotic and abiotic parameters. The final principal component analysis (PCA) comprised nine variables (Figure 9).

Figure 8. Divers surveying seagrass beds along transects and in quadrats *(Martinique, 2013).*

Figure 9. Classification using principal component analysis (PCA) of the 31 monitoring points for seagrass beds in Martinique, comprising three main types of beds, 1) single-species beds of *Thalassia testudinum* (ttes), characterised by the additional presence of corals (cora) and sponges (spon), 2) mixed beds comprising *Syringodium filiforme* (sfl) and *T. testudinum* with the presence of *macroalgae* genera *Halimeda* (hali) and *Penicillus* (peni), and of branching calcareous algae (bca), and 3) beds of *Halophila stipulacea* (hsti).



Environmental conditions affect the species composition to form three main types of beds

The analysis revealed three main types of beds, differing primarily in terms of the species composition of the phanerogams, but also in the density of certain taxa of macrofauna and macroalgae (Figure 9). The identified beds were single-species beds of *Thalassia testudinum*, mixed beds of *Syringodium filiforme* and *T. testudinum*, and beds of *Halophila stipulacea*. Whereas the single-species beds of *T. testudinum* and the mixed beds of *S. filiforme* and *T. testudinum* were found mainly off the eastern and southern coasts, the beds of *Halophila stipulacea* were observed primarily off the western coast (Figure 10). The main factors explaining these features are the hydrodynamics and access to light. The members of the work group agreed that the typology proposed for Martinique was also valid for Guadeloupe within the bathymetric range of 1 to 6.5 metres.

Natural, temporal variability of the ecosystem...

In terms of species succession over time, the single-species beds of *Thalassia testudinum* represent the climax stage of the ecosystem, whereas the presence of *Syringodium filiforme* signals instability in the ecosystem (Zieman, 1982; Bouchon *et al.*, 2003, Figure 11, p. 30). As long as the climax has not been reached, there is continuous competition between *T. testudinum* and *S. filiforme* that can result in heterogeneity (both spatial and temporal) within the bed, e.g. a bed may, at a given point in time, be composed of single-species zones and mixed zones, and a given zone may shift in the space of just a few months from single-species to mixed (or *vice versa*). The distribution of the monitoring points in the principal component analysis (Figure 9, p. 27) illustrates the spatial heterogeneity, with a continuum between the clearly single-species points comprising beds of *Thalassia* (e.g. point 5) and those dominated essentially by *Syringodium* (e.g. point 15). This instability in the seagrass beds may be the result of continuous or repeated natural disturbances, for example substrate erosion (Patriquin, 1975). This natural instability may be compounded by instability due to anthropogenic disturbances, which would tend to shift the succession process of species toward the transition phase as is indicated by the Caricomp monitoring carried out in the Caribbean since 1993 (van Tussenbroek *et al.*, 2014, Figure 11, p. 30).

... that must be integrated in the analyses

In light of the above, the group of experts was of the opinion that the index developed to assess the health status of seagrass beds for monitoring of the marine protected areas (Bouchon *et al.*, 2003) should not be adapted to WFD monitoring.

This is because the WFD would use seagrass monitoring to assess the ecological status of the water

Figure 10. Positions of the seagrass monitoring points around Martinique, identified according to the three types of beds observed. *Source: Seagrass layer, Legrand, 2010.*

● *Single-species beds of* Thalassia testudinum
▲ *Mixed beds of* Syringodium filiforme *and* T. testudinum
★ *Beds of* Halophila stipulacea
◆ Monitoring points where different assemblages of species were observed

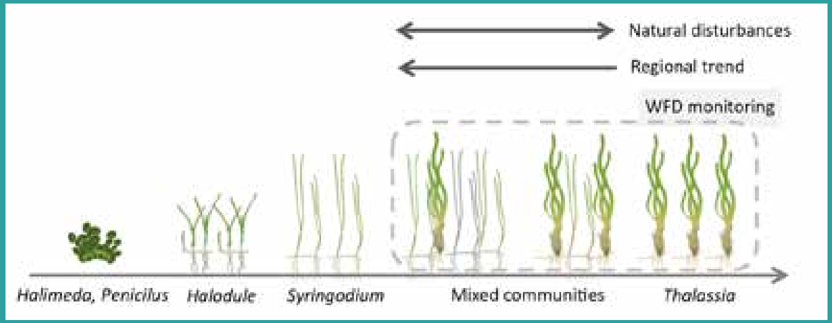


Figure 11. Theoretical diagram showing the succession of marine phanerogam species in the Caribbean as a function of the natural and/or anthropogenic disturbances weighing on the ecosystems. *Succession diagram adapted from Zieman (1982).*
Phanerogam illustrations: T. Saxby & C. Collier, IAN Image Library (ian.umces.edu). WFD monitoring should begin, if possible, on single-species beds of Thalassia testudinum*, which may occasionally be mixed with* Syringodium filiforme*, depending on the spatial and temporal evolution of the species. The appearance of* Syringodium filiforme *in these beds must be taken into account, however it will not be seen as a disqualifying parameter in the assessment of the ecological status of water bodies. The arrow indicates the succession of species over time.*

bodies in which the seagrass grows in order to identify any local, anthropogenic disturbances.

But the index developed by Bouchon *et al.* (2003) does not differentiate between the impacts of natural and anthropogenic disturbances. More precisely, a shift from the "high health status" (single-species bed of *T. testudinum*) to the "good health status" (mixed bed of *T. testudinum* and *S. filiforme*) is the sign of ecosystem instability, however that instability is not necessarily related to a local, anthropogenic disturbance. The presence of the *S. filiforme* pioneer species does not always signal an anthropogenic disturbance and should not be interpreted as a sign of poor ecological status for WFD purposes.

For the above reason and in order to filter out natural variability as much as possible, the national work group recommends including the two types of seagrass beds in WFD monitoring and, if possible, to start monitoring of the single-species beds of *T. testudinum*. The appearance and evolution over time of *S. filiforme* should be taken into account during monitoring in order to keep tabs on changes in the natural conditions, but should not be used as disqualifying parameters in assessing the ecological status.

The third type of observed bed, comprising *Halophila stipulacea*, was not selected for the time being for WFD monitoring because the dynamics specific to the species would appear, first of all, not to be linked to anthropogenic disturbances and, secondly, to be highly affected by acute, natural disturbances such as cyclones. However, any changes in the presence of the species in beds of *S. filiforme* and/or *T. testudinum* should be taken into account.

A typology of seagrass beds in Mayotte

In 2014 in Mayotte, the marine nature park launched an update of the existing maps of seagrass beds (Ballorain & Dedeken, oral presentation). On the basis of an analysis of the initial results, WFD monitoring will most likely address a specific type of bed, namely multi-species intertidal beds that are dominated in terms of numbers by three or four species, of which the main species are *Halodule uninervis* (65%), *Syringodium isoetifolium* (15%), *Halophila* spp. (10%) and *Thalassia hemprichii* (10%). This type of bed represents the intermediate stage of the ecosystem in the succession process of species (Figure 12). The combinations of species vary with the depth, substrate and the level of herbivory, where the latter is the main factor determining bed structure.

One of the main differences in the functioning of seagrass-bed ecosystems between Mayotte and the Caribbean lies in the levels of

Figure 12. Theoretical diagram showing the succession of marine phanerogam species in Mayotte for the multi-species intertidal type of bed. *Phanerogam illustrations: T. Saxby & C. Collier, IAN Image Library (ian.umces.edu).*
Currently, the most common species in the seagrass beds of Mayotte are Halodule uninervis *and* Syringodium isoetifolium*, two species that are characteristic of the intermediate stage in the succession process (Box).*

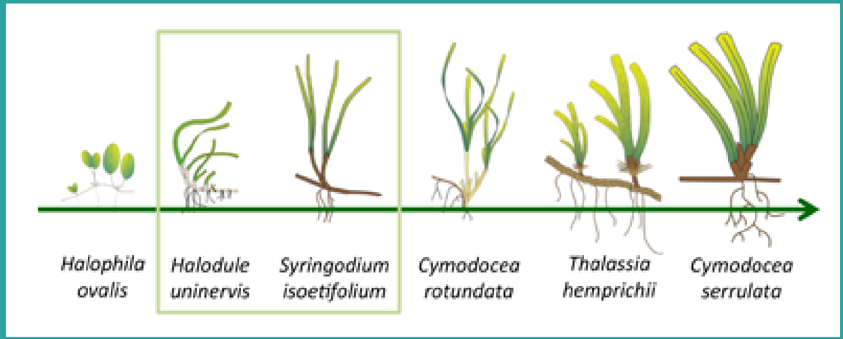


Figure 13. A green sea turtle *Chelonia mydas* in a seagrass bed in Mayotte (2013) and the photo of a section of bed protected from herbivory for a period of 400 days (2008).

herbivory. Whereas in the Indian Ocean, the level is high and the pressure is exerted primarily by green sea turtles *Chelonia mydas* (Figure 13), in the Caribbean, the level is relatively low and due essentially to sea urchins, given that the large herbivores were decimated over the previous centuries (Jackson *et al.*, 2001).

2.4 - Reefs and seagrass, essential ecosystems and necessary assessment tools

The WFD and the other monitoring programmes for reefs and seagrass in the OSTs have the same general objectives in terms of the conservation, protection and sustainable management of ecosystems and their resources. The management objectives characterising each programme bring specific assessment approaches into play that are implemented over different temporal and spatial scales. It is these differences that create the complementarity between the programmes, however the technical implementation of each programme requires particular conditions.

For example, contrary to other monitoring programmes, the use of coral reefs as a bioassessment tool for the WFD raises an array of technical difficulties given the high, natural variability of these ecosystems, their exposure to extreme, natural disturbances and their low degree of resilience. However, the fact that they represent one of the main ecosystems in tropical coastal waters and that they are sensitive to local, anthropogenic pressures constitutes a serious argument in favour of their value in assessing the ecological status of water in the OSTs.

The recommendation is therefore to develop a WFD bioassessment tool based on coral reefs, even if the process is complex and will probably require technical adaptations to the guidelines imposed by the directive.

Seagrasses are deemed a relevant factor in responding to WFD requirements, but first a preliminary step to developing assessment tools was undertaken. To meet the specific needs of the directive and particularly in view of comparing water bodies of the same type, a typology of seagrass beds was created in the Caribbean. In Martinique and Guadeloupe, it is advised to begin monitoring on beds of *Thalassia testudinum*, which may in some cases be mixed with *Syringodium filiforme*. In Mayotte, WFD monitoring will most likely be carried out on multi-species, intertidal beds, dominated primarily by *Halodule uninervis* and *Syringodium isoetifolium*. The differences revealed between Mayotte and the Caribbean in the succession stages of phanerogam species due to the natural and anthropogenic disturbances led the experts to formulate specific monitoring strategies for each region.

CHAPTER 3

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Parameters in assessing the ecological status of water

Reef benthos and phanerogam beds are sensitive to local, anthropogenic disturbances and capable of signalling changes in water quality, in terms of both its degradation and improvement. The second step in the work of the group of experts was to identify the biological parameters capable of revealing the changes and to identify as clearly as possible the responses of the biological communities to the impacts of environmental pressures.

3.1 - Parameter selection focussing on the biological responses to anthropogenic pressures

An anthropogenic disturbance may produce a biological response on the scale of a single organism, of a population, a community or an entire biocenosis. In other words, the impact of a disturbance may be measured on any organisational level and at any degree of biological complexity, ranging from the biochemistry or the metabolism of an organism up to the characteristics of entire sets of communities.

The responses produced by a disturbance are initially detectable in terms of the physiology/biochemistry of an individual, then on the morphological or behavioural level, and finally via the characteristics of populations and communities (Figure 14).

In order to select the most useful parameters for WFD purposes, a large number of biological responses were reviewed and an assessment of the theoretical response to the pressure was carried out. This approach focussed on the anthropogenic pressures most commonly observed in the coastal waters of island OSTs, e.g. inputs of nutrients, reduced light due to an increase in turbidity, sedimentation, physical destruction due to fishing and boating. Finally, pragmatic aspects and the operational ease of implementation were crucial factors in selecting the parameters.

A status condition (level) was assigned to each of the selected parameters:

- **Level 1** for useful parameters that should be easily integrated in an index;
- **Level 2** for parameters that would appear to be useful for WFD purposes and that will probably be included in an index once their usefulness has been confirmed after five years of data acquisition;
- **Level 3** for parameters that would appear to be useful for WFD purposes, but that require more information and will be a topic of further research;
- finally, a series of **additional** parameters, explanatory in nature, that will not be integrated in bioassessment tools, but that will provide information likely to assist in interpreting changes in the indices or to orient the study on pressures.

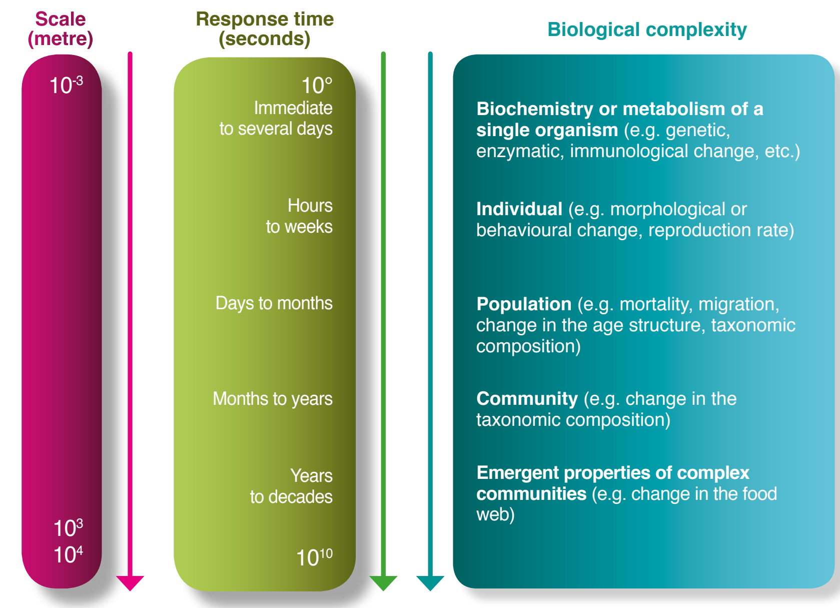

Figure 14. Biological complexity and average response times to disturbances. *According to Martinez-Crego* et al., *2010.*

3.2 - Reef benthos, parameters reacting to multiple pressures

Parameter selection

Reef ecosystems can produce a large number of known biological responses to anthropogenic stresses, but there are few biological responses that occur for a specific pressure, on the contrary most are known to occur in a context of multiple pressures (Table 4).

Table 4. Parameters of reef biocenoses known to respond biologically to anthropogenic disturbances.
Summary of information drawn from articles by Jameson et al., *2001; Jameson and Kelty, 2004; Chabanet* et al., *2005; Fichez* et al., *2005; Cooper* et al., *2009.*

	Parameters / indices	Pressure	Organisms	Number of studies
Physiology / biochemistry	N isotope ratio	Nutrients	Scleractinia, macroalgae	17
	C isotope ratio	Nutrients	Corals	2
	C:N:P ratio	Nutrients	Macroalgae	5
	RNA/DNA ratio	Multiple	Scleractinia	1
	Expression of genes	Multiple	Corals	2
	Histopathological indices	Sediment	Corals	1
	Activity of alkaline phosphatase	Nutrients	Macroalgae	1
	HSP protein	Multiple	Scleractinia	3
	Concentration of amino acids	Multiple	Scleractinia	1
	ATP concentration	Multiple	Scleractinia	1
	Lipids concentration	Multiple	Scleractinia	3
	Chlorophyll a concentration	Multiple	Zooxanthellae	1
Individual / colony	Productivity	Multiple	Macroalgae	3
	Productivity and calcification	Multiple	Corals	4
	Growth rate	Multiple	Scleractinia	4
	Mucus production	Multiple	Scleractinia	1
	Skeleton density	Multiple	Scleractinia	3
	Symbiont density	Multiple	Zooxanthellae	1
	Loss of zooxanthellae	Multiple	Zooxanthellae	3
	Tissue thickness	Multiple	Scleractinia	1
	Tissue abrasion	Physical	Scleractinia	4
	Surface roughness	Multiple	Scleractinia	1
	Mortality	Multiple	Scleractinia	2

(Table 4 continued on next page)

Table 4 (cont.). Parameters of reef biocenoses known to respond biologically to anthropogenic disturbances.

	Parameters / indices	Pressure	Organisms	Number of studies
Population / coral community	Disease	Multiple	Corals	8
	Destruction of coral	Physical	Scleractinia	4
	Larval recruitment	Multiple	Corals	19
	Deterioration index (mortality / recruitment)	Multiple	Branching corals	1
	Coral vitality index	Multiple	Scleractinia	3
	Habitat occupation index	Multiple	Corals	1
	Hard-coral cover rate	Multiple	Scleractinia	14
	Other cover measurements	Multiple	Corals	5
	Cover / diversity	Multiple	Scleractinia	2
	Coral shapes	Multiple	Scleractinia	4
	Architecture (structural complexity, rugosity)	Physics	Scleractinia	4
	Taxonomic richness	Multiple	Corals, macroalgae	1
	Size structure	Multiple	Corals	1
	Max. depth of development	Multiple	Corals	1
	Population structure	Multiple	Scleractinia, macrofauna, parasites	6
Other communities	Coelobite index	Sediment	Coelobites	1
	Foram index	Multiple	Foraminifera	11
	Benthic filter feeders	Multiple	Sponges, ascidians (sea squirts)	1
	Diversity indices	Multiple	Sponges, gorgonians	4
	Heterotrophic macroinvertebrates	Multiple	Filter feeders, bioeroders	11
	Stomatopod crustaceans	Multiple	Stomatopods	6
	Amphipoda	Multiple	Amphipoda	23
	Corallivores	Multiple	*Acanthaster, etc.*	2
	Bioeroders	Multiple	Cyanobacteria, sponges, polychaetes	8
	Density of algal community	Multiple	Macroalgae	5
	Biomass of algal community	Multiple	Macroalgae	2
	Composition of algal community	Multiple	Macroalgae	4
Several communities	Dominant-community ratio	Multiple	Scleractinia, sponges, macroalgae	5
	Community structure	Multiple	Scleractinia, macrofauna, macroalgae, parasites	11
	Coral Health Index (CHI)	Multiple	Corals, fish, viruses	1
	Ecological change	Multiple	Scleractinia, sponges, macroalgae	1
	Index of biological integrity	Multiple	Ecosystem fragmentation	4
	Overall structure (satellite images)	Multiple	Ecosystem fragmentation	2

Study of the physiological and biochemical responses of corals generally requires advanced and expensive equipment and specialised knowledge in molecular biology, biochemistry and physiology that is not necessarily available in all OST labs and consulting firms. Parameters measured on the population and community levels are better suited to routine monitoring.

A total of 16 parameters are recommended for monitoring of reef benthos (Table 5), including six parameters considered useful in determining water quality, assigned to levels 1 and 2, five additional

Table 5. Reef-benthos parameters recommended for WFD monitoring and their theoretical response to a pressure.
L1: useful parameters for the WFD that should be easily integrated in an index;
L2: parameters apparently useful for WFD purposes and that will probably be included in an index once their usefulness has been confirmed after five years of data acquisition;
ADD: additional parameters that will not be integrated in bioassessment tools, but that may provide information to assist in interpreting the influence of the natural variability and of the pressures; [C]: Caribbean, [IO]: Indian Ocean

L1 and L2 parameters	Nutrient inputs	Increased turbidity	Increased sedimentation	Physical destruction
Macroalgae cover (L1)	↗	↘	↘	↘
Macroalgal taxa (L2)	↗ ↘	↗ ↘	↗ ↘	Not useful
Cover by living Scleractinia (L1)	↘	↘	↘	↘
Coral taxa or categories (L1)	↗ ↘	↗ ↘	↗ ↘	Not useful
Octocorallians (Alcyonaria) (L1 [IO])	↗	↗	↗	↗ ↘
Zoantharians / corallimorpharians (L2 [IO], ADD [C])	↗	↗	↗	↗ ↘

Additional parameters	
Related to water quality	Density of adult colonies, density of juvenile colonies, bleaching due to local stress / necrosis / disease, sponges, gorgonians [C]
Explanatory parameters	Bleaching due to a regional or global stress, sea urchins[1], Acanthaster [IO], herbivorous fish, corallivorous fish [IO]

[1] The herbivorous pressure of sea urchins was designated as a Level 2 parameter during the second symposium, but given that it is not directly related to water quality, it was decided to reclassify it as an additional parameter.

parameters with the potential to provide information on water quality and five additional parameters capable of informing on changes in the ecosystem, but not related to changes in water quality.

The following paragraphs present the parameter-selection criteria in general terms, with illustrations in Figures 15 and 16 (p. 42 and 43). Additional details are available in the symposium proceedings (GT DCE Herbier & Benthos récifal, 2014a, 2014b).

It has been proposed to integrate macroalgae parameters into both the reef index and the seagrass index. This topic is discussed in detail below, in a section devoted to both indices (section 3.4.).

Parameters for scleractinian communities

In terms of parameters for hard-coral colonies, **coral cover** is the most robust parameter for comparisons between sites. It can be used to calculate metrics such as the living coral to colonisable surface area ratio and the living coral to dead coral ratio.

Taxonomic identification of corals is recommended to the level of the genus if possible, if not, then simply in coral categories. This is because it is *a priori* possible to distinguish the coral genuses or categories more sensitive to disturbances, e.g. acropora coral in the Indian Ocean or the branching corals in general. On Réunion, the experts of the local WFD work group for the “hard-substrate benthos” have already proposed metrics based on the acropora/non-acropora ratio or the branching & table acropora/ acropora ratio (GT DCE Réunion “Benthos substrats durs”, 2012, Monnier *et al.*, 2016). In the Caribbean, acropora populations have already declined significantly over the past decades and it will be necessary to devise other metrics.

The densities of adult and juvenile coral colonies are parameters sensitive to pressures and that were initially ranked as Level 2 parameters. However, they manifest high spatial variability (between sites) as well as temporal variability (interannual) that make them relatively incompatible for WFD purposes. What is more, tests carried out in Martinique in 2013 during surveillance monitoring reported technical difficulties in implementation. As a result, they were downgraded to additional parameters to be used if the necessary means are available locally.

Coral bleaching may be caused by stresses resulting from local, anthropogenic pressures. It may also be the consequence of regional or global disturbances, for example a rise in water temperature. Consequently, it will be essential to distinguish the causes of bleaching by monitoring events reported locally or worldwide and/or by confronting observations with data on water temperatures.

In the field, bleaching is often difficult to distinguish from **diseases** and **necrosis**, which explains why the observations of these different phenomena are grouped. The links between the propagation of diseases and environmental conditions are still poorly understood, even though the connections between certain diseases and anthropogenic pressures have already been confirmed.

Parameters for soft corals and other categories of organisms attached to the substrate

The **zoantharians, corallimorpharians, sponges, gorgonians** and **octocorallians** are organisms that compete with corals for living space, particularly when environmental conditions decline. They are also potential indicators of degraded water quality. For example, certain sponges, such as the *Cliona*, can resist increases in organic matter and develop when the pressure grows. The same would appear to be true for zoantharians and corallimorpharians in the Caribbean, and for octocorallians in the Indian Ocean when the waters have high concentrations of suspended matter.

Moving organisms and other indicators

The pressures exerted by herbivory and predation, respectively on algae and corals by **sea urchins and fish**, structure the compartments of reef benthos. In the event significant changes take place in these biotic interactions, the functioning and structure of reef communities may be severely disturbed. For example, if excessive numbers of herbivores are caught, the development of macroalgae may be encouraged. In this particular example, the resulting development is not due to a change in water quality, a fact that illustrates the value of monitoring these major compartments in order to distinguish between indirect pressures and local, direct pressures. However, measurement of these aspects would severely complicate the protocols and their inclusion for WFD purposes must still be discussed, particularly as concerns fish.

Two parameters were initially designated as Level 3, namely the Foram index and the Coral health index (CHI). In the end, however, the Foram index was not selected, primarily due to the high level of expertise required in identifying the species, and a decision on the CHI must still be made once the results of the experiments in Réunion in the framework of the Eutrolag programme are available.

Figure 15. Different ecological status conditions in coral reefs in the Indian Ocean, illustrating contrasting situations in terms of several parameters (cover by living Scleractinia, coral categories, necrosis).

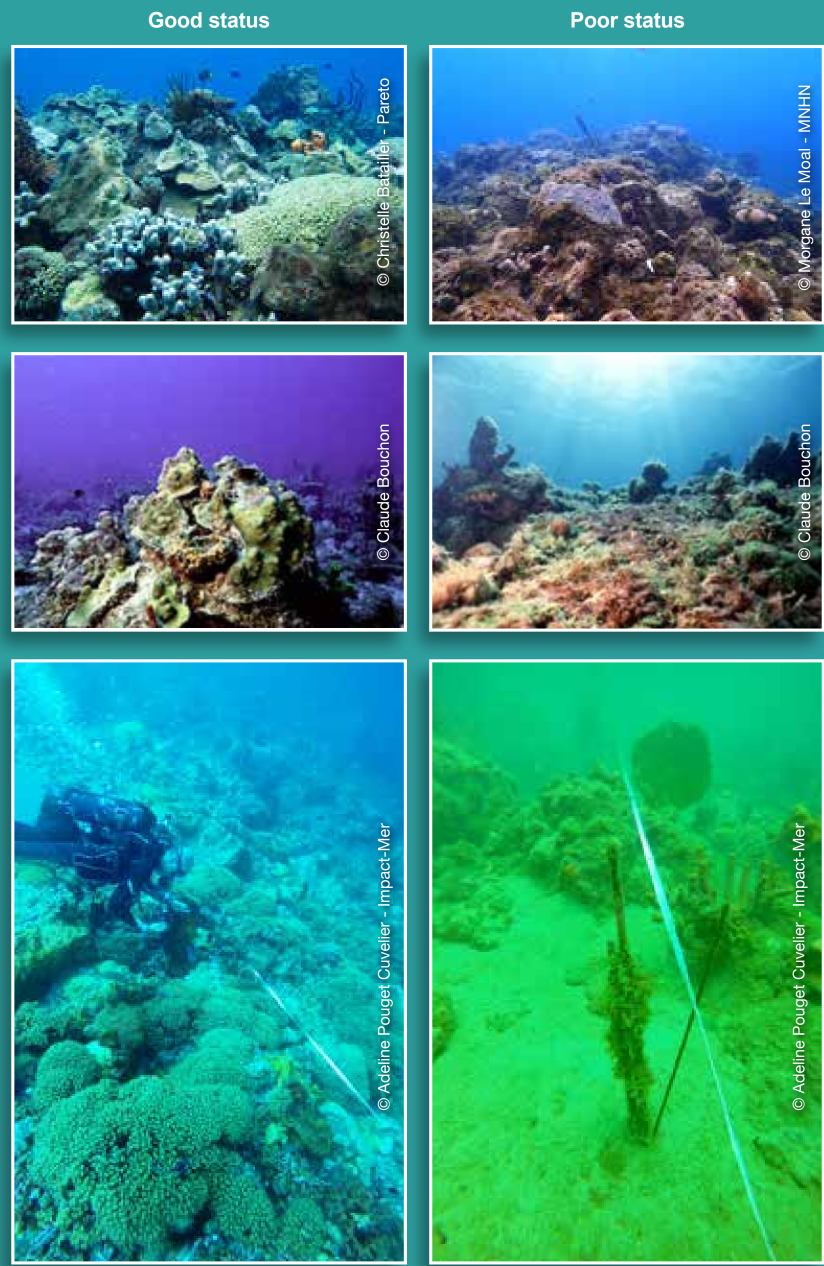

Figure 16. Different ecological status conditions in coral reefs in the Caribbean, illustrating contrasting situations in terms of two parameters (cover by living Scleractinia and by macroalgae).

3.3 - Seagrass, the importance of abundance parameters linked to eutrophication

Parameter selection

There are numerous biological responses of phanerogams to anthropogenic pressures, but similar to coral reefs, there are only a small number of specific responses (Table 6).

Contrary to reefs, seagrass beds have been the topic of many studies addressing the development of bioassessment tools to provide information on water quality, particularly in Europe for WFD implementation. Among the 42 monitoring programmes for seagrass beds and 49 indices identified in 2013 in Europe, 66% and 43% respectively were devoted to DCE implementation (Marba *et al.*, 2013). These programmes focus primarily on mixed beds of *Zostera marina* and *Z. noltii* in the north-eastern Atlantic, the Baltic Sea and the Black Sea, and single-species beds of *Posidonia oceanica* in the Mediterranean (Marba *et al.*, 2013).

Most of these indices are based on a single metric (Marba *et al.*, 2013). A few multimetric indices have been developed, primarily in the Mediterranean, by testing a number of parameters along pressure gradients and selecting those best correlated to changes in water quality. A partial list of these indices with the selected parameters is presented in Table 7. Outside of Europe, seagrass beds are used as bioassessment tools for water quality, e.g. in the programmes to monitor water status on the Great Barrier Reef in Australia and in certain coastal regions of India (McKenzie *et al.*, 2012; Arthur *et al.*, 2008, Table 7). Parameter selection is generally based on expert opinion.

All the parameters selected for these indicators were reviewed and discussed. A total of 18 parameters

Table 6. Biological responses of phanerogams to anthropogenic pressures. *According to Martinez-Crego* et al., *2008.*
( ): number of publications referring to the type of biological response N: nitrogen; P: phosphorous; C: carbon; OM: organic matter; dC13, dN15: carbon and nitrogen isotopes.

Biological complexity	Parameters	Number of species			
		Less light	Nutrient inputs	OM / anoxia	Physical / sedimentation
Physiology / biochemistry	N, P levels	↑ (4)	↑ (9)		
	Amino-acid levels	↑ (1)	↑ (6)		
	C and carbohydrate levels	↓ (6)	↓ (3)	↓ (1)	↓ (1)
	dC^{13}	↓ (3)		↓ (1)	
	dN^{15}		↑(6) ↓(4)		↑ ↓ (1)
Individuals	Morphological parameters	↓ (7)↑(1)	↑ ↓ (7)	↓ (2)	↓ (3)↑(1)
	Necrosis		↑ (2)	↑ (1)	
Population	Density, cover	↓ (6)	↓ (3)	↓ (2)	↓ (9)
	Type of rhizome growth				↑ (2)
	Baring of rhizomes				↑ (4)
Community	Epiphyte biomass	↓ (4)	↑ (10)		
	N, C levels in epiphytes	↓ (1)	↑ (1)		
	Herbivorous pressure		↑ (4)		

Table 7. Partial list of multimetric indices for seagrass beds developed to assess the ecological status of coastal water bodies in various bioregions.

Bioregion	Index and reference	Parameters
Mediterranean	*Posidonia oceanica* Multivariate Index (POMI), Romero *et al.*, 2007	N, P levels, sucrose, dN^{15}, dS^{34}, % necrosed leaves, leaf surface areas, cover, density, % subsurface rhizomes, N level in epiphytes, metals
	Martinez-Crego *et al.*, 2008	P level, asparagine, serine, sucrose, dS^{34}, % necrosed leaves, type of rhizome growth, cover, density, metals
	Valencian ECS, Fernandez Torquemada *et al.*, 2008	Ratio of bared/buried rhizomes, leaf surface areas, % necrosed leaves, density, % subsurface rhizomes, % dead plants, cover, herbivores, epiphyte biomass
	Posidonia oceanica Rapid Easy Index (PREI), Gobert *et al. in* MEDDE, 2013*	Leaf surface areas, density, depth and type of lower limit, epiphyte biomass
	Cymodocea nodosa index (CYMOX), Oliva *et al.*, 2011	N, P levels, dN^{15}, dS^{34}, canopy height, root biomass, epiphyte biomass, metals
North-eastern Atlantic	Auby & Jeanneret in MEDDE, 2013*	Surface area, density, species richness
Tropical Indo-pacific region	McKenzie *et al.*, 2012	Leaf C:N:P ratios, epiphyte abundance
	Arthur *et al.* in prep.	N, P levels, leaf morphometrics, necrosis, density, cover, depth of lower limit, distance between rhizomes, metals

**Indices adopted in continental France.*

were subsequently recommended (Table 8):

• eight were deemed useful for water-quality assessments and were designated as Level 1 or 2;

• seven were listed as additional parameters, potentially related to water quality;

• three were listed as additional parameters capable of explaining ecosystem evolution.

The following paragraphs present the parameter-selection criteria in general terms, with illustrations in Figures 17 and 18. Integration of **macroalgae** in the angiosperm index, recommended for the reef-benthos indices as well, is discussed in detail in section 3.4.

Table 8. Parameters recommended for WFD monitoring of seagrass beds in the OSTs and their theoretical response to a pressure.
L1: useful parameters for the WFD that should be easily integrated in an index;
L2: parameters apparently useful for WFD purposes and that will probably be included in an index once their usefulness has been confirmed after five years of data acquisition;
ADD: additional parameters that will not be integrated in bioassessment tools, but that may provide information to assist in interpreting the influence of the natural variability and of the pressures; ^{C}: Caribbean, ^{M}: Mayotte

L1 and L2 parameters	Nutrient inputs	Increased turbidity	Increased sedimentation	Physical destruction: moorings, trampling, etc.
Cyanobacteria cover (L1)	↗	Not useful	Not useful	Not useful
Macroalgae cover (L1)	↗	↘	↘	↘
Macroalgal taxa (L2)	↗ ↘	↗ ↘	↗ ↘	Not useful
Phanerogam cover (L2)	↗ ↘	Not useful	↘	↘
Bed fragmentation (L2)	?	?	↗	↗
Phanerogam species composition (L2)	↗ ↘	↗ ↘	↗ ↘	↗ ↘
CNP levels in phanerogam tissue (L2)	↗*	Not useful	Not useful	Not useful
Morphs of certain phanerogams (L2 ^{M})	?	?	?	Not useful
Epibiosis, (N2 ^{M} ADD ^{C})	↗	↗	↗	Not useful
Additional parameters				
Related to water quality	Flowering, premature senescence, baring of rhizomes, corals, bed surface area, sediment analysis			
Explanatory parameters	Sea urchins, megafauna, bioturbation			

**Depends on the selected metric.*

Figure 17. Different ecological status conditions in seagrass beds in the Caribbean, illustrating contrasting situations in terms of several parameters (phanerogam, cyanobacteria and coral cover, phanerogam species composition).

Figure 18. Different ecological status conditions in seagrass beds in Mayotte, illustrating contrasting situations in terms of several parameters (phanerogam cover and species composition, cyanobacteria cover).

Details on the parameters selected for indices

Phanerogam cover, bed fragmentation and **surface areas** are parameters providing information on the occupation strategies of seagrass beds. They are likely to change under the pressure of environmental modifications linked to human activities. The phanerogam species composition in these beds can also change in response to similar pressures, for example certain species such as *Thalassia testudinum* in the Caribbean are in some cases more sensitive than others. The development of **epibiosis**, **premature senescence** or morphological alterations such as **dwarfism** are potential indicators of declining water status, whereas the **baring of rhizomes** may be due to physical pressures related to boating or fishing (mooring, dredging).

Conversely, observations of **flowering phanerogams** or of certain species of **coral** within seagrass beds may be a sign of pristine waters. The absence of flowering plants or of corals cannot however be interpreted as a sign of poor water quality, except for corals in cases where they have disappeared from a site between two monitoring inspections. Measurement of **CNP levels (carbon, nitrogen, phosphorous) in phanerogam tissues** is recommended, as is already the case in monitoring programmes for water status on the Great Barrier Reef and in coastal waters in India. This would appear to be one of the rare parameters capable of responding specifically to pressures such as nutrient inputs. It is also relatively easy to measure and inexpensive compared to other responses measured on the physiological level. Grain-size analysis of sediment samples should be a means of measuring changes in the impact of the land and more precisely of the terrigenous inputs.

Additional parameters to understand ecosystem evolution

Herbivorous pressures are caused primarily by **sea urchins** in the Caribbean and by **megafauna** in Mayotte. Even though this parameter is not directly related to water quality, monitoring of this pressure is deemed essential to understanding the changes in these ecosystems, notably in Mayotte where feeding by green sea turtles is one of the main factors determining the structure of the beds. **Bioturbation** is another parameter not directly related to water quality, however it provides information on bed fragmentation, particularly in Mayotte.

Numerous parameters were not selected. For example, the density and height of the canopy are measured in monitoring programmes for the nature reserves, but they were not selected for WFD monitoring because the *in situ* measurements are very time consuming and the links with changes in water quality are not particularly clear. Concerning biomass calculations, they depend too closely on herbivorous pressures, notably in Mayotte. They also require invasive techniques and are time consuming.

3.4 - Integration of macroalgal parameters

Macroalgae can be good indicators of the ecological status of water bodies, particularly in terms of eutrophication pressures. That explains why they are widely used in Europe for WFD purposes (Table 9) in spite of a certain complexity (strong, natural variations, high level of taxonomic expertise required, etc.). The approaches developed in Europe to manage these difficulties may be of great use in developing indices for tropical zones and have been analysed by the work group (Le Moal & Payri, 2015).

Parameters used in European indices

Analysis of cover rates and the species richness of **perennial species** compared to those of **opportunistic species** constitutes a fundamental element in all the indices proposed in Europe (Table 9). This is because local, anthropogenic disturbances are known to cause shifts in ecosystems from a preserved condition where perennial species dominate in the climax stage of ecological succession to a degraded state where opportunistic, annual species dominate (Orfanidis *et al.*, 2011). **Species richness** itself is widely used (Table 9) because it is considered a more suitable metric to measure ecological change than **species composition**, given that it is less subject to natural variations (Wells *et al.*, 2007). This is because species richness would seem to be relatively constant in an undisturbed environment whereas the species composition of an algal community undergoes significant, natural changes over time. A **high level of expertise** is required to identify all the species present, however it is not always available. That is why **reduced species lists** have been proposed (Wells *et al.*, 2007; Juanes *et al.*, 2008; Neto *et al.*, 2012; Ar Gall & Le Duff *in* MEDDE, 2013). The species richness and distribution of algal communities also varies as a function of the **morphology of rocky shores**. To filter out this natural, geomorphological variability, a description of the shore morphology is included as a corrective factor in a number of indices (Wells *et al.*, 2007; Ballesteros *et al.*, 2007; Neto *et al.*, 2012, Table 10). The **spatial representativeness** of samples is also a crucial point in developing bioassessment tools. In the Mediterranean, the Carlit (*Cartografía litoral*) method proposes a different approach than diving on monitoring points.

This method uses a boat to map, for each coastal section of each water body, the communities on rocky substrates that are dominated by macroalgae (Ballesteros *et al.*, 2007, Table 9). In all of the indices listed below, the species lists and the thresholds for shifts in the ecological status are based on vast amounts of information available in the literature and on the analysis of generally quite extensive data series, plus expert opinion in some cases (Le Moal & Payri, 2015).

Table 9. Partial list of multimetric indices for macroalgae, developed in Europe for WFD assessment of the ecological status of coastal water bodies.

Bioregion	Index and reference	Metrics
Mediterranean	**Ecological evaluation index** (EEI) Orfanidis *et al.*, 2001, 2003, 2011	Cover by perennial species, cover by opportunistic species
	Benthos Index Pinedo *et al.*, 2007	Description of the community (e.g. a community dominated by *Cystoseira mediterranea*, a community dominated by green algae, etc.)
	Littoral community cartography * (Carlit) Ballesteros *et al.*, 2007 Thibault *in* MEDDE 2013	Length of coast of each geomorphological type, length of coast for each community, each geomorphological type and the sensitivity of communities
North-eastern Atlantic	**Reduced Species List** (RSL) Wells *et al.*, 2007	Species richness, % Rhodophyta, % Chlorophyta, % opportunistic species, perennial/opportunistic species ratio, geomorphology
	Quality of Rocky Bottom (CFR) Juanes *et al.*, 2008	Species richness, cover by characteristic species, cover by opportunistic species, physiological status
	Marine macroalgae assessment tool (MarMAT) Neto *et al.*, 2012	Species richness, geomorphology, % Chlorophyta, number of Rhodophyta species, opportunistic/perennial species ratio, % opportunistic species, cover by opportunistic species
	Macroalgae on hard substrates in the intertidal zone * Ar Gall & Le Duff *in* MEDDE, 2013	% of plant surface area per vegetation zone, number of characteristic species, % cover by opportunistic species per zone
	Macroalgae on hard substrates in the subtidal zone * Derrien-Courtel & Le Gal *in* MEDDE, 2013	Lower limits (depth) of different algal zones, density of algal species determining staging, number of characteristic algal species representing > 10%, density of opportunistic algae, presence of algal species indicative of good ecological status, total algal species richness, average length of *Laminaria hyperborea* stipes, surface of *Laminaria hyperborea* covered by epibionts
	Macroalgae blooms * Rossi & Dion *in* MEDDE, 2013	Maximum % of colonisable surface area covered by green algae, average % of colonisable surface area covered by green algae, frequency of blooms

** Indices and metrics selected for WFD implementation in French coastal waters.*

Integration of macroalgae in the OSTs

To date, there are no WFD tools based on macroalgae in the OSTs. However, given their frequency in the coral-reef and seagrass ecosystems, it was decided to integrate macroalgae in the coral-reef and seagrass bioassessment tools currently being developed. Unfortunately, there is far less available knowledge on the ecology and the functioning of the tropical, marine ecosystems in the OSTs than on the ecosystems in Europe. When the group of experts started its work in 2012, even the lists of species for certain OSTs, e.g. Guadeloupe and Mayotte, were incomplete. It was in this context that a five-day mission was undertaken in Guadeloupe in October 2014 to visit 14 coral-reef and seagrass monitoring points, most of which belonged to the WFD monitoring network (Le Moal & Payri, 2015, Figures 19 and 20). The objective of the mission, organised by MNHN with IRD, Pareto and the University of the Caribbean, was to inventory to main algal communities growing together with the coral reefs and the seagrass beds.

Results of the Guadeloupe mission

The mission results made it clear that, in spite of the limited information available on macroalgae in the OSTs, it was possible to begin with the integration of macroalgae in WFD monitoring by simply **identifying the plants down to the genus** and by grouping them in three main categories, namely perennial, seasonal and opportunistic algae.

Perennial algae constitute an important functional group that is naturally present in undisturbed tropical waters. Examples of perennial algae among the green algae are the Bryopsidales with the genuses *Caulerpa, Halimeda, Udotea, Penicillus* and *Avrainvillea* particularly frequent in rocky and sandy coastal habitats, among the red algae are the Nemaliales with the Galaxauraceae family in which the

Figure 19. Identifying the communities of macroscopic algae among the coral reefs and seagrass beds in Guadeloupe (2014).

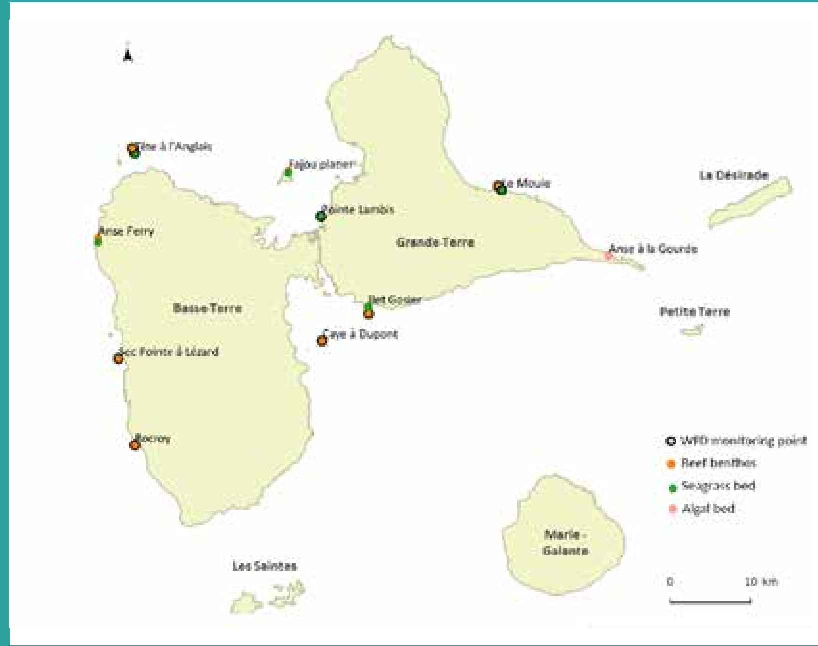

Figure 20. Monitoring points visited during the macroalgae mission to Guadeloupe in 2014.

genuses *Galaxaura* and *Dichotomaria* are relatively abundant and diversified, and finally among the brown algae are the Sargasses (Fucales) and certain Dictyotales of which the *Dictyota* genus has a particularly high number of species.

These algae are a common fixture in reef seascapes and their disappearance or abnormal proliferation would be a problem potentially indicative of local, anthropogenic pressures (Figures 21 and 22, p. 54 and 55).

Seasonal algae are epiphytes in some cases and may serve as an indication of water quality. As their name indicates, these algae have a seasonal development cycle during which the morphological phase is not visible part of the year. This makes it more difficult to include these species in annual monitoring programmes, except perhaps if they are monitored only during their growth season. Filamentous red algae such as *Dasya* or *Spyridia*, the Liagoraceae family and certain Dictyotales, etc. fall under this category (Figures 21 and 22).

Opportunistic algae are not sensitive to disturbances, on the contrary, they are tolerant. Their presence may indicate anthropogenic pressures, e.g. nutrient inputs. This category is represented notably by the Ulvales, Cladophorales, Chaetomorphales, etc. (Figures 21 and 22).

The list above may be improved and quality classes may be proposed on the basis of the data acquired during the initial years of WFD monitoring. A number of missions to inventory species have taken place recently or will take place soon in the Caribbean, e.g. the Karubenthos mission in the spring of 2013 in Guadeloupe and the Madibenthos mission in the fall of 2016 in Martinique, organised by

Figure 21. Algal communities observed on reefs in the Caribbean. Perennial (A: *Dichotomaria*; B: *Amphiroa*; C: *Halimeda, Caulerpa, Dictyota*; D: *Amphiroa, Dictyota*), seasonal (E: *Dasya*; F: *Liagoracea*) and opportunistic algae (G: filamentous green algae).

MNHN, and the Pacotilles mission by IRD in April 2015.

The results of these missions will also serve to improve the lists of species. In Réunion, the Eutrolag study already provided an initial reduced list of species that could be used for WFD monitoring (Zubia *et al.*, 2012).

Figure 22. Algal communities observed on seagrass beds in the Caribbean. Perennial (A: *Avrainvillea* and *Halimeda*; B: *Caulerpa prolifera*, *C. ashmediea* and *Amphiroa*; C: *Dichotomaria obtusata*; D: *Galaxaura subverticillata*), seasonal (E, F: Liagoraceae) and opportunistic algae (G, H: filamentous green algae).

More study required on macroalgal indices

Macroalgae are present in reef and seagrass ecosystems, but they also form their own ecosystems and biotopes, called algal beds. Prime examples are beds of Sargassum and beds of the *Halimeda* genus of green algae on soft substrates. The question arose as to the utility of developing a specific macroalgal index as is the case in Europe. Theoretically, a macroalgal index should be capable of assessing the ecological status of water bodies in the OSTs, similar to the situation in continental France. But pragmatically speaking, it is first necessary to determine the usefulness of the BQE in the OSTs and the feasibility of developing such an index. Outside the algal beds on the Atlantic coast of Martinique, are there any other ecologically significant algal beds in the OSTs and, if yes, in which types of water bodies and to what degree? To what degree would a macroalgal index compensate for the insufficiencies of other BQEs in the "aquatic flora other than phytoplankton" compartment? Would this type of index replace reef-benthos indices if the corals disappeared locally and there was no hope of restoration (phase shift), a potential situation foreseen by the most pessimistic scenarios?

The group of experts is of the opinion that the managers must first answer these questions before it is possible to make a coherent proposal on the need (or lack thereof) to develop macroalgal indices for the OSTs.

3.5 - Summary on the parameters selected by the group of experts for reef benthos and seagrass indices

Following an examination of the many existing biological responses, an assessment of the theoretical response to pressures and an evaluation of the operational ease of implementation, 16 parameters were selected for the development of WFD bioassessment tools for reef benthos and 18 for seagrass. A "relevance" level taking into account all the above criteria was assigned to each of the selected parameters, given that relevance can vary from one bioregion to another.

For reef-bentos monitoring, six parameters capable of informing on water quality are recommended:
- Scleractinia cover;
- macroalgae cover;
- macroalgal taxa;
- coral taxa;
- presence of octocorallians and zoantharians, in the Indian Ocean;
- presence of corallimorpharians, in the Indian Ocean.

In addition, five parameters that may be related to water quality and five parameters informing on ecosystem changes may also be taken into account, particularly during the development phase of the indices (Table 5).

For seagrass monitoring, eight parameters are considered useful in terms of the information provided on water quality:
- cyanobacteria cover;
- macroalgae cover;
- phanerogam cover;
- macroalgal taxa;
- phanerogam species composition;
- bed fragmentation;
- CNP (carbon-nitrogen-phosphorous) levels in phanerogam tissues;
- morphs of certain phanerogams and epibionts for Mayotte.

Seven parameters are ranked as additional parameters and potentially linked to water quality, while another three parameters are ranked as additional, explanatory parameters (Table 8).

CHAPTER 4

Protocols suited to local situations

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4.1 - To what extent should the OSTs have a joint approach?

Intercalibration not mandatory for status thresholds in OSTs...

The EU Member States coordinate their indices via a process of intercalibrating the good and high status thresholds using the same metrics. This work is done by different geographic intercalibration groups (GIG) corresponding to the large biogeographic regions. The objective is to ensure that assessment results are comparable between the Member States (Reyjol *et al.*, 2013). Intercalibration is not mandatory for the ultra-peripheral regions (UPR) of Europe, however the status thresholds must be consistent from one OST to another, in other words they must correspond to equivalent levels of impacts by pressures. That is why the group of experts attempted to ensure consistent approaches in defining the parameters used. Protocol selection, on the other hand, depends primarily on the local situation and on the means available in each OST. A shared approach in this aspect is not essential.

... but consistency in OST approaches is required

However, general recommendations have been issued on sampling reef benthos and seagrass. Monitoring should be carried out annually, if possible during the transitional period between the dry and wet seasons, ideally in June in the Caribbean and in November in the Indian Ocean. The environmental conditions such as the weather, currents and tides at the time of monitoring should be mentioned. Ideally and notably during the development phase of the indices, monitoring should be carried out by the same people from one year to the next to ensure the quality of the data. If that is not possible, it is essential that the protocols be correctly transmitted. Effective, operational deployment of bioassessment tools also depends on the protocols being easily reproducible. Selection of a sampling point (Figure 23) should be confirmed by an expert and the point itself should be representative of a sector, i.e. a geographic unit that is consistent in terms of its geomorphology, environment (climate and oceanographic aspects) and of the human activities that take place in that sector.

For WFD purposes, a sector and a water body may be considered the same thing. It is advised to set up long-term transects on monitoring points in order to reduce any spatial variability. Transects should be clearly identified by stakes planted at each end.

The next two sections present in general terms the protocols proposed for reef benthos and seagrass beds.

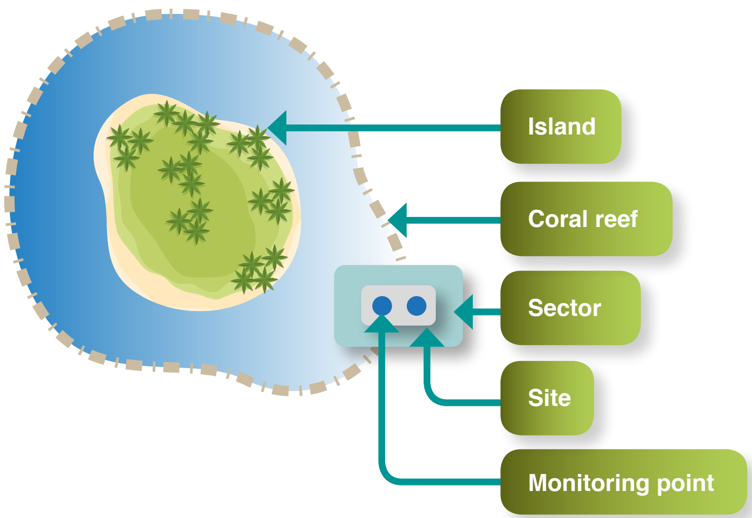

Figure 23. Sector, site and monitoring point. *According to Conand* et al.*, 1997. A sector is a geographic unit that is consistent in terms of its geomorphology, environment (climate and oceanographic aspects) and of the human activities that take place in that sector. For WFD purposes, a sector and a water body may be considered the same thing. A site is a geographic unit used to characterise a sector. A monitoring point is a reference area used for measurements, where transects and quadrats are established.*

4.2 - Reef benthos, different protocols for different OSTs

Maintaining continuity with past monitoring results in Réunion and the Caribbean

In the Caribbean and Réunion, reef-benthos monitoring will be carried out on specific sites, along transects (Figure 27, p. 65). In order to maintain continuity with the existing, local data series, the parameters will be measured using the point intercept transect (PIT) method in the Caribbean and the line intercept transect (LIT) method on Réunion (Box, p. 63). In these three OSTs (Guadeloupe, Martinique, Réunion), the measurements will be filled out with data acquired from belt transects. The lengths of the sampling units must be rigorously determined on the basis of past monitoring or by running tests.

Typology and methods adapted to the local situation in Mayotte

In Mayotte, monitoring will be carried out on the fringing reefs which would seem to be less sensitive to bleaching than the barrier reefs and are more directly exposed to local, anthropogenic impacts. The quadrat method using a glass-bottom boat is recommended. It can be used to monitor long distances along coasts, which makes it the solution best suited to integrate the high degree of natural, spatial variability (plasticity) of Mahoran fringing reefs (Figure 24, next page). This method is also well suited to the human and logistic resources and means available on site.

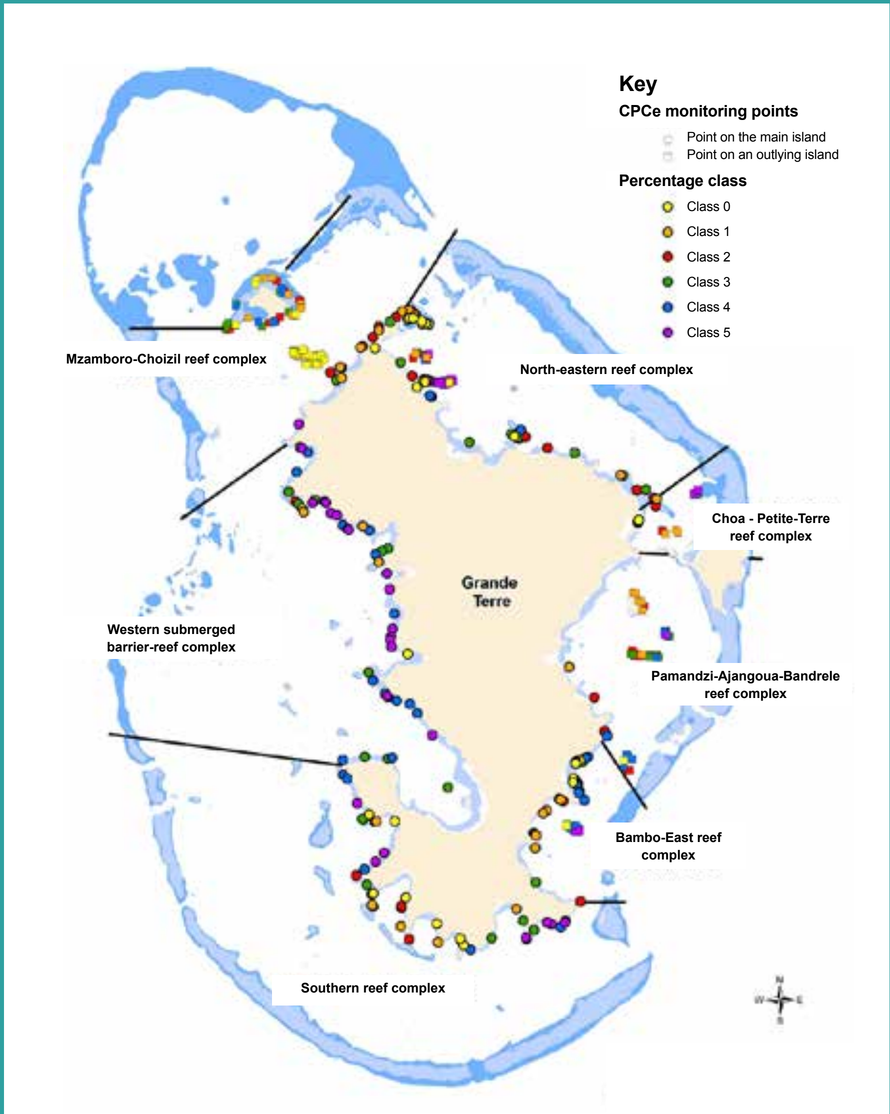

Figure 24. Spatial variability of coral cover in the fringing reefs of Mayotte (photographic campaign 2012). *According to Pareto, 2013.*
CPCe: Coral Point Count with Excel extensions (Box, p. 63); percentage of living coral: 0: 0%; 1: 0-5%; 2: 5-20%; 3: 20-50%; 4: 50-80%; 5: > 80%.

Monitoring methods for benthic communities

Both methods, PIT (point intercept transect) and LIT (line intercept transect) measure, along a transect in the form of a graduated tape, the cover rate of the benthos, i.e. the organisms identified in taxonomic groups or by their species, and the substrate. For the LIT method, each change in the benthos along the transect is noted, whereas for the PIT method, the operator notes the objects encountered at predetermined distances or points along the transect (Figure 25).

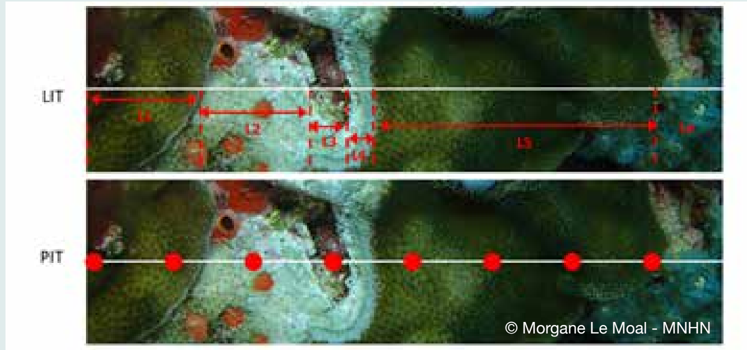

Figure 25. The LIT (line intercept transect) and PIT (point intercept transect) methods.

The **belt** transect method consists of noting all the target organisms within a given surface area, generally a band or belt between 0.5 and 1 metre wide on both sides of a transect (a tape).

A glass-bottom boat can be used to take **quadrat photographs** of the benthic communities. The photographs can subsequently be analysed using software such as the Coral Point Count with Excel extensions (CPCe), which randomly positions the points under which the benthos should be identified (Figure 26).

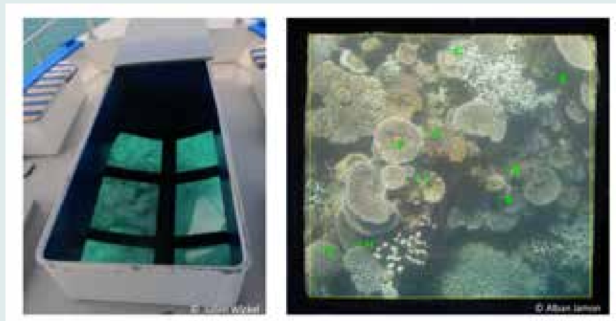

Figure 26. Boat with a glass bottom and a quadrat photograph.

4.3 - Seagrass, a similar protocol for all the OSTs

Hyperbaric and free diving as survey methods

In the Caribbean and Mayotte, seagrass monitoring will be carried out on specific sites, along transects, with in addition a “random itinerary” (Figure 27). In this manner, the monitored area is adapted to the natural heterogeneity of the seagrass beds and the protocol takes into account a number of local, operational constraints. In the Caribbean, hyperbaric diving techniques are used and it must be possible for two people to monitor a given site during a single dive. In Mayotte, the great difference between high and low tide levels makes it possible during low tides to monitor the intertidal seagrass beds using simply a mask, tuba and flippers. Mayotte works closely with the Mohéli marine protected area in the Comoros in the framework of joint conservation measures and must propose a protocol that has been agreed upon on the regional level.

Data acquisition using the transect method

The minimum number of transects per site is three, however this number may be increased for highly fragmented beds. In the Caribbean, the length of transects is set at 50 metres whereas in Mayotte, it is equal to the width of the beds (perpendicular to the shore), which on average is 145 metres. It is recommended to measure the parameters annually (with the exception of surface areas which can be done every six years) using aerial photos, satellite images or a boat with GPS, depending on the situation for each bed and the locally available means.

Feedback to improve the protocols

Generally speaking in the OSTs, there is less project feedback on seagrass monitoring than for coral-reef monitoring. The protocol proposed by the group of experts is iterative in nature. Operational implementation will be refined and adapted in response to the local feedback and taking into account the initial data acquired via the WFD monitoring networks. At the same time, the links created with the seagrass section of the Ifrecor project (an observation network cross-cutting topic) will serve to discuss the various protocols used and to make progress on their operational implementation. One of the main objectives of the seagrass section is to establish an integrated monitoring protocol, i.e. a “protocol toolbox” to unify the approaches of the various monitoring programmes and to make progress toward the use of similar protocols for the joint parameters.

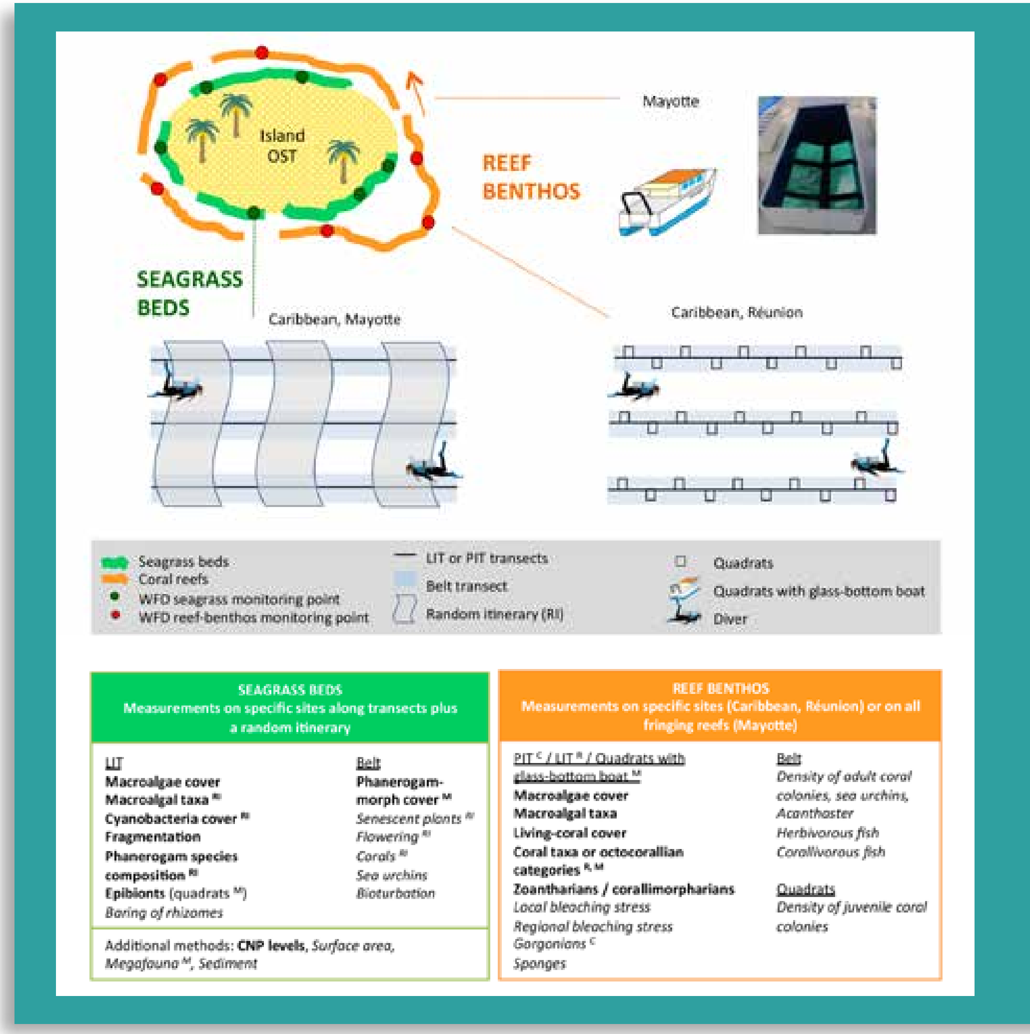

Figure 27. Monitoring protocols for reef benthos and seagrass beds.
Level 1 and 2 parameters are shown in bold type (they will likely be included in the indices, see Chapter 3), the additional parameters are shown in italic; C: Caribbean; R: Réunion; M: Mayotte; RI: random itinerary.

4.4 - Conclusion. Shared parameters, but protocols adapted to local situations

The work group made an effort to ensure consistency between the approaches in the different OSTs by drafting a uniform list of parameters for coral-reef and seagrass monitoring, but concerning the protocols, it was decided to adapt their selection to the local situations and to the available means in each OST.

Consequently, for reef benthos in the Caribbean and Réunion, monitoring will be carried out on specific sites along transects, whereas in Mayotte, all the fringing reefs of the island will be monitored using the quadrat method and a glass-bottom boat.

For seagrass in the Caribbean and on Mayotte, monitoring will be carried out on the specific sites, along transects, with in addition a random itinerary. But in the Caribbean, where the difference between high and low water levels is slight, hyperbaric diving techniques will be used, and in Mayotte, the intertidal beds of seagrass will be monitored using simply a mask, tuba and flippers.

CHAPTER 5

Different methods to define ecological-quality criteria

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5.1 - An assessment of the data for an optimum strategy

It is necessary, for each selected biological parameter and metric, to establish quality criteria indicating the impact levels of pressures on the ecological status (pressure-impact and/or pressure-status models). The first step is to determine a reference state (Box, p. 71) corresponding to undisturbed ecological conditions, then set threshold values for the various ecological status levels. It is critically important to determine the values of the biological parameters under the reference conditions because the values measured in the field for each biological parameter will be compared to these reference values. The results are expressed as Ecological quality ratios (EQR = observed values / reference values).

Hill *et al.* (2012) recently assessed the robustness of the various strategies used to determine the reference conditions in marine environments.

These reference conditions may be defined, in order of preference, on the basis of:

- **existing monitoring points in reference zones;**
- **historical data;**
- **modelling;**
- **expert opinion** or by combining some or all of the above.

In the OSTs, where very small quantities of current or historical data are available, the most effective approach to establish pressure-status relationships may consist of combining several of these sources in order to mobilise all the available data and expert opinion (Monnier *et al.*, 2016, Figure 28).

With that objective in mind, the work group attempted to locate all the available sources of data and to list the projects in each OST, in order to devise the best strategies over the short to mid-term to set the quality criteria.

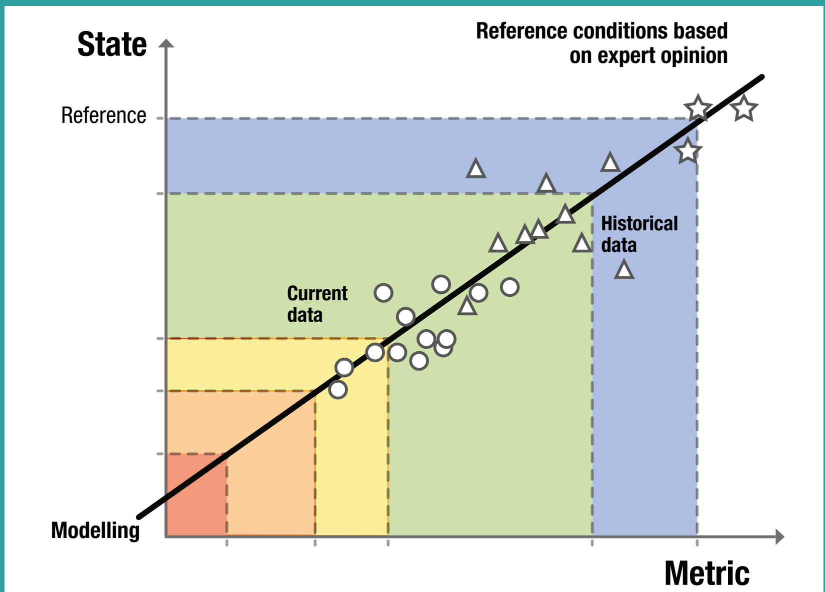


Figure 28. Theoretical approach to setting up the ecological-quality criteria in the OSTs, given the lack of available data. *Source: Monnier* et al., *2016.*

Bad status *Moderate status* *High status*
Poor status *Good status*

Different reference states for different issues

The **pressures** targeted by the WFD are local, anthropogenic pressures producing a direct impact on ecosystems, e.g. for seagrass and coral reefs, nutrient inputs, increased turbidity and sedimentation, physical disturbances caused mooring of boats or dredging, etc. These ecosystems are also subjected to other types of direct and indirect pressures such as cyclones and increased water temperatures, factors that may be amplified by global warming, excessive capture of herbivorous animals or of the organisms that feed on coral (corallivores).

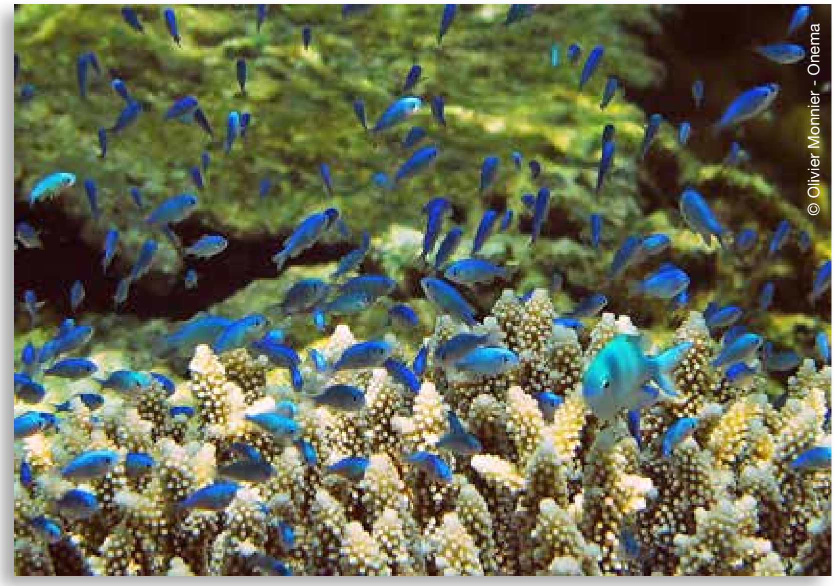
In the WFD framework, a **reference state**, whether currently observable or modelled, is likely to shift over time in step with the long-term changes in natural conditions. It corresponds to a state in which the anthropogenic pressures are negligible, however it is not necessarily a state in which other types of pressures are absent, e.g. pressures capable of causing lasting environmental change on a large geographic scale. A WFD reference state does not necessarily correspond to the reference conditions for other issues, e.g. nature conservation. Certain activities that are not harmful to a good or high water status in the WFD context may be damaging to other objectives in other fields.

5.2 - Reef-benthos quality criteria, differences among the OSTs

Useful historical data in the Indian Ocean, but not in the Caribbean

The coasts of the OSTs are impacted by many anthropogenic pressures and there no longer exist any undisturbed areas that could serve as reference sites. It would also appear difficult to find undisturbed areas even by widening the search to the region as a whole. In the Indian Ocean, the coral island Juan de Nova, in the Mozambique Channel, and certain reefs in the Chagos archipelago, for example, are still preserved from local, anthropogenic pressures, but according to the work group, the reef habitats are too different from those of Mayotte or Réunion to be of any use as WFD reference sites. In the Caribbean, the Yucatan reefs or some Cuban reefs would appear to be preserved from most anthropogenic disturbances, but it would be difficult to confirm these suppositions and the cost of carrying out measurements on-site would be excessive.

The idea of using historical data to define the reference states was put forward due to the changes in ecosystem status thought to have occurred in response to the significant increase in anthropogenic pressures over the past centuries and particularly over the past decades. For the coral reefs, the work group agreed that only the data acquired prior to 1990 may be considered historical data and potentially used in defining reference states (the members were nonetheless aware that certain environments had already been impacted by anthropogenic pressures prior to 1990). Such data exist for Réunion, where numerous studies carried out in the beginning of the 1970s described a relatively well preserved environment, just before economic development and population growth took off on the island (Faure & Montaggioni, 1970; Pichon, 1971; Faure, 1982; Tourrand *et al.*, 2013). The same is true for Mayotte where, following initial observations in 1959 (Guilcher *et al.*, 1965), extensive data on the fringing reefs were acquired in 1989-1990 (Durand & Thomassin, 1992), before the population of the island underwent exponential growth and the local economy was significantly modified.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In the French Caribbean, no historical data of any use for coral reefs exist. The first data sufficiently detailed for WFD purposes were collected in the beginning of the 1980s (C. Bouchon, per. com.), at a time when the marine environment had already been subjected to major anthropogenic pressures and the signs of degradation were already obvious. On the regional level, it would be worthwhile to contact the International Union for the Conservation of Nature (IUCN) or researchers in the Caribbean to see if older data exist.

In the four island OSTs, “current” data (as opposed to historical) have been collected since the end of the 1990s at the monitoring points of the global coral reef monitoring network (GCRMN). In Mayotte, monitoring campaigns were also carried out on the fringing reefs in 1997, 2004 and 2012. In Réunion, the outer reefs (fore reefs) were monitored in 2009 using the Medium Scale Approach (MSA).

Collective expertise in defining the ecological-quality criteria

In the Indian Ocean, the work to define the quality criteria has started. In Réunion, in the framework of the “Good status” project to define the good ecological and chemical status of water and the work by the local WFD group for benthos on hard substrates, an initial index for monitoring the outer reefs has already been produced (GT Benthos substrat dur, 2014). Analysis of the historical and more recent data, in conjunction with expert opinion, was used to set reference values and thresholds for shifts between ecological-status levels for six metrics (Table 10, p. 74). A similar approach has been adopted in Mayotte since 2014 by the local work group for littoral waters, whose objective is to define the bioassessment methods and the monitoring networks required to meet the requirements of both the WFD and the marine nature park (Pareto, 2014). Less progress has been made in the Caribbean where a local work group does not even exist yet. However, criteria have nonetheless been proposed for two metrics (Impactmer & Pareto, 2012, Table 10) on the basis of bibliographical research and analysis of data produced by the WFD monitoring networks, the oldest of which dates back to 2006.

In the Caribbean, there is clearly a need to put things in motion locally, for example by setting up a work

Table 10. Project implemented (in black) and projects that should be implemented over the short (green) and mid (purple) terms to identify the metrics and define the quality criteria for the reef-benthos indicators in the OSTs. *Source: Pareto, 2014.*

The criteria may be defined using historical (H) or current (C) data series, recent research (R) or expert opinion (EX). L1: useful parameters for the WFD that should be easily integrated in an index;
L2: parameters apparently useful for WFD purposes and that will probably be included in an index once their usefulness has been confirmed after five years of data acquisition;
ADD: additional parameters that will not be integrated in bioassessment tools, but that may provide information to assist in interpreting the influence of the natural variability and of the pressures. Only those additional parameters related to water quality are shown in the table (Table 5, p. 39).
C: Caribbean; IO: Indian Ocean; MA: macroalgae; col.: colonisable; GCRMN: global coral reef monitoring network; Eutrolag: programme to characterise eutrophisation of coral reefs in Réunion lagoons; Dypocamp: population dynamics of corals in marine protected areas. The term "Monitored" means that no significant change linked to pressures has been observed to date.

Parameters	Caribbean	Réunion	Mayotte
Macroalgae cover (L1)	**Macroalgae / col. substrate** C (WFD), EX; A (GCRMN), EX	**Upright MA / col. substrate Calcareous MA / col. substrate** H, C, EX	**Upright MA / col. substrate Encrusting calcareous MA / col. substrate** H, EX, C
Macroalgal taxa (L2)	C (WFD), EX	R (Eutrolag), D	EX
Cover by living Scleractinia (L1)	**Living coral / col. substrate** C (WFD), EX; C (GCRMN), EX	**Living coral / col. substrate** H, C, EX	**Living coral / col. substrate** H, EX, C
Coral taxa or categories (L1)	C (GCRMN), EX	**Acropora / non-acropora Branching & table acropora / acropora** H, C, EX	**Acropora / hard coral Table acropora / acropora Branching acropora / acropora** H, EX, C
Octocorallians (Alcyonaria) (L1 IO)	-	**Soft coral / col. substrate** H, C, EX	**Soft coral / col. substrate H** H, EX, C
Corallimorpharians, zoantharians (L2 IO, ADD C)	EX	Monitored	Monitored
Density of adult colonies	EX	C (quadrat photos)	EX, C
Density of juvenile colonies	C (GCRMN), EX	R (Dypocamp)	C, need for EX
Local bleaching, necrosis, diseases	C (GCRMN), EX	R (thesis by M. Séré)	
Gorgonians C	EX	-	-
Sponges	EX	Monitored	Monitored

group. A collective effort is required to define the quality criteria and make progress in acquiring data. Access to the GCRMN data and to the 1980s data would support the work undertaken by the local stakeholders (Table 10) and an effort in this direction was launched in 2014 during the reef-benthos symposium organised by the work group. In the Indian Ocean, the work can focus on developing the criteria for the parameters that are not yet finalised (Table 10).

5.3 - Seagrass quality criteria, based exclusively on expert opinion

For seagrass, the group of experts is of the opinion that reference conditions in the WFD sense no longer exist in the OSTs given that there are no sites not subject to anthropogenic disturbances. For this reason and even though the quality status of certain seagrass beds may seem to be high on the macroscopic level, based on observation of the phanerogams, the experts think that these macroscopic parameters are not capable of truly informing on their ecological status. The assessment must be filled out with measurements on the physiological level or on the community level, for example measurements of CNP (carbon-nitrogen-phosphorous) levels in tissues or integration of any associated fauna and flora. On the regional level, there are most likely in the Caribbean zone beds of seagrass not subjected to the pressures targeted by the WFD, for example the beds in the *Islas de la Bahía* in Honduras. However, the use of reference sites outside of the French territories is not advised by the group of experts because the costs and difficulties in carrying out the work on-site would be excessive and there would be no guarantee of access to the information required on the pressures. On the other hand, if information or data series concerning such sites exist and can be obtained, they might be of use in defining the quality criteria.

Contrary to reef benthos, the beds of phanerogams in the OSTs have not been monitored over long periods and there is no current or historical data available. In Guadeloupe, the data acquired by the national park and the nature reserves are not of use for the WFD because they deal essentially with the “density” and “canopy height” parameters that were not selected by the group of experts for WFD purposes.

This means that the quality criteria for the entire set of parameters must be set exclusively on the basis of expert opinion. Currently, reference sites *stricto sensu* do not exist in the OSTs, but there are sufficiently diverse situations that it is possible to start the work of defining the criteria. Teamwork will be essential in carrying out this project.

5.4 - Conclusion. Consolidation of ecological-status thresholds based on expert opinion

For both coral reefs and seagrass beds, there no longer exist in the OSTs undisturbed sites that may be characterised as reference sites and attempts to identify such sites regionally would appear to be overly difficult or not particularly useful.

Data on coral reefs was collected just before the great upswing in economic and population growth in Réunion and Mayotte, but similar, historical data are not available in the Caribbean. On the other hand, “current” data are available in all four island OSTs. In the Indian Ocean, analysis of the current and historical data, in conjunction with expert opinion, has made it possible to define quality criteria for a number of metrics and several indices are already available. In the Caribbean, there is clearly a need to put things in motion locally and make progress in acquiring data.

Contrary to reef benthos, current and historical data do not exist for phanerogam beds in the OSTs. This means that the quality criteria for the entire set of parameters must be set exclusively on the basis of expert opinion and by studying sufficiently diverse situations. Teamwork will be essential in carrying out this project.


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