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HANDBOOK II

METHODOLOGY FOR SCALING MITIGATION AND COMPENSATORY MEASURES IN TROPICAL MARINE ECOSYSTEMS

MERCI-COR

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1 SCALING ENVIRONMENTAL MITIGATION AND COMPENSATION

1 SCALING ENVIRONMENTAL MITIGATION AND COMPENSATION

The mitigation hierarchy, Avoid, Reduce and Offset (ARO) or Prevent, Minimise, Restore/Compensate and Offset (BBOP & UNEP, 2010; UNEP, 2002) is recommended for all Environmental Impact Assessments. Compensation measures (Figure 1) are to be considered only after all possibilities for impact avoidance and minimisation have been explored. The Reduce and Offset options include elements of risk (as compared with Avoidance) which have to be carefully studied in the early phases of the project, as marine ecological engineering is often complex and costly.

"Restoration of coral reef ecosystems is still in the experimental phase; but today it is possible, under certain conditions, to restore on average 65% of degraded coral reef habitats and salt marshes, and approximately 38% of seagrass beds in tropical areas (Bayraktarov et al., 2015). Mechanically, costs are between 10 to 400 times higher than for terrestrial or wetland ecosystem restoration (Ibid)."

Figure 1: Submersion of artificial reefs made up of blocks of calcareous rocks in compensation for the degradation of coral reefs in Florida (© S. Pioch)

Take, for example, a restoration programme carried out in the Philippines, 20 years ago on 40,000 hectares of mangroves, which succeeded in increasing this habitat by a mere 10%, with an investment of US$ 17.6 million (Samson & Rollon 2008; Lewis, 2009). Scientific literature indicates that surface area is an important parameter, however there is no correlation between sums invested and success; a situation most often observed in terrestrial or continental freshwater ecosystems (Bayraktarov et al., 2016). Common sense and a systematic approach coupled with local and/or contextual knowledge, is extremely valuable in the development of ecological engineering solutions.

"Seagrass mitigation here in Florida has improved over the past 30 years. The biggest difference is we no longer allow seagrass mitigation projects that attempt to plant in bare spots. If seagrasses don't grow there now, there is a good reason for it. If you can find areas where seagrasses once grew, but are no longer present, then identify and correct the reason why they don't grow there now, the odds of successful mitigation are significantly increased. Examples include finding seagrass beds that had been dredged or filled long ago. If the dredged holes or spoil islands are still surrounded by functional seagrass beds, filling the holes or removing the spoil to historic elevations should provide viable seagrass habitat. Ship wakes in lagoons can scour littoral shelves and other shoals, and thereby eliminate seagrass beds. Breakwaters have been used effectively in those settings to stabilize the shallow sediment, and allow seagrasses to become reestablished" Marty Seeling, Florida Department of Environmental Protection.

1.1 Aims of compensation measures

The primary aim of compensation measures is to offset losses in species composition, community structure and function of impacted ecosystems. Habitat restoration, areas for reproduction, growth and feeding, as well as corridors to enable species to complete their biological cycles must be ensured.

Under most types of legislation or policy, compensation must, as far as possible, be: carried out near the impacted site, scaled according to the project's residual effects and sufficient, so that the results of the environmental operation lead to a zero (equivalent) or a positive balance.

According to Maron et al. (2012), three primary factors limit the success of a compensation project:

1. Time difference (period producing interim losses)
2. Uncertainty (environmental risk)
3. Measurability of the value to be compensated (metric)

As it is impossible to separate a compensation project from a restoration project (environmental engineering) we will use the latter, in a study by Bayraktarov et al. (2016) to show three primary causes of failure:

1. Poor choice of host site (e.g. substrate, geomorphology, hydroperiod/hydrology, seasonality)
2. Unexpected events (e.g. storms, invasive species)
3. Human pressure (e.g. inadequate management, cumulative impacts)

and the following five criteria for success:

1. Understanding how ecosystems work (biologically and physically)
2. Elimination of human pressure or other impacts that can hinder the environment's natural regeneration
3. Definition of objectives and clear indicators (criteria) to measure success in the restoration
4. Intensive monitoring over a period of 3-5 years, followed by annual monitoring for 15-20 years
5. Involvement of local populations and stakeholders in building and managing the restoration project

Gardner et al. (2007) suggested the conditions necessary for the implementation of compensation measures in the field and the manner in which different involved parties perceive them. They stress: *"There is a fundamental difference between compliance with laws and achieving quality environmental results. Satisfying permit requirements does not mean that the restored reef area ends up having the desired environmental functions (those that have been or will be degraded by the project)".*

Work is on-going in regulatory design and field work (implementation and evaluation), however more is required, prior to being able to make definitive statements about the recovery of rare or threatened ecosystems or of robust ecological restoration science (Levrel et al., 2015).

1.2 Calculation methods for compensation ratios

The primary methods for calculating and scaling compensation over the last 25 years utilise ratios a priori. Ratios must take the form of outputs resulting from analytical procedures that take into consideration past, current and future socio-environmental systems (Bas et al., 2016). Surface ratios are most often used (Bezombes et al., 2017) based on the principle that for each hectare lost (losses) there is the need to restore (n) number of hectares (gains). The project manager must thus be in a position to restore environments that are geographically close to those that have been impacted and present an equivalence as far as ecological functions are concerned (Bas et al., 2016).

In France, compensation ratios of one surface unit destroyed to 1.5–2 restored units, are sometimes utilised in texts or framework documents relating to aquatic ecosystems dealing with Water Development and Management Schemes (SAGE under its French acronym), or French Master plans for Water Development and Management (SDAGE under its French acronym). However, in this case the ratio is an input, which means that it does not consider ecological or social specificities of the study area.

The National Council for the Protection of Nature (CNPN under its French acronym) that rules on exemptions relating to the destruction of protected species and habitats (see previous chapters), has some experience in compensation ratios. An analysis of CNPN advice reveals categories of ratios adapted to the importance of the habitat or species, as well as to the degree of uncertainty in the application of the measure (Table 1).

From 1988 to 2004, the State of Florida (Pioch et al., 2015a) used the following ratio guidelines (area of mitigation: area of impact), in coastal areas:

For creation or restoration	For enhancement	For preservation
From 1:1 to 5:1	From 4:1 to 20:1	From 10:1 to 60:1

Nb: ratio is = surface gained: surface lost

This type of tables establishes a compensation ratio only as a function of the status of the impacted species or habitats and does not consider concepts of connectivity between habitats, ecological function, or a site's socio-cultural or aesthetic values. The ratios are inputs, which means that they do not consider ecological or social specificities of the study area.

A similar method attributes a percentage of the project's total budget for compensation, as is the case in Brazil for example. At its simplest, it involves the payment of approximately 1% of the cost of works into a fund "for nature" (Jacob et al., 2014). This approach would give the project manager a precise estimation of the budget allocated for environmental measures.

However, small projects can have similar or greater environmental impacts than larger projects, with considerably higher costs. For example, even minor restorations of seagrass beds associated with reef systems can reach sums ranging between US$ 570,000 and US$ 972,000/hectare, or greater, depending on distance and/or the availability of local resources (Kirsh et al., 2005; Stowers, 2000). Finally, the compensation figure of 1% does not take into consideration disparities in residual impacts on ecosystems (no estimation of significant residual impacts) of different sized projects.

French Cases	Compensation ratio
Standard destruction of nature	1:1
Average-level issue of habitat or species destruction: habitat, species, or heritage-type habitat, but not on the IUCN Red List	2:1
High-level issue of habitat or species destruction or species' habitat: protected species or habitat and on the IUCN Red List	5:1
Critical-level issue of habitat or species destruction or species' habitat: priority habitat, Red List, or concentration of habitats, species or individuals	10:1

Table 1: Compensation ratios applied by CNPN according to cases found in waiver requests for strict species' protection (Barnaud & Coïc, 2011)

Although these approaches have the advantage of enabling early planning of compensation (a priori definition), they are currently being challenged. More integrated solutions are in the process of being developed, which are based on the geographical, socio-economic and ecological context of projects as well as their likely effects on the environment. The evaluation and comparison of ecological losses linked to residual impacts and gains associated with the compensation measure, using biophysical analytical tools, is thus required.

1.3 New approaches to calculating biophysical equivalencies: MERCI-Cor

In order to bridge the gaps in determining compensation ratios, numerous methods of calculating biophysical equivalences in nature have been developed for marine and coastal environments, mainly in the United States of America. There are more than 100 methods, depending on the environments, tools available and regulations in place (Fenessy et al., 2007; Levrel et al., 2012; Pioch et al., 2015b; Bas et al., 2016).

These methods can be grouped in three categories:

- comparative methods,
- reference methods or using an index,
- analytical methods.

In a recent study Bezombes et al. (2017) evaluated 13 large methodological groups for the calculation of equivalence:

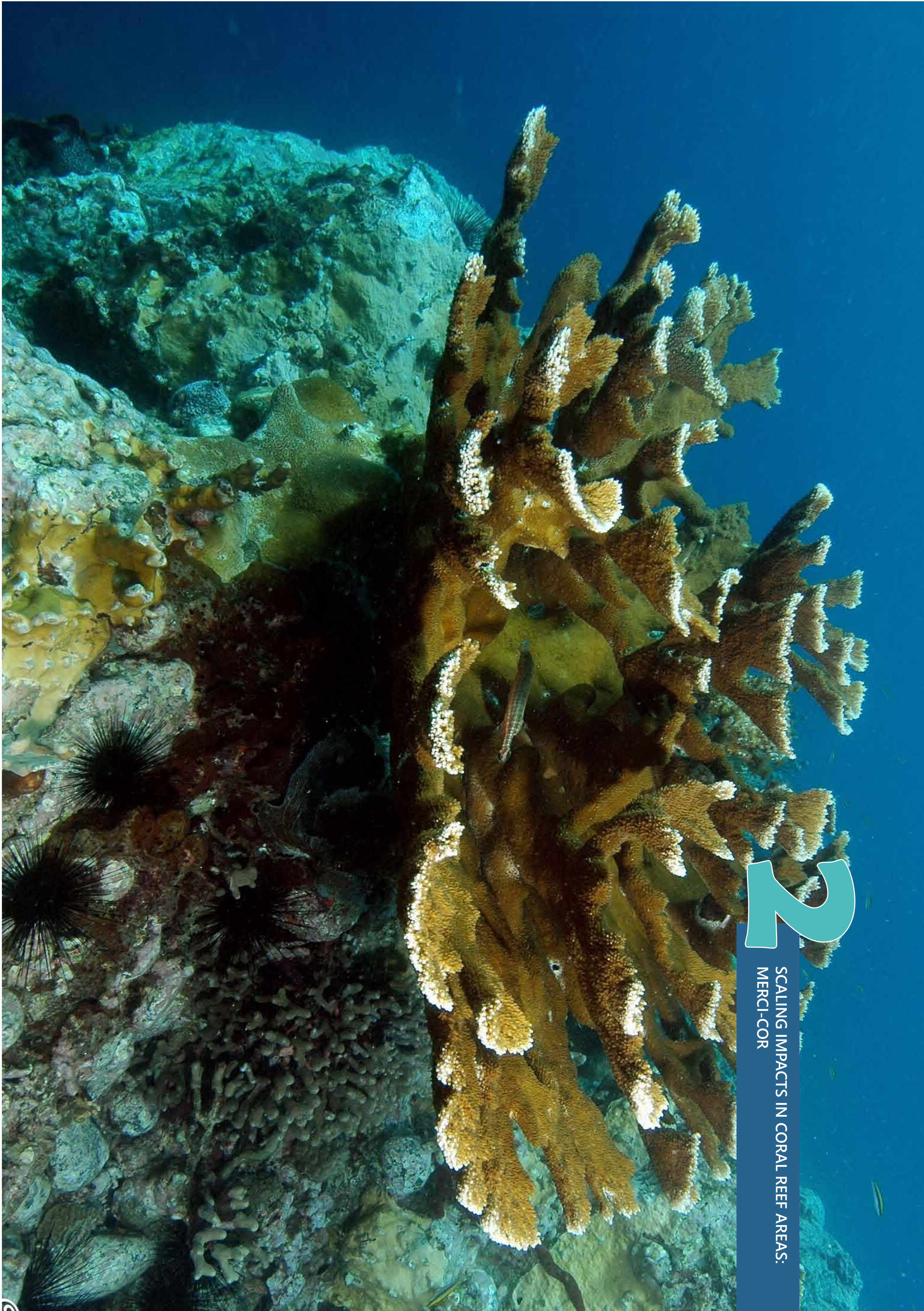
- operational capability (e.g. speed, level of expertise),
- thoroughness (e.g. types of indicators),
- the robustness of the scientific approach.

The analysis shows that integrated approaches present the best balance among these three categories.

Based on this study, for aquatic environments, the Uniform Mitigation Assessment Method (UMAM), developed by the State of Florida in the United States of America, offers the best compromise (Bezombes et al., 2017). This method uses metrics to compare the net value of functions lost at the proposed impact site to the net value of functions gained at the mitigation site, and then includes adjustments for the risk factor (degree of uncertainty that successful mitigation can be achieved) and the time lag (Pioch et al., 2015a).

Although not covered in this guide, in the case of accidental (unauthorized) impacts, data on the initial status of a destroyed area is often difficult to come by. The Habitat Equivalency Analysis (HEA) was specifically developed to compensate for this lack of data in situ, by proposing the calculation of the functional value of the initial status via a proxy (or composite proxy) or an indicator based on an adjacent intact habitat (Pioch et al., 2017). Software, Visual HEA 2.6 was developed by Nova University in cooperation with University Montpellier 3 Lab. CEFE with the aim of assisting with this method.

While the identification of the ecological functions affected is an essential step in the evaluation of losses (see Handbook 1 – EIA methodological frameworks), the calculation models presented in the following chapters are not aimed at qualifying the impacted ecological functions, but rather rely on these known functions, processes and ecological dynamics to quantitatively estimate or scale biophysical losses suffered by the environment.



2

SCALING IMPACTS IN CORAL REEF AREAS: MERCI-COR

2 SCALING IMPACTS IN CORAL REEF AREAS: MERCI-COR

MERCI-Cor is the coral reef version of the MERCI method, initially developed within the framework of the research partnership between the University of Montpellier (UPVM under its French acronym), The National Center for Scientific Research (CNRS under its French acronym) and the National Office for Water and Aquatic Environments (ONEMA under its French acronym) (ARO programme method 2013-2016, Méchin & Pioch, 2016) and designed for scaling compensation measures in wetlands and freshwater environments.
The MERCI method is itself based on the US UMAM method that belongs to the large family of Rapid Assessment Methods (RAM) (Bezombes et al., 2017). Several actors- government authorities, consulting firms, the Regional Scientific Council for Natural Heritage (CSRPN under its French acronym), project managers and scientists, collaborated in the development of this ARO sequence.

2.1 Overall approach to the method

The MERCI-Cor method involves the evaluation of ecological losses caused by a given development project and ecological gains obtained following the application of compensation measures with the aim of a "no net loss" (equivalence between ecological losses and gains). It also takes into consideration uncertainties linked to the ecological trajectories of compensation measures and delays between the launch of a project and achieving the ecological status targeted by compensation.

The method proposes a highly operational approach to help different actors in the ARO sequence establish and analyse projects. The idea for such a tool arose from shared findings regarding the inadequacy of existing tools to deal with the specificities of coral reef areas (specific indicators). This is in addition to the lack of a standard methodological framework using skill sets available to most environmental assessment service providers.

We reiterate that the measurement of ecological losses and gains is recommended, though to date, difficult to apply when using the ARO sequence. Unlike other existing approaches, the MERCI-Cor method evaluates the conservation status of an area as a whole and does not only target specific, often protected, species, habitats or ecological functions. In addition, the conservation status of the environment is analysed from the perspective of its state of health, relative to its exposure to anthropogenic impacts (Figure 2).

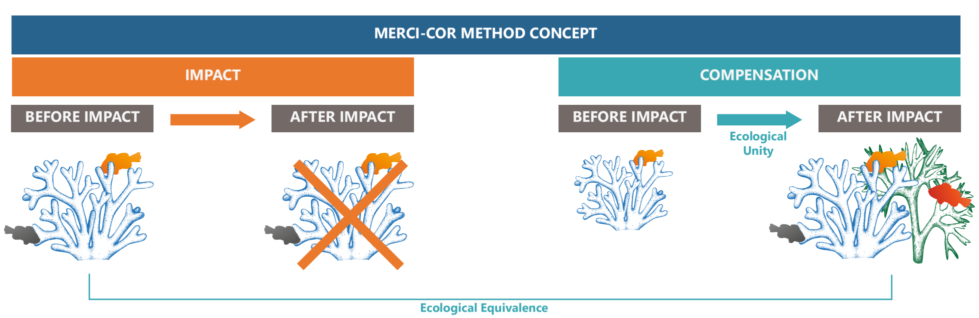


Figure 2: Principle of the MERCI-Cor method and ecological equivalence goal ("no net loss")

The calculation of environmental gains and losses depends on three components:

1. The site, the environmental landscape and the level of interdependence and connectivity with adjacent areas,
2. The environmental structure (oceanic, physicochemical and meteorological context) of each habitat,
3. The ecological structure (coral, fish and macro-benthic populations) of each habitat.

It is important to note that the proposed impact (losses) and compensation (gains) areas are evaluated using the same indicators.

After a preliminary survey, carried out with five government bodies and four consulting firms (in France) as pilot users of the tool, the following advantages were identified:

- Flexibility of use and transparency: indicators, coefficients, accessible calculation formulae,
- Balance between scientific efficiency, completeness and robustness,
- Ease of access: high level experience not a pre-requisite, inexpensive (< 5 days),
- Prioritizes avoidance and reduction (or minimization) prior to offsets, and calls for a greater focus on avoidance and reduction measures,
- Can be implemented at any stage in a project (draft, project proposal studies or the project itself, then as a performance indicator of measures taken – see also Figure 7 p24).

2.2 Framework, scientific base and scope of application

2.2.1 Design method

The basic principle of the MERCI-Cor method is to evaluate and compare environmental gains and losses caused by projects in coral reef environments and the implementation of compensation measures.

This environmental assessment takes into consideration adjustment factors depending on regulatory requirements involving the consideration of risk and time delays (or time lag) between the beginning of the authorized impact and the point at which the mitigation fully replaces the ecological unity losses. These two concepts are to be considered when assessing compensation and are referred to as environmental uncertainty (risk) and time delay (time).

Additionally, the method was conceived with a view to providing the regulatory body with a margin for manoeuvring and negotiation. Other adjustment factors can be proposed following advice from government bodies, if they appear to be aligned with regulatory requirements and local management priorities such as: Protected Species or Habitat Factor (PSF) or Conservation Adjustment Factor (CAF) so as to consider the project's position within a Key Marine Ecological Feature (KEF).

The ecological approach of the method thus involves the assessment of losses or gains linked to the degradation or restoration of a site, using environmental and socio-environmental indicators comprising the method's "non-negotiable cornerstone". These losses and gains are then reduced or increased with the application of adjustment factors, comprising the method's "regulatory approach"; henceforth to be referred to as "adjusted" losses and gains (Figure 3).

	Impact area		Compensation area
Ecological approach	**Ecological loss** Ecological state before impact Ecological state after impact ➔ **Δ impact** = before – after EL = Impacted surface x **Δ impact**		**Ecological benefits** Ecological state before compensation Ecological state after compensation ➔ **Δ comp** = after – before EB = Comp surface x **Δ comp**
Regulatory approach	**Adjustment factors** ...		**Adjustment factors** Risk R Delay T ...
	Adjusted loss Impacted surface x **Δ impact**	=	**Adjusted benefits** **Comp surface x Δ comp / R x T x ...**

Figure 3: Framework of the experimental MERCI method

The ecological state of an area under study (initial, impacted, restored) is assessed with the assignment of a score between 0 and 10, with 1 being the best environmental status in terms of the chosen references. In this case, the ecological state corresponds to the health of the entire ecosystem studied, as compared to an ecological reference framework (pristine habitat) or in other words, its degree of functionality.

The primary question to be asked when assessing an area is: "How well does it function, ecologically?" (Fenessy et al., 2007).

In the next section we shall see the scientific basis on which the ecological state assessment is based, as well as why and how to deal with the question of choice among ecological reference frameworks.

2.2.2 Scaling compensation: final calculations and their interpretation

- ***Calculation of a compensation area***

The impacted and compensation areas are evaluated using the same indicators, making it possible to compare adjusted losses and gains.

The regulatory obligation of ecological equivalence (at the quantitative level) is captured in the following equation:

Adjusted losses × Impacted area = Adjusted gains × Compensation area

If the following input data is available:

- Initial state of the impacted area
- The impacts (ecological losses) supposedly caused by the development project (Δ impact)
- Impacted area (area of footprint + buffer zone)
- Initial state of compensation area
- Foreseen compensation measures (ecological gains) (Δ compensation)
- Adjustment factors (ecological risk "R" and time delay "T")

The compensation area needed to comply with the quantitative equivalence requirement can be calculated thus:

$$\text{Compensation area} = \frac{\text{Impacted area x } \Delta \text{ impact x R x T}}{\Delta \text{ compensation}}$$

The compensation area is directly proportional to the impacted area and impact intensity, as well as to the risk and time delay. It therefore encourages avoiding and reducing impacts, and then proposes the most effective compensation measures possible (maximum ecological gain per surface area).

- ***Estimation of anticipated ecological gains***

Depending on the specific case and on the project's stage of advancement, the compensation measures may not yet be known. However, if the terrain has already been identified, knowing the proposed effects of the project on environment (Δ impact), the impacted area, the available compensation area and making assumptions regarding adjustment factors linked to the environmental risk (R) and the time delay (T) an estimation of potential gross environmental gain (Δ compensation) is possible.

This can provide relevant information such as, if the expected Δ compensation is high and the health status of the compensation area is rather good prior to intervention, it is likely that the ecological restoration of the compensation surface would be insufficient to compensate for the losses. Thus, assuming a low ecological gain per surface unit, following the implementation of compensation measures, a very large compensation area would be needed to achieve ecological equivalence.

2.2.3 Ecological state of a coral reef habitat assessed through an integrated scoring system

The aim of the method is to assess the status of a site through an integrated number-based score. In fact, the purpose of this assessment is to convert an ecological state into comparable environmental losses or gains, and to proceed towards determining a surface area to be compensated. This number-based and integrated approach is therefore absolutely necessary; however, it is still a "number" from an expert, so we recommend comparing the results from two or more expert evaluations. The idea is to reach consensus, however if it cannot be found, finding an average would be a suitable solution.

The ecological state, assessed using the MERCI-Cor method, as in all Rapid Assessment Methods (RAM), corresponds to a level of ecological integrity of typical functions of the analysed habitat. The initial ecological state of the impacted site and of the compensation site can be measured in situ with semi-quantitative "large-scale" assessment methods (Handbook I – general characterisation of study area). Both the final impacted and compensated ecological states are then deducted from: the project's expected effects, the vulnerability of identified habitats exposed to these effects, and the regeneration capacity of these habitats, once compensation measures (ecological restoration) have been carried out. It is the difference between the initial and the final impacted and compensated ecological states (before and after project) that will define the "Δ impact" and the "Δ compensation" in the MERCI-Cor calculation model.

As indicated by Fennessy et al. (2007) in their article analysing RAMs for wetland ecosystems (but which can be adapted for the coral reef environment), some ecological functions, ranging from the most specific to the most cross-cutting and which are the result of their physical, chemical and biological components, contribute to maintaining ecological integrity, that includes both ecosystem structure and processes. The "optimal" or "excellent ecological state", to which authors refer as the "ecological reference framework", is a concept to which we will return later.

It is important to note that the MERCI-Cor method does not measure the state of a function but whether the state conforms to that expected for the reference type of ecosystem analysed.

For example, a nearshore coral reef located on a low-relief, hard-bottom is regularly scoured by the movement of sand, and so does not support the same diversity and biomass as an off-shore coral reef. However, it does provide a source of new-growth macro algae (more palatable than old-growth algae) and is preferentially used as shelter for many species of larval fish. These are different community types and provide different ecological functions, so they have different optimal states by which they should be measured. Thus, an ecosystem with a healthy ecological state may not perform certain functions at a high level (Figure 4). A lagoon zone, for example, even in excellent health, will generally have a low percentage of coral cover because of its sandy dominance and the specific hydro-sedimentary conditions present in these confined habitats. As Fennessy et al. (2007) suggest, if one wants to assign a particular value to certain functions, extra points or "value-added metrics" can be used. However, these should be clearly separated and distinguishable from the assessment of the ecological state.

Figure 4: Basic principles on the pressure gradient which determines ecological states, scored with indicators (0 to 10)

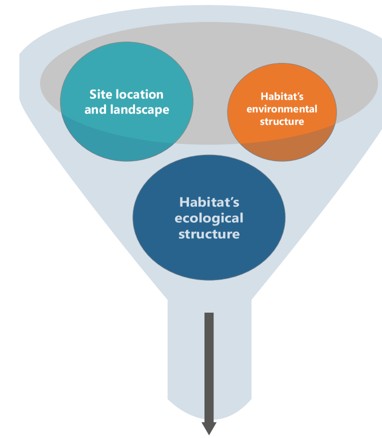
This basic principle is translated into the MERCI-Cor method via the previously described two-pronged ecological (indicators) and regulatory (adjustment factors) approach. The possible adaptation of the MERCI-Cor method to specific regulatory or local management requirements or societal priorities must be carried out through the application of the adjustment factors. For example, the introduction of the indicator "wealth of protected/heritage species" to assess the overall ecological state is not pertinent (Bennett, 2003). It is however, acceptable to introduce a specificity, linked to the presence of protected or heritage species, using adjustment factors.

- ***Indicators***

Again with reference to Fennessy et al. (2007) RAMs are based on indicators of the overall ecological state (Figure 5). Those of the MERCI-Cor method relate to:

- location of and exchanges with adjacent systems (landscape ecology),
- hydro-geomorphological characteristics,
- biological communities of the studied area.

According to the design principles of the MERCI-Cor method, the indicators allow one to evaluate the level of integrity of the different components studied with respect to factors of alteration.



- ***A required ecological reference framework***

The approach proposed by the method draws on the previously mentioned concept of the ecological reference framework. The ecological reference framework corresponds to the highest level of ecological integrity ("optimal" or "excellent"), this being the ecological status that has been the least modified by factors of human origin. The query that accompanies this definition is that of knowing what is the highest level of ecological integrity for the specific ecosystem. If one takes a totally pristine state as the reference, being a state prior to any human activity (water pollution, erosion, climate change, etc.), very few coral ecosystems of this type exist which can be used as a reference in our assessments. In some cases, where a high level of integrity no longer exists or is very low, one can value an imaginary system (with the best knowledge available). However, reference sites still have to be used when establishing the metrics for successful mitigation.

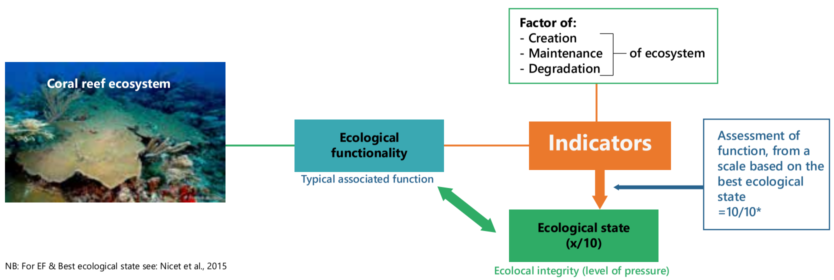
With respect to the MERCI-Cor method, we suggest basing our reference on the European Union Habitats Directive (92/43/EEC) that prescribes ecosystem conservation priorities at the European level. This choice makes sense to the extent that it is a political choice taken by European Union Member States. The directive targets what are referred to as "natural habitats" (Article 2) defined as "terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural" (Article 1, b).

The mention of "semi-natural" characteristics clearly introduces the possibility of human activities modifying, to a certain degree, the characteristics of an environment, which can be interpreted as resulting in resilient and self-sustaining ecosystems, sheltering numerous species. The question of the definition of the reference on which to base the implementation of our assessment is not a simple one, and the debate falls well outside the scope of this guide.

Even though the MERCI-Cor method does not aim at providing a definitive answer to this question, it cannot be avoided. Clear definition of a reference framework does have the merit of making the criteria on which environments are assessed, more transparent. It also allows for clarification of the issues and choices linked to the ARO sequence. In current practice, as demonstrated by exchanges with government bodies and consulting firms, this question is often eclipsed, being handled by different players, each with their own background information.

Finally, in order for the method to be operational, this reference framework should be available in standardized classification units, with clear definitions for each unit (Figure 6). Unfortunately, to date (2017) there is no comprehensive catalogue of coral habitats. However, within the framework of IFRECOR, one such catalogue, with detailed typologies is planned (Nicet et al., 2015). It will be compatible with previous efforts, including:

- Millennium Coral Reef Mapping Project,
- UNIS (reference typology at European level),
- Natural Marine Zone of Ecological, Animal and Plant Importance (ZNIEFF-Mer under its French acronym)
- Global Coral Reef Monitoring Network (GCRMN), under International Coral Reef Initiative (ICRI) recommendations.



* Note 10/10 correspond to the highest level of ecological integrity, «Optimal Ecological State», optimal level of function.

Figure 6: Basic approach of MERCI-Cor, with an ecological state of a coral reef habitat assessed through an integrated scoring system

2.2.4 Scope of use

The method can be applied to different stages of a development project, however, it is designed primarily for application at the scaling stage of compensation, either by the project manager, or on examination of files by State services, as set out below:

- The regulatory perimeter covered by MERCI-Cor at the compensation stage,

The possibilities of applying the method in the initial stages of development projects with a view to providing inputs during the avoidance and reduction stages of ecological impacts.

- ***Regulatory perimeter***

The regulatory principles, linked to the ARO sequence in general and to compensation in particular, are multiple. At this stage, some are taken into consideration by the model, at two levels:

- In the analysis stage of projects,
- In the calculation of compensation areas, or the adjusted losses and gains, i.e. compensation scaling.

Table 2 summarizes the different principles governing ecological compensation and how these are integrated in MERCI-Cor.

Table 2: Regulatory principles of the ARO sequence considered in the MERCI-Cor method as part of the French Office of the Commissioner for Sustainable Development (CGDD under its French acronym) requirements (2013) pages 10 and 11 of the general guidelines and Environment Code's regulations.

Regulatory principles relating to ecological compensation	Considered in the MERCI-Cor method
Ecological equivalence *Ecological equivalence includes several elements:* • *type of habitats* • *type of functions carried out by the ecosystem* • *level of functionality of the ecosystem* • *level of environmental losses and gains*	 Project analysis Project analysis Scaling Scaling
Consider risks associated with doubts regarding efficiency of compensation measures	Scaling
Consider time delay	Scaling
Ecological Additionality	Scaling
Geographical proximity *(same water body)*	Project analysis
Proportionality of the compensation with respect to intensity of impacts	Scaling
Feasibility *(choice of an ecological restoration technique and associated organizational procedures)*	Allows one approach
Effectiveness (objectives of results and monitoring of compensation)	Allows one approach
Conditions for the functioning of areas likely to provide support for measures	Allows one approach

Sources:
Articles L. 122-3, R. 122-5 and R. 122-14 of Environment Code (projects subject to impact assessment);
Articles R. 214-6 and R. 212-13 of Environment Code, ministerial decrees with general prescriptions regarding session 3.1.5.0., circular of 24 December 1999 and dispositions of SDAGEs, SAGEs or other planning documents (case of projects subject to sections of Water Law nomenclature);
Articles L. 414-4 and R. 414-23 of the Environment Code (projects requiring Natura 2000 impact notification);
Articles L. 411-2-4, Decree of 19 February 2007 and circular of 21 January 2008 (projects subject to «protected species» waiver).

- ***Avoid and Reduce***

The approach proposed by MERCI-Cor can be used for purposes other than strict compensation scaling. Indeed, both compensation and impacted sites are assessed by the same indicators both before and after projects. It can thus be used in the initial stages of project development, during early phases of design review and work supervision from the consultant services, as illustrated in Figure 7.

This before and after comparison, as well as the representation of the functioning of the ecosystem through various indicators, can provide highly interesting indications for targeting and prioritizing avoidance and reduction measures (that can be evaluated), to choose less impacting work design. The applicant is better able to respect the hierarchy between avoidance, reduction and compensation. Moreover, the speed with which the method can be applied, allows its use in the initial, and repeatedly, following stages of a project. With the comparison of various development scenarios, it enables those responsible (applicant) to choose the option with the least environmental losses.

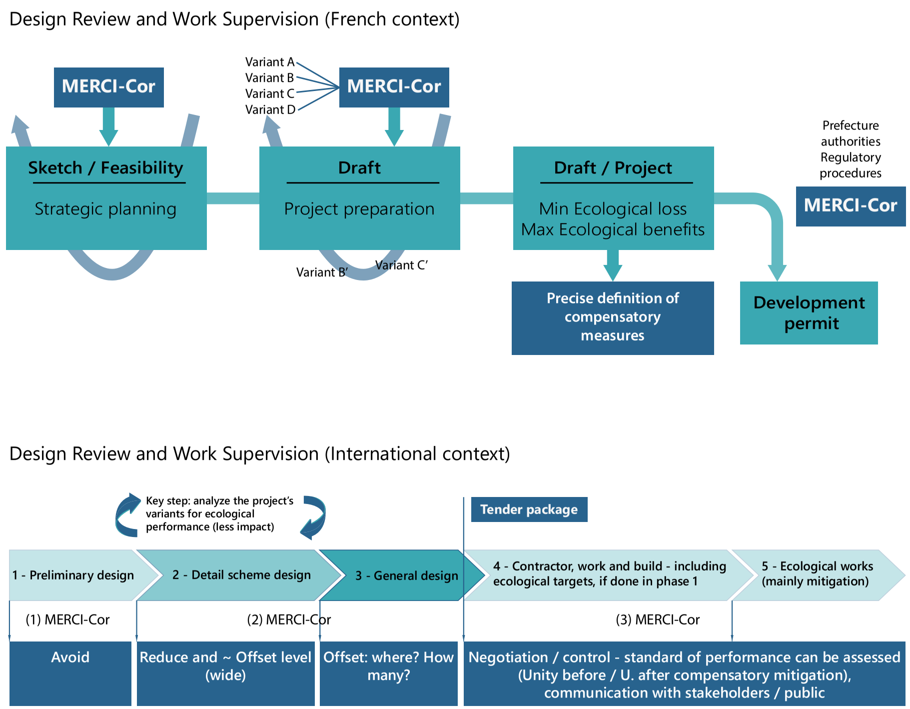


Figure 7: Application (upper) of the experimental method MERCI-Cor in different stages of a development project, in mainland France, according to missions defined by the law on public project contracting (MOP Law 85-704 of July 12th 1985) and in international cases (lower)

The MERCI-Cor method can also provide project managers with essential information on the environmental cost/benefit analysis (or technical choice) of a particular scenario, along with economic or geotechnical studies frequently carried out at this stage of the projects. It can thus spur further research into measures to avoid and reduce environmental impacts.

In particular, it can be used to compare compensation scenarios by calculating the ecological gains of the various scenarios (Δ compensation) on the basis of their location, and evaluation of their initial ecological state as well as by making assumptions on the R (Ecological risk) and T (time shift) coefficients.

This comparison is necessary for choosing the best compensation scenario. If the expected compensation level is high and the ecological state of the compensation site is rather good, it is probable that the improvement of this ecological state will be inadequate to compensate for the losses, or will require very large compensation area.

2.3 Application protocol

The MERCI-Cor in 3 steps (Figure 8).

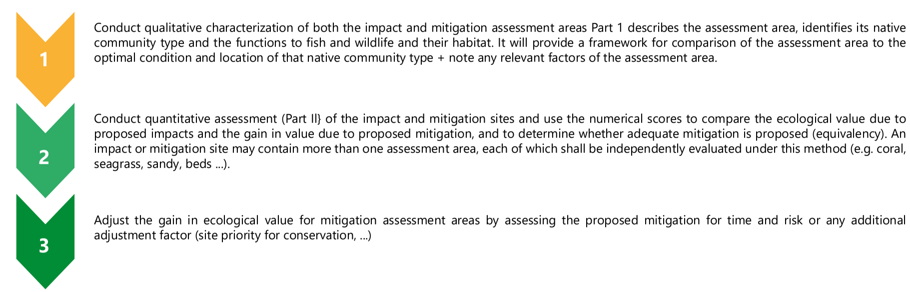


Figure 8: Three primary steps of the MERCI-Cor method

These steps, are explained in the following paragraphs.

2.3.1 Steps in the application of the method

Application of the MERCI-Cor method involves the following steps:

Part 1

1. Qualify habitat types and compensation measures (impacted and compensation areas). Part of this crucial step is to identify the ecological functions that are being provided by each habitat. That helps determine if the functions at the impact site will be offset at the mitigation site,

Part 2

2. Assess (quantify) the ecological state of the impacted area prior to development. This corresponds to the pre-construction (initial) state of the impacted area (authorized damages),
3. Assess the ecological state of the impacted area after development. This is the post-construction state of the impacted area,
4. Assess the ecological state of the compensation area prior to application of compensation measures. This represents the pre-measures (initial) state of the compensation area,
5. Assess the ecological state of the compensation area once the compensation measures are applied and after they have started to show results. This leads to the post-measures state of the compensation area (objective of the compensation),

Part 3

6. Estimate the adjustment factors,
7. Proceed with calculation of adjusted losses and gains, apply the equation and analyse the results obtained.

While some deskwork can be carried out once required documents, databases and cartographic tools have been transmitted to the user, indicator assessments based on observations require fieldwork.

The initial states of the impacted and compensated zones can therefore be estimated by comparing bibliographic and field information. The estimate of the post-construction state on the impacted area and post-measure state on the compensated area is a theoretical projection. However additional re-assessment should be done, as many projects result in secondary impacts (such as deposition of suspended sediment). These cannot be quantified up front, and can only be measured through monitoring. The secondary impacts are generally measured by comparing pre-construction surveys of the surrounding area to post-construction surveys. A re-adjustment of the amount of mitigation can be, by the way, proposed and discussed with the applicant before the EIA authorization.

Since the impact and the compensation have not yet taken place at the time of their evaluation, it is up to the user of the MERCI-Cor calculation model to estimate the evolution of the indicators, measured during the initial states, subject to the pressure of the development project on the impacted area, and supported by the restoration measures on the compensated area.

2.3.2 Qualification of impact and compensation areas

Part I of the MERCI-Cor calculation table enables qualification of the project's environment type and provides general information on the impacted and compensated sites (Tab. 3). A form is to be completed for each impacted and compensated site (e.g. the restoration and management of two different sites). This form enables validation of the ecological equivalence between the types of environment impacted and compensated for.

PART I – Qualitative description of the study site (impacted or compensated)
Authors / Services / Year

<table>
<tr><td colspan="4">Name or number of the study area
Barbados West Coast</td><td colspan="4">Name or number of study site
Bay Point</td><td colspan="4">File number
CR001/2/B</td></tr>
<tr><td colspan="3">Code of classification of use and type of ground cover
CR</td><td colspan="3">Other classification (optional)</td><td colspan="3">Impacted or compensated site
Impacted</td><td colspan="3">Surface of the study site
2 Ha</td></tr>
<tr><td colspan="3">Watershed reference</td><td colspan="4">Class of affected watershed</td><td colspan="5">Protection status of the area</td></tr>
<tr><td colspan="3">Waterbody n°XXX</td><td colspan="4">Class</td><td colspan="5">All corals protected around the island</td></tr>
<tr><td colspan="12">Geographical relationship and hydrological connection with other waterbodies</td></tr>
<tr><td colspan="12">**The study site is located on the north west coast of the island within the Territorial Sea. It's in open water and therefore expected to be an ecological corridor for fish and coral larvae. Prevailing currents on the west coast run from the north to the south, so while detailed studies have not yet been carried out, one would expect the site to be a recipient for and a supplier of coral and fish larvae.**</td></tr>
<tr><td colspan="12">Description of the study site</td></tr>
<tr><td colspan="12">**The study sites contains a relatively healthy bank reef coral reef ecosystem, characteristic of the west coast bank. Top of the reef is in 40ft of water with a seaward slope down to 120ft. The reef supports a vibrant community of fauna, including fish (reef and pelagic fish) and is heavily used for diving activities. Relatively high fishing pressure is present.**</td></tr>
<tr><td colspan="6">Environmental characteristics of areas adjacent to the study site</td><td colspan="6">Rarity of habitats/species in study site compared to bio-geographic species pool</td></tr>
<tr><td colspan="6">All functions other than larval recruitment of pelagic origin</td><td colspan="6">No</td></tr>
<tr><td colspan="6">Remarkable species likely to be present from bibliographic elements</td><td colspan="6">Species protected or included in a list of vulnerable species likely to be present on the study site</td></tr>
<tr><td colspan="6">**Acropora palmata, Scaridae sp.,**</td><td colspan="6">**All coral species, Hawksbill and Green turtles.**</td></tr>
<tr><td colspan="12">Species whose presence is established on the study site by direct or indirect (skeleton, test, carapace, burrows, tumuli, etc.) visual census</td></tr>
<tr><td colspan="12">List of previously recorded species (bibliography, personal communication)</td></tr>
<tr><td colspan="12">Characteristic features of the study site and adjacent sites, not previously mentioned</td></tr>
<tr><td colspan="12">**Close proximity to the Barbados Port and Bridgetown.**</td></tr>
<tr><td colspan="6">Name of the organization in charge of the environmental impact assessment</td><td colspan="6">Date of completion of the study (field period, reporting date)</td></tr>
<tr><td colspan="6">**Coastal Zone Management Unit**</td><td colspan="6">**02/25/2016**</td></tr>
</table>

Table 3: Part I of the MERCI-Cor method describing the quality of the environment

2.3.3 Concepts of the footprint and buffer zone areas for the MERCI-Cor method

We have seen in previous chapters (Handbook I – Definition of study areas) that the criteria used to determine the study area in the authorization application, is based on topography, ecology, geology, hydrodynamics and land-use elements, among others.

The study area exceeds the area directly impacted by the project's footprint. Certain impacts, notably those caused by construction, can exceed the footprint area (e.g. changes to currents, degradation in water quality and sediments on the edges of the project area). A project's indirect and cumulative impacts are also not strictly limited to its footprint. Thus, for example, breaks in ecological continuity, due to the increase in maritime traffic following the extension of port infrastructure (haphazard anchoring, noise, pollution, etc.) or the disruption of migratory routes by linear infrastructure, should be considered in the assessment of losses. The study area thus evolves as a project's impacts are better defined in their space-time dimensions (CGDD, 2013).

In practice, a project's impact area can be divided into two distinct zones, in which complementary assessments could be carried out: footprint and buffer zones (Figure 9). Two MERCI-Cor assessments have to be conducted, and added, to have the footprint and the buffer zone losses, as well as gains. While the footprint can be easily defined by the geometry and architecture of infrastructure, the delimitation of the study area's buffer zone requires a thorough knowledge of the initial state, both from biotic (species richness, migrations, corridors) and abiotic (geomorphology, hydrodynamics, dispersion mechanisms) perspectives.

In the absence of sufficient knowledge that would allow for the precise delimitation of the buffer zone (scouring effect, projected shadow on seagrass) we propose that a zone with a minimum width of around 500 metres could be applied over a marine area situated on the periphery of the footprint, or along the entire length of linear infrastructures. Within each area or zone, the effects of a project's intensity (very heavy, heavy, weak, none) and type (direct, indirect, cumulative) can be different and cause different biophysical losses in each area or zone (2 assessments). The buffer zone score can also be calculated during the construction time, as impacts are higher (noises, sedimentation suspension...). In this case, we propose to add a multiplication factor to the final losses score, post impact. This "buffer construction time" (BCT) factor needs to be discussed with stakeholders. A time parameter could also be discussed, as with the HEA method (Pioch et al., 2017). We also refer readers to the article of Bas et al. (2016) and the future versions of MERCI-Cor, using such multiplication factors (BFT), not developed here.

Figure 9: Impact area, footprint and buffer zone on a fictitious hotel complex in a reef zone.

2.3.4 Environmental status after development of the impacted area

Assessment of the ecological state of an impacted area after development calls for predicting the ecological functions of the area (Figure 10).

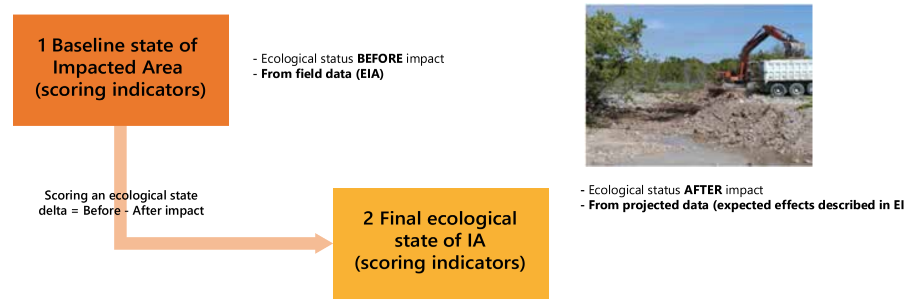


Figure 10: Assessing ecological state from the impacted area

The use of different indicators in the assessment matrix of MERCI-Cor can help guide and frame the reasoning behind decisions made.

However, several questions arise:

- What time scale should be used?
- What impacts are to be considered?
- What external factors are to be considered?

- ***Time scale***

This refers to the status once the project has been terminated, and related activities are fully developed.

- ***Impacts to be considered***

Depending on whether the footprint or the buffer zone is assessed, direct, indirect and distant impacts should be considered. Regulatory requirements also call for the consideration of cumulated impacts, these being "caused by other known projects, not yet in service, whatever project manager is concerned" (CGDD, 2013).

- ***External factors to be considered***

If projections are made for over 10, 20 or 30 years, the external conditions to which the assessed area is subjected will have evolved: population growth (or decline), development of other economic activities, climate change, etc.

From a purely ecological standpoint, the consideration of these external factors is needed in order to determine ecosystem status. However, within a compensation framework it is possible to waive these external considerations as, on the one hand, the high level of uncertainty considerably complicates the exercise, and on the other, the objective is to evaluate the environmental losses for which the project manager is responsible.

It is for this purpose that the adjustment coefficients R (ecological risk) and T (temporal shift) have been integrated into the calculation model of MERCI-Cor. They take into account some of the factors that go beyond the spatio-temporal scale of the project (and the project manager) if there are tangible and proven elements (erosion of the coastline, local coral bleaching, etc.).

More specifically, the coefficient R represents the possible deviation of the ecological traits envisaged in the loss and gain scenarios (unexpected chain reactions, coral mortality, etc.) while the coefficient T represents the estimated delay between the ecological losses suffered by the impacted area and the gains from restoration measures on the compensated area, which could result in an ecological net loss (see handbook 1 on the concept and aims of the "no net loss" of biodiversity).

2.3.5 Compensation area

- ***Compensation area perimeter***

The compensation area includes the entire area that is subject to the legal transaction (contractual arrangements, purchase, etc.). That means that if work, undertaken within the framework of compensation measures, only covers a part of the area, the assessment must still cover that entire area, and not only that location where work was carried out.

Example: 10 hectares (ha) of salt marshes are proposed for the implementation of compensation measures that involve the creation of 3 hectares of mangroves. Assessment will be of the 10 hectares and not merely the 3 hectares. These 3 ha, of mangrove creation are part of the 10 ha proposed (7 ha are not directly implicated in the creation, but subject to the legal transaction).

- ***Pre-measurements (initial) state of the compensation area***

As in the case of the impacted site, the acquisition of the information required to assess the initial state of the compensated area is based both on previous knowledge (bibliographic) and on information acquired in the field (see handbook 1 on the general characterization of the study area - "large scale" study). MERCI-Cor ensures that the assessment methods are the same at both the impact and the compensation sites, allowing comparison between losses and gains.

- ***Post-measurements (final) state of the compensation area***

This is the state of the ecosystem after achieving the objectives of the compensation measures. This estimate depends on the time scale considered, which may be longer or shorter depending on the type of ecosystem and restoration and the reliability of the assumption that the measures will produce the expected effects. As we have seen previously, this uncertainty about the ecological traits and the temporality of achieving the expected results is translated into the MERCI-Cor model through the R and T coefficients (Figure 11).

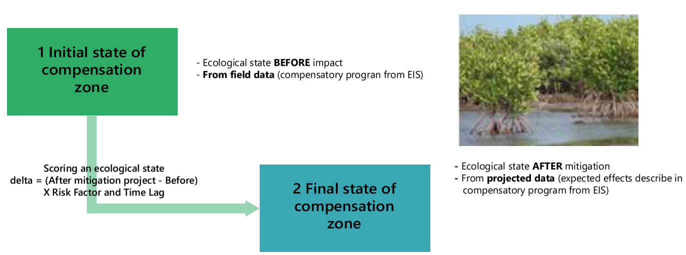


Figure 11: Assessing ecological state from the compensation area

2.3.6 Environmental status assessment: the indicators

After describing the general characteristics of the environment (Tab. 3), the second part of the method is to quantify biophysical losses and gains in order to test and, if possible, validate equivalence: Loss = Gains. As explained earlier, the indicators are organized into three groups, called components, which correspond to the factors to be analysed, in order to understand the functioning of the coral environment.

Each indicator is evaluated using a score between 0 and 3 and should be estimated in:

1. its initial state,
2. its state after impact (post-construction) or compensation (post-measures).

The initial state of the indicators (on impact and compensation areas) is estimated through field surveys. It can be prepared by a bibliographic analysis that will optimize the sampling strategy (see handbook 1 - on methods, sampling strategies and data analyses). In contrast, the estimation of indicators after impact or compensation is carried out by expert opinion.

This estimate by an "expert opinion", which has to take into account the expected effects of the project on the ecosystem, requires a thorough knowledge of coral reef ecology and the regulatory mechanisms that govern them. Thus, a mechanical impact on a surface colonized by branched corals will have the effect of reducing the percentage cover of hard substrates by coral organisms, as well as the density of organisms sheltered by these colonies and which depend on them more or less directly (crustaceans, echinoderms, fish, etc.). The level of competence and experience of the experts carrying out the estimates should therefore be determined by their curriculum vitae and knowledge of their previous relevant experience.

Each score is associated with specific text, which should assist the user in determining what score should be attributed to ecological situations. This is aimed at reducing the level of subjectivity involved in the process. Four ranks, from 0 to 3, express 4 levels of assessment from "minimal" to "strong". To enhance the sensitivity of the score, the range of notation is from 0 to 10, under Rank 0 means a score of 0 to 1, Rank 1 means a score from 1 to 4 etc.:

Rank 0 => minimum score 0 to 1 (minimal)

Rank 1 => scores of 1 to 4/10 (low)

Rank 2 => scores of 4 to 7/10 (average)

Rank 3 => scores of 7 to 10/10 (strong)

The sum of the scores has to be divided by the number of indicators scored, to obtain the average score per each of the three categories of indicator (see example in section 5).

- ***Component relating to location of site or landscape***

This component deals with the geographical location of the assessed area, its interactions and interdependencies with adjacent areas and relates to the smooth functioning of an area at the landscape level (Tab. 4 partially reproduced here).

In the ecological sense, landscape is defined as a geographical area organized in patches of habitats and corridors that ensure connectivity between these habitats, within an area altered by human activity (Forman & Godron, 1986; Burel & Baudry, 1999).

Indicators	*Score*	*Metric*
Site location and landscape		
a. Are the uses identified in the areas adjacent to the study site a risk for the species of fauna and flora present on the study site?		«0. Areas adjacent to the study site are highly urbanized, have a high industrial, port or agricultural activity or high capacity (> 30000PE) or non-compliant wastewater treatment plant. 1. Areas adjacent to the study site are moderately urbanized and have limited agricultural and industrial activities. They may have a fishing port/with small recreational vessels, with a limited footprint (<15ha). 2. Areas adjacent to the study site have diffuse urbanization, with agricultural activities far from the coast and little or no industrialization. They may have very limited coastal shelter (<1ha). 3. Areas adjacent to the study site are either slightly urbanized or not at all, or free from industrial, port and agricultural activities, but they may have a low capacity to treat wastewater and compliant wastewater treatment plant.»
b. Are the most sensitive habitats exposed to impact factors other than those of the study project?		"0. Habitats are chronically subjected to domestic, petrochemical, chemical, organic, superheated or desalinated discharges. 1. Habitats receive treated discharges (environmentally compliant) from diverse activities of small and medium sizes or are subject to intensive exploitation of their natural resources. 2. Habitats are only subjected to a moderate exploitation of their natural resources without altering the ecological balance (trophic, size and maturity structures, etc.). 3. Habitats and their natural resources are only exposed to very low exploitation rates or to sources of pollution far removed from the study site."
c. Can exchanges between habitats within and outside the study area be made freely and easily (ecological continuity)?		«0. Habitats are fragmented and exchanges between habitats within and outside the study site are constrained by an artificial barrier (dykes, harbor walls, etc.). 1. Habitats are fragmented and separated by large sedimentary areas but no artificial barriers constrain exchanges between habitats within and outside the study site. 2. Habitats are continuous but exchanges between habitats within and outside the study site are constrained by a natural (estuary, pass, isthmus) or small artificial barrier. 3. Habitats are continuous and there are no geographic barriers to exchanges between habitats within and outside the study site.»
d. Do the areas adjacent to the study site have the full range of habitats necessary for the life cycle of fauna and flora species present in the study site and are these habitats large enough to allow for the renewal of their populations?		"0. Adjacent areas contain no habitat essential to the life cycle of the species present on the study site (nursery, growth, reproduction, feeding). 1. Adjacent areas contain certain habitats that are essential to the life cycle of the species present on the study site, but their size is insufficient for the renewal of their populations. 2. Adjacent areas contain certain habitats that are essential to the life cycle of the species present on the study site and sufficiently large for the renewal of their populations. 3. Adjacent areas contain all the habitats essential for the life cycle of the species and these habitats are large enough to allow the renewal of their populations."
e. Is the study site likely to benefit adjacent areas in terms of their essential ecological functions (spillover effect)?		"0. The species present on the study site do not have populations capable in terms of density, size classes and maturity, of allowing rapid colonization of adjacent areas. 1. Some of the ubiquitous species present on the study site have populations capable in terms of density, size classes and maturity, of allowing rapid colonization of adjacent areas. 2. Some populations of species characteristic of specific habitats (non ubiquitous species) on the study site, have populations capable in terms of density, size classes and maturity, of allowing rapid colonization of adjacent areas. 3. Some populations of exceptional species (keystone, ecosystem engineers, etc.) on the study site have populations capable,in terms of density, size classes and maturity, of allowing rapid colonization of adjacent areas."
f. Is the study site likely to benefit from adjacent in terms of their essential ecological functions (source zones)?		"0. With the exception of larval recruitment of pelagic origin, the renewal of populations present on the study site does not benefit from any ecological function offered by the adjacent areas. 1. The renewal of the populations present on the study site benefits from the ecological functions offered by the adjacent areas but can also be delivered by onsite mechanisms. 2. The renewal of the populations present on the study site benefits from at least one ecological function offered by the adjacent areas. 3. The populations present at the study site can fully benefit from the ecological functions offered by the adjacent areas for their renewal."
g. Is there a proven risk of invasive (Acanthaster planci), toxic (Gambierdiscus toxicus), epizootic (corals, fish, etc.) or epiphytic species (mangrove, seagrass, algae) on the study site or on the adjacent areas?		"0. The study site is affected by frequent epizootic / epiphytic events or exotic / toxic species proliferations (on bibliographic basis). 1. Some events have been recorded in the past and proliferation conditions are present on the study site but only rare and recent observations of small groups or isolated individuals have been reported. 2. No large-scale events have been reported in the past in spite of the presence of some recent observations of isolated individuals. Conditions conducive to proliferation are present on the study sites. 3. No epizootic / epiphytic event or exotic / toxic species proliferation have been reported in the past and the conditions necessary for the occurrence of these phenomena are not present on the study site."
TOTAL 1	0	
AVERAGE (/ 10)	0	

Table 4: Indicators for the location of sites or landscapes (including buffer zone)

- ***Component linked to a habitat's environmental structure (hydrodynamics and physicochemical processes)***

These indicators enable the assessment of ecosystem health based on external physical or chemical characteristics (abiotic) including water quality. These indicators are recorded from field observations and water quality monitoring. (Tab. 5 partially reproduced here).

in cases where the required information cannot be supplied and/or completed, the indicator can be disregarded or experts consulted on the issue. This analysis will be carried out in each habitat (homogenous ecological unity) identified within the footprint area and the buffer zone. Equivalence between impacted and restored habitats during compensation can also be controlled during this phase.

Indicators	*Score*	*Metric*
Habitat 1 - physical environment		
1. What is the general physicochemical state of the littoral waterbody within which the habitat is located?		"0. The waterbody is very turbid (1 to 3 m of average visibility), very desalinated (<32 ‰) or highly exposed to human inputs (erosion, agricultural, domestic or industrial pollutants). 1. The waterbody is turbid (3 to 6 m of average visibility), desalinated (32 to 35 ‰) or moderately exposed to human inputs. 2. The waterbody is clear (6 to 12 m of average visibility), with normal salinity (35 ‰) and low exposure to human inputs. 3. The waterbody is extremely clear (> 12 m of average visibility), with normal salinity (35 ‰) and very low exposure to human inputs."
2. What is the sedimentation rate observed on the habitat?		"0. All subtrates, even recently submerged, and benthic organisms are covered with fine or flocculent sedimentary deposits, resuspended by the diver's hand. 1. Substrates exposed to currents are cleaned, but covered surfaces, crevices and benthic organisms tend to fill or clog. 2. Substrates exposed to currents are cleaned, only the interstices, the algal assemblages and the cracks allow the accumulation of sedimented particles. 3. Substrates exposed to currents are cleaned, no sedimented particles are resuspended by the diver's hand."
3. What is the general physicochemical state of the surrounding sediments?		"0. Sediments are muddy to sandy mud, with a high proportion of fine particles and a marked anoxic stratification (black strata). Possibility of a living veil of cyanobacteria. 1. Sediments are sandy-muddy, with a high proportion of fine particles but without visible anoxic stratification. Possibility of a living veil of cyanobacteria. 2. Sediments are isometric fine sand, with a small fraction of fine particles and without anoxic stratification or cyanobacteria. 3. Sediments are coarse sandy, with a very small fraction of fine particles without anoxic stratification or cyanobacteria."
4. Does the habitat contain or is it near the mouth of a river or coastal resurgences?		"0. The habitat is located in the estuarine zone or in the immediate vicinity of a river mouth or freshwater coastal resurgences. 1. The habitat is located outside the estuarine zone, but is regularly influenced by its turbid or desalinated plume. 2. The habitat is located at a distance of several hundred meters to a few kilometers from the nearest hydrographic system and is subject to its influence only in a diffuse and discontinuous manner. 3. The habitat is not subjected to any influence of hydrographic systems or coastal resurgences."
5. How is the habitat exposed to currents and swells?		"0. The habitat is shallow (<10 m) and very exposed to swells and general currents (trade winds, monsoons, wind waves). 1. The habitat is located deeper (between 10 and 30 m), but very exposed to swells and general currents. 2. The habitat is shallow (<10 m), but relatively sheltered from swells and general currents. 3. The habitat is located deeper (between 10 and 30 m) and is relatively sheltered from swells and general currents."
6. What is the frequency and the most probable trajectory of cyclonic events?		"0. Cyclonic events are frequent (annual to multi-year) and preferentially oriented towards the study site. 1. Cyclonic events are moderately frequent (biennial) and preferentially oriented towards the study site. 2. Cyclonic events are frequent, but the study site is relatively sheltered from their most probable trajectories. 3. Cyclonic events are rare to very rare, whatever their trajectories."
TOTAL 2		
AVERAGE (/ 10)		

Table 5: Indicators of a habitat's environmental structure

- ***Component linked to a habitat's ecological structure (biological processes)***

This involves the assessment, particularly of coral, macro-benthic and fish communities, of whether conditions are favourable for the maintenance of species expected in the ecosystem (Tab. 6 partially reproduced here).

Although mobile species (fish, some molluscs, etc.) may travel in and out of the area under assessment, their use of the habitat makes them nonetheless good indicators, primarily in terms of population structure. Their strong temporal variability does however call for assessments to be carried out under controlled environmental conditions (tides, season, lunar cycles, etc.) so as to allow comparison of results before and after works, and on impacted and compensated sites.

Assessment of these indicators involves the correct identification of the ecological reference framework of each identified habitat within the footprint area and the buffer zone, corresponding to their healthy environmental status, as well as the identification of each change within ecosystems, associated with a degraded status.

restored habitats during compensation can also be controlled during this phase.

Indicators	*Score*	*Metric*
Habitat 1 - biological environment		
1. Are the coral communities diversified (species richness), characteristic of specific environments (deep, swell, confined, etc.) and do they contain exceptional species (keystone or mutualistic sp., ecosystem engineer, etc.)?		"0. Few or no coral species are recorded on the habitat. These are mainly pioneer, ubiquitous species with no exceptional characteristics. 1. The habitat has high species richness, but there are few exceptional species such as keystone species 2. The habitat has limited species diversity, but these are characteristic of the specific ecosystems and may contain a relatively large proportion of exceptional species. 3. The habitat has high species richness, contains a high proportion of species characteristic of thespecific ecosystems as well as exceptional species."
2. What percentage of hard substrates is covered by coral communities and what proportion of this coral cover is represented by Acropora species?		"0. Corals cover less than 10% of hard substrates, regardless of species involved in coverage. 1. Corals cover 10-30% of hard substrates, of which Acropora species represent less than 20%. 2. Corals cover 10-30% of hard substrates, of which Acropora species represent more than 20% or corals cover 30-60% of hard substrates, of which Acropora species represent less than 20%. 3. Corals cover more than 30% of hard substrates, of which Acropora species represent more than 20% or corals cover more than 60% of hard substrates, of which Acropora species represent less than 20%."
3. Are coral communities predominantly flat (encrusting, foliaceous), compact (massive, sub-massive) or upright (branched, tabular, columnar) forms and do they offer a wide variety of habitats to other reef organisms?		"0. When present, coral communities are predominantly flat and small, offering little habitat to other reef organisms. 1. Coral communities are predominantly flat, with few large but scattered massive colonies, offering some overhangs and crevices as habitat for reef organisms. 2. Coral forms are diverse with large massive colonies, however the proportion of upright forms remains low (<20% of coral cover), limiting the number of habitats available. 3. All coral forms are present, with large massive colonies and an exceptional proportion (>20%) represented by upright forms, offering numerous and diversified habitats."
4. What is the average size of live coral colonies and how are their size classes distributed within the community (homogeneous or heterogeneous distribution)?		"0. When present, live coral colonies have homogeneous size classes, with diameters predominantly less than 15 cm. 1. The size classes of live coral colonies are homogeneous, with a central class between 15 and 30 cm in diameter. 2. The size classes of live coral colonies are heterogeneous, with the majority of colonies smaller than 30 cm in diameter. 3. The size classes of live coral colonies are heterogeneous, with the majority of colonies larger than 30 cm in diameter and possibly also, some very large colonies."
5. What is the health (necroses, bleaching, cracks, fluorescence, etc.) and the resilience potential (abundance of recruits, cm. in diameter) of the identified coral reef communities?		"0. Necrosis and cracks (debris) are evident on coral communities. Some colonies are bleached. Algae invade hard substrates and larval recruitment is low. 1. Necrosis is abundant , but little debris. Colonies may be bleached (<30%). Algae colonize hard substrates and recruitment is low. 2. Some coral colonies may be bleached or fluorescent (<30%), but little necrosis is evident and algae do not invade hard substrates. Recruitment is strong. 3. Most corals are healthy. Very few colonies are dead, necrotic or fissured, and algal assemblages are scarce. Recruitment is strong."
6. Are the fish communities diversified (species richness), characteristic of specific environments (deep, swell, confined, etc.) and do they contain extraordinary species (keystone or mutualistic sp., etc.)?		"0. Few or no fish species are recorded within the habitat. These are mainly pioneer and ubiquitous species with no extraordinary characteristics 1. Habitat has high species richness, but predominantly, these species are ubiquitous and there are few extraordinary species. 2. Habitat has limited species diversity, but these species are characteristic of specific habitats and may contain a relatively large proportion of extraordinary species. 3. Habitat has high species richness, which is characteristic of specific habitats and contains a high proportion of extraordinary species."
7. How can the relative abundance of fish populations be qualified at the scale of the study site, the region and the biogeographic pool (relative to a pristine site)?		"0. Fish communities are very scarce at the scale of the study site, the region and the biogeographic pool. 1. Fish communities are moderately abundant at the scale of the study site, but they are scarce at the scale of the region and the biogeographic pool. 2. Fish communities are relatively abundant at the scale of the study site, but exhibit average values of the region and the biogeographic pool. 3. Fish communities are abundant at the scale of the study site,the region and the biogeographic pool."
8. How are diets, size classes and maturity rates distributed within the fish communities (top-down or bottom-up regulation, population strategy, trophic network, etc.)?		"0. Fish communities are composed of juvenile, small-sized, school-dwelling individuals, the majority of which are represented by few species of low trophic levels. 1. Fish communities are composed of juvenile, small-sized individuals, the majority of which are represented by few species, including some rare apex predators. 2. Size and maturity classes are heterogeneous, abundances are fairly equally distributed among species, but high-trophic predators remain rare or small. 3. Fish communities have many adult individuals of large sizes, in schools or solitary, fairly equally distributed among species and mainly of high trophic level."
9. How can the relative abundance of hard substrate, starfish and sea urchins be qualified at the scale of the study site, the region and the biogeographic pool (relative to a pristine site)?		"0. The densities of sea urchins or starfish on hard substrates are significant at the scale of the study site, the region and the biogeographic pool. 1. Sea urchins or starfish are moderately abundant at the study site scale, but elevated at the regional and biogeographic pool scale. 2. Sea urchins or starfish are relatively scarce at the study site scale, but remain within the regional and biogeographic pool average. 3. Densities of sea urchins or starfish are small at the scale of the study site, the region and the biogeographic pool."
10. Species of interest to fisheries (fish, molluscs, crustaceans, sea cucumbers, etc.), sold on the market or exported, show signs of overexploitation (reduction in size classes and densities, majority of juveniles, scarcity, etc.)?		"0. Species of major interest to fisheries are absent or almost absent, the few individuals observed are small-sized (juveniles) and fleeing - Malthusian overexploitation type. 1. Species of interest to fisheries are present but rare and observed in low abundances, with majority juveniles - Recruitment overexploitation type. 2. Species of interest to fisheries are fairly common, moderately abundant with an absence of large mature individuals - Growth overexploitation type. 3. Species of interest to fisheries are common, abundant and size classes are equitably distributed between small and large individuals - No overexploitation."
11. What is the prevalence of diseases (fish, corals, mangroves, etc.) and how can it be qualified at the scale of the study site, the region and the biogeographic pool (relative to a pristine site) ?		"0. Disease symptoms are frequently observed on the affected organisms. some have died recently, others show an imminent mortality by their behavior or appearance. 1. Symptoms are observed on many individuals or colonies, but the vitality of communities seems to balance the resulting mortality. 2. Disease symptoms are rarely observed on a few individuals or colonies, at a frequency equivalent to the regional and the biogeographical pool average. 3. The health of the organisms is optimal, no necrosis is observed, corresponding to a low prevalence at the regional and biogeographic pool scale."
TOTAL 3	0	
AVERAGE (/ 10)	0	

Table 6: Indicators of a habitat's ecological structure

2.3.7 Consideration of regulatory requirements and management priorities: the adjustment factors

As previously seen, these factors enable environmental gains and losses to be adjusted, so as to comply with specific regulatory requirements, management priorities, societal choices, etc. These factors either increase or reduce the compensation area calculated at the end of the process (weighting adjustment).

At this stage in the method's development, two basic adjustment factors are proposed: risk "R" and delay "T" factors, as they allow for a direct translation of European regulatory requirements (CGDD, 2013).

Suggestions for other potential adjustment factors are also made [Protected Species or habitat Factor (PSF) or Conservation Adjustment Factor (CAF)] based on observations and discussions with stakeholders involved in the ARO sequence during testing of the method.

- ***Risk "R"***

This factor assesses the level of uncertainty associated with the ecological trajectories of ecosystems that are subject to compensation measures. It can range between 1 and a maximum value to be established by authorities. In tests, carried out by the authors, the maximum value of 3 (which was established in Florida) was chosen after negotiations with many stakeholders in the ARO sequencing method.

A score of 1 corresponds to minimum risk: the compensation is well-designed and carried out in an ecologically stable area in which compensation measures are expected to be successful. It could also express "up front" mitigation, that was implemented and achieved successfully, prior to the authorized impacts. The assessment of this adjustment factor is based on ten questions that cover the different components expected to contribute to the success of the compensation measures, which are detailed in Table 7. A score of 3 corresponds to maximum acceptable risk, once mitigation is still expected to succeed. Mitigation that does not have a clear expectation of success is too risky, and should not be accepted. By using a multiplier of 3, the impacts might still be fully offset if the mitigation only results in providing a third of the expected functions.

Indicators of Risk		
Lowest risk: 1	***Moderate risk: 2***	***Highest risk: 3***
1. Can the environment and water bodies, located within a distance of 1 km from the footprint area, be potentially exposed to more intense uses and exploitation or cause unanticipated secondary impacts?		
All habitats and water bodies located within a distance of 1 km will be, or are already, included in a protected area	The habitats and water bodies are not properly managed but secondary sources of impact or exempted activities are unlikely, based on urban planning documents and the history of prevailing use beyond the 1 km area	The habitats and water bodies are not properly managed and, in addition, potential sources of secondary impacts or exempted activities within this area have already been identified
2. Is the size or the scale of the compensation area sufficient to provide the essential habitat(s) for local species?		
The compensation area is vast or is part of public or private protected domains, which are sufficiently large to resist fragmentation or disturbances from outside the area	The compensation area is not sufficiently large and is not part of public or private protected domains, sufficiently large to resist fragmentation or disturbances from outside the area. On the other hand, fauna exist that will not be affected by low levels of fragmentation or disturbances from outside the area	The compensation area depends on resources located outside the area to accommodate fauna within it. The fragmentation of habitat outside the area will probably reduce the benefits the area provides to fauna
3. Does the design of compensation measures use proven and well-documented methods with analyses adapted to their complexity?		
The methods have been shown to be successful in other sites	The proposed actions require adaptation but use proven methods	Proposed interventions rely on experimental un-mastered conditions, or proposed interventions depend on methods that are unproven
4. Is the water body contributing to the study area sufficiently protected and controlled to provide an aquatic environment (i.e. having water of acceptable quality) compatible with the expected compensation?		
The contributing water body is sufficiently controlled or protected to be compatible with the compensation measures. If the hydrology depends on tides or currents, the neighbouring water body is sufficiently controlled or protected also, so as to provide water of acceptable quality	The majority but not the totality of the contributing water body is sufficiently controlled or protected; there is, however, an area within the water body that is neither protected nor controlled	The majority of the contributing water body is not sufficiently controlled or protected
5. What is the compensation area's potential for infestation by exotic or invasive species?		
Exploration of the studied area, and adjacent water bodies, reveal no invasive or exotic species. Adjacent water bodies are subject to a sustainable management plan that includes the treatment or removal of invasive or exotic species	Exploration of the studied area, and adjacent water bodies, reveal no invasive or exotic species. But nothing is known of adjacent areas.	Exploration of the studied area, and/or adjacent water bodies reveals invasive or exotic species,. Adjacent water bodies are not subject to a management plan or are not controlled by authorities or the manager
6. Does the design of compensation measures use proven methods to restore, create or develop the targeted ecosystems?		
Planting, transplanting, grafting and other techniques proven on other sites, are to be implemented in the area under study	Plantation, transplanting, grafting and other techniques found in scientific literature will be implemented in the area under study; however, there are few documented cases of success on other sites	Experimental or non-proven techniques are proposed. They depend on natural recruitment in the area where natural regeneration capacities to develop are unknown
7. Are soils, substrates or sediments in the compensation area appropriate for the communities targeted for restoration?		
The sediments or substrates of the studied area are similar to those associated with targeted native communities and will not be modified	The sediments or substrates of the studied area should be able to support the targeted communities. Otherwise, the plan allows for other techniques backed by documented successes in other sites (immersion of artificial supports)	Experimental modifications or non-proven techniques are proposed and the nature of sea beds in the studied area is different from that associated with native communities
8. What degree of risk is associated with the complexity of earthworks, ground works or changes to sediments or substrate related to the implementation of compensation measures?		
The natural topography or bathymetric variations are comparable to those associated with targeted native communities: no terracing, or changes to sediments or substrates are necessary or proposed	Proposed actions include sediment or substrate modifications, and / or earthworks, but proposed methods are demonstrated to have been successful in other similar sites	The natural topography or the bathymetry of the studied area is not comparable to that which is normally associated with targeted native communities. Or the proposed actions include sediment or substrate modifications, and / or earthworks, but the methods considered have not been successfully demonstrated in similar sites

9. Are the considered long-term management measures sufficient to succeed and perpetually maintain ecological processes in the compensation area?		
Techniques that are documented and proven to be successful in other sites are proposed, and all necessary action to maintain the type of chosen habitat are contemplated in the plan	Targeted communities or the conditions specific to the site are not covered by management plans, or the long-term management plan covers some but not all actions necessary to completely facilitate the continuous development of native communities	Experimental compensation measures, with requirements regarding maintenance that are not defined, are proposed. Either the long-term management plan is insufficient to ensure the permanent protection from exotic, invasive or harmful species, or the proposed actions are inadequate for providing for the on-going development of native communities
10. What level of protection is ensured by the conservation instrument of the compensation area?		
The area is managed by a third party (MPA manager, NGO, association, etc.) for a period adapted to the environmental restoration project	The area is the subject of a temporary authorization to occupy, but for a short period or without a clearly defined or mandated manager	The area is not the subject of an agreement, use management or plan monitoring

Table 7: Guide to rating risk "R" factor

If previous studies are insufficient to inform the risk adjustment factors, then the levels proposed in table 8, will depend on the type of environmental compensation project selected according to the ecological engineering standard developed by the Society for Ecological Restoration (Pioch et al., 2015).

Type of compensation	*Corrective scores linked to risk*
Conservation	1 – 1.25
Improvement (rehabilitation)	1.25 – 1.75
Restoration	1.75 – 2.5
Creation	2 – 2.5

Table 8: Corrective scores linked to the risk associated with selected compensation project

- ***Time Delay "T"***

The adjustment factor associated with the delay in compensation, relative to the loss of the impacted site, reflects the additional compensation required due to the delayed recovery of coral reef functions. Guidelines specify that the determination of compensation measures must consider the time delay between a project's impact and the effects of measures taken.

This raises the question: how long must one wait for compensation measures to produce the expected results? The answer is not always an easy one, as we do not in all cases have data on the times required for each ecosystem's restoration.

In general, the delay varies according to compensation planning which itself is related to the impacts. The restoration of a coral reef environment involves a delay due to the establishment of ecological processes that are often much longer than the majority of restoration activities on land. Within coral reefs and associated ecosystems, coral reef systems need more time to establish their ecological processes than mangroves or seagrass beds.

Factors to be considered when assigning this delay, include:

- compensation/restoration/enhancement plan,
- biological, physical and chemical processes,
- the quality of water and sediments associated with nutrient cycles,
- the development of living communities and their reproduction.

We propose to simplify the choice of delay by using a time period that reflects the general trends previously described on environmental restoration periods. The delay is converted into a coefficient factor greater than or equal to 1, with a factor of 1 corresponding to a minimal delay, and is calculated on the basis of a discount rate.

This discount rate allows the current economic situation to be considered throughout the entire period required for the replacement of the lost ecological processes of the impacted ecosystem. It is for this reason that gains and losses are assessed on an annual basis (or monthly, quarterly or biannually according to time required). The annual rate is fixed at 3% per year in the USA (Tab. 9) and 4.5% per year in the Lebègue et al. (2005) report. The economic discount tool is thus used to compare gains and losses, which take place over different periods, on the same timescale.

This adjustment factor provides an estimation of "foregone earnings" regarding services, assessed on an annual basis and over the period necessary for the complete recovery of the lost ecological processes. It should be noted that the delay between the implementation of works (impacts) and the initiation of compensation measures should be added to the total delay in the replacement of a lost ecological process, when calculating the adjustment factor. Inversely, if a compensation measure is initiated prior the works being carried out, this should be subtracted from the total delay in recovery.

Average number of years (time lag) necessary for the replacement of ecosystem functions	**Time-related adjustment factor (T) 3%/yr**
< or = 1	1
2	1.03
3	1.07
4	1.1
5	1.14
6 – 10	1.25
11 – 15	1.46
16 – 20	1.68
21 – 25	1.92
26 – 30	2.18
31 – 35	2.45
36 – 40	2.73
41 – 45	3.03
46 – 50	3.34
51 – 55	3.65
> 55	3.91

Table 9: Example of a 3% time-related adjustment factor

2.3.8 Proposal for complementary adjustment factors

- ***High-level heritage issue: Protected Species or habitat Factor (PSF)***

Impacted habitats and species are often assessed from the perspective of a "high-level heritage issue" or "environmental interest" on impact assessments, but this way of perceiving ecosystems and species reflects management priorities or conservation choices. Based on Fennessy et al. (2007) we do not recommend this type of indicator to be included in the assessment matrix, as was frequently proposed by the French government bodies and consulting firms contacted during our tests. Instead, we propose the inclusion of a coefficient reflecting the high-level heritage issue, referred to as Protected Species or Habitat Factor (PSF) that could be applied to environmental gains and losses.

This coefficient will complement the protected species aspect, Natura 2000 or ZNIEFF-Mer by considering species and habitats that are not necessarily listed, but are nonetheless of major significance.

- **Key Marine Ecological Features issue: Conservation Adjustment Factor (CAF)**

Key Ecological Features (KEFs) are the components of the marine ecosystem that are considered to be of importance for a marine region's biodiversity or ecosystem function and integrity. If the compensation project is located in a KEF, or is a key area such as a corridor due to its connectivity, the Conservation Adjustment Factor (CAF) can be applied so as to increase the project's environmental value. The same factor can be applied if the impact is located in an area identified by a Blue-Green Network (European regulation), so as to increase the value of losses.

However, it is best to remain cautious in the extrapolation of adjustment factors that will result in a potentially excessive increase in compensation areas, while respecting the demands of qualitative equivalence.

2.4 Precision regarding application procedures

MERCI-Cor´s initial operational trials have provided practical recommendations regarding application procedures.

2.4.1 Study Area

The assessment of gains and losses can be complicated when the area to be studied is vast and includes several different ecosystem types which can potentially overlap.

Several situations can be encountered (Figure 9):

- **The area may be small or vast but comprises just one type of ecosystem** that appears homogenous: the assessment can be carried out on the entire area, as a single entity.
- **The area is vast and comprises different ecosystem types, which are separated from each other:** the assessment can be carried out by dividing the managed area into sub-areas, corresponding to each ecosystem or habitat, and identifying the different ecological functions of habitat. In this case, environmental losses of the sub-area 1 are calculated, followed by those of sub-area 2, etc., then the environmental losses of the buffer zone, and finally all the environmental losses are combined.
- **The area is vast and comprises different ecosystem types with considerable overlap and diversity.** This situation is found where environments have been successively modified and impacted in some areas and not in others. In such cases, it is preferable to divide the area into homogenous blocks, each representing the degree of modification or organization of the habitats therein. It is also possible to determine percentage cover of a total area by fragmented ecosystems and to assign to each sub-system the value of indicators measured at each of the represented stations. This requires a prior analysis of the area's history, in order to understand successive developments or activities that took place in the area and resulted in this fragmentation.

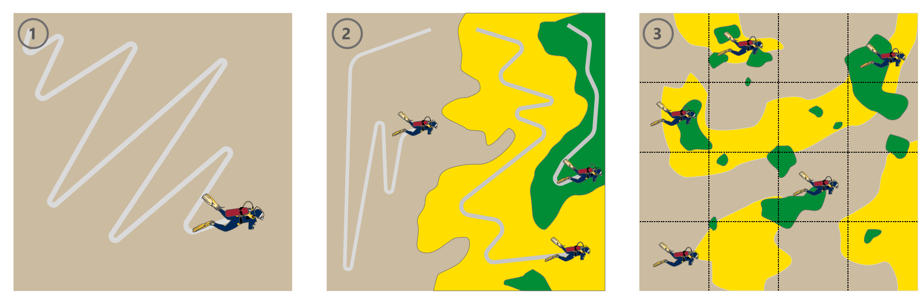


Figure 12: Different types of study area: 1. Any sized area, but with only one type of ecosystem, 2. Large area with different types of distinct ecosystems, 3. Vast area with different nested ecosystems.

2.4.2 Ecological reference framework

Previously (paragraph on the principles of the MERCI-Cor method) we explained the requirement of an ecological reference framework to determine the environmental status of an ecosystem. At the operational level, the ecological framework must be adapted to a specific ecosystem/habitat that will provide, for this ecosystem/habitat, the maximum score (10/10).

Broad reef health information can be garnered globally from the Reef Check network, with more defined information from the Atlantic and Gulf Rapid Reef Assessment (AGRRA), the Global Coral Reef Monitoring Network (GCRMN). Reef Base, a global database on coral reefs is another good resource for determining habitat health. For Europe, habitat records and local inventories from Natura 2000, ZNIEFF-mer and Framework Directive Marine Strategy (DCSMM under its French acronym) provide good ecosystem descriptions, indications on their ecological degradation features, as well as precisions on biogeographical conditions on their development.

In order to identify, in practice, the ecosystem that could be used as a reference framework for the studied environment, one should propose areas that are better preserved and have the best conservation status, close to the subject area. It is also possible to refer to old studies or aerial photographs.

2.5 Application example of the MERCI-Cor method

This tool and instructions for use, still under development, will be updated regularly, based on feedback and regulatory updates. The aim is to provide a standardized methodology and application tool for the ARO sequence, and in particular, to evaluate the losses and gains caused by significant residual impacts of the projects as well as the effects of compensation measures.

This chapter is based on the following document "Application of the MERCI-Cor model to the fictitious case of the Sainte-Rose wastewater treatment plant (Réunion Island)", in its latest update. This working document (in French), which will evolve during the various MERCI-Cor workshops will be available by request, at the end of the workshops planned around the MERCI-Cor theme.

2.6 Limitations of the method

As in all methods, MERCI-Cor does not answer all issues raised in the application of ARO. The primary limitations of this tool are outlined in the table 10.

Limitations	Details and explanations
1. Margin for interpretation of indicators and observations	Interpretation may make it difficult to assign a score to an indicator when applying the method. This can lead to significantly different results, such as harsh or indulgent scores, in the same assessment carried out by different people. It is recommended that assessments of the impacted and compensation areas, both before and after, are carried out by the same person, so that such a bias will have no effect. To offset this problem, persons applying the method must be trained, and use guidelines that are as comprehensive as possible for application and interpretation, with examples to minimize possible bias.
2. Develop/complete indicators	Work remains, which will be informed by the use of the MERCI-Cor method, both in the continuous improvement in the choice of indicators, and in the establishment of the proposed scores.
3. Definition of ecological reference framework	Despite the choice of institutional reference framework (e.g. Natura 2000 in Europe), there remains room for bias. This could be reduced by the training workshops and group discussions proposed by IFRECOR (2016-2018). Another way is to use a team of experts to assess the values (cross scores) for a consensus opinion.
4. Experimental status	Sensitivity tests are to be carried out to evaluate the difference in scores among assessors and the sensitivity of the method with different ecological states. Calibration tests should be carried out based on recent good examples, and compared to compensation results from the application of the method. This will enable the range in the variation of factors to be adjusted and aligned with each national context. Group discussions, via an interactive web platform for example, will facilitate such harmonization. The interpretation of indicators remains to be refined and completed by testing the method on a wide variety of projects and environments. Here again the web platform and group discussions are highly recommended.
5. Protected species/habitats approach	The method, as currently proposed, does not take into consideration protected species/habitats as an indicator, risking a situation where proposed compensation does not target protected or heritage species at all. An adjustment factor is proposed, however, in the form of the Protected Species/Habitats Adjustment Factor (PSF) which involves social and environmental contexts.
6. Establishment of a function-by-function qualitative equivalence	The method enables the assessment of the level at which the ecological processes are functioning, in other words, the point at which it carries out the expected ecological functions. However, in its current form, it does not provide information on the precise functions which are carried out (or not). Many regulations call for this in order to judge qualitative equivalence.

7. Danger of depending on existing diagnoses	The method can be applied to existing diagnoses, such as the initial state established by consulting firms and project managers. One must take great care regarding the reliability of these diagnoses and their inclusion in the MERCI-Cor assessment as this might skew results. Ground truthing will often be required.
8. No model yet developed for coral reef associated ecosystems	Coral reef associated ecosystems, primarily mangroves and seagrass beds, do not yet have appropriate ecological indicators in the current version of the MERCI-Cor tool. These ecosystems, which are very often closely linked with coral reef ecosystems, will be the subject of special tables that are under development.
9. Exclusion of sandy and sandy-silty habitats (lagoons, bay heads, estuary area, etc.) in the calculation of biophysical losses	It is recognized that sandy and sandy-silty habitats can play an important role in maintaining coral reef ecosystems (ecological niche, nutrition, nursery, corridors, etc.), and these cannot be assessed in the same way as habitats with a hard substrate (reefs, rocks) or pebbles, mainly due to the cryptic nature of resident flora and fauna (often burrowing species). Projects' impacts can nonetheless be estimated, with MERCI-Cor´s framework trying to express the functions that sandy areas provide to a coral or seagrass community through the Location of Site or Landscape analysis. However, we recommend the use of additional possible visible indicators (siltation, sediment cohesion, appearance of anoxic stratification, flocculation, etc.), based on the structure of communities living on the surface or slightly buried in the sediment (proliferation, ecological disturbance, etc.), physical-chemical (level of organic matter, grain size, pollutants, etc.), or others (odours, etc.) to be added in Location of Site or Landscape table. Some indicators adapted to this type of habitat have been developed by Bigot (2006) in La Reunion, within the European Water Framework Directive (DCE).

Table 10: Limitations of the MERCI-Cor experimental method

This method, still in an experimental state, proposes a systematic approach to the application of the ARO sequence. With a view to improving the method we recommend the development of:

- **training workshops or group discussions,** to share and apply these methodological principles in the field,
- **an interactive web platform**, "MERCI-Cor user community" for example, in order to promote the harmonization of practices and update feedback, both of which are required for its development and evolution.

3 CHOICE OF COMPENSATION SITE AND ENVIRONMENTAL ENGINEERING TECHNIQUES

3 CHOICE OF COMPENSATION SITE AND ENVIRONMENTAL ENGINEERING TECHNIQUES

Whatever the method used in the assessment of compensation measures and their scaling, the compensation site should be chosen based on specific criteria. In the absence of a hierarchy, a multi-criteria study would draw attention to the Strengths, Weaknesses, Opportunities and Threats (SWOT analysis) of the different sites contemplated for compensation.

The compensation site should be situated as near as possible to the impacted site. Such proximity contributes to the objective of conserving regional uniqueness and ensuring beneficial impacts within the same functional ecological groups, as well as for the users who have suffered from the project's residual impacts. This condition is also required for the compensation of degraded ecological function, such as nursery restoration within the area dependant on that functionality (notion of essential habitat). However, this prerequisite of proximity is not always possible or desirable, as in the case of project impacts that can degrade nearby habitats. While other proposals for a site outside the area can be considered, the choice must be justified by prohibitive constraints (re. close sites) or considerable opportunities (re, distant sites). Distant sites must also (as much as possible) provide ecological composition, structures and functions similar to those of the degraded site.

The similarity between impacted and compensation sites is the second element to be considered. This must allow for opportunities that are as similar as possible regarding uses, heritage and landscapes. This similarity will be considered optimal when compensation takes place on the same project site; for example, where environmental engineering measures aiming at reinforcing or substituting a degraded ecological function (destruction of essential habitats, fragmentation, breaks in connectivity, et.) are carried out. In such cases. There is no difference between reduction and compensation measures.

The third criterion is the **presence of, or the opportunity to implement a management plan on the compensation site** by incorporating measures and enabling their sustainability via monitoring, evaluation and sustainable management of renewable resources. Furthermore, restored ecosystems sometimes require assistance, and have to be put on "life support". This is undertaken through handling/manipulation, often prescribed in post-restoration management plans, with a view to achieving the original objectives. This option might create problems if the compensation measure requires continuous intervention in the long term (restoration should be sustainable). This must be indicated from the design phase of the restoration project, the level of the Risk Factor and highlighted as requiring an adaptive management approach.

Constraints linked to the technical feasibility of the measure can also play a role in site selection. Thus, maritime access, location near a port, bathymetry or hydro-dynamism are all variables that may complicate or, on the contrary, facilitate the application of the measure. The site offering the best opportunities in terms of technical implementation, which also have reduced risk, will thus be given preference. Such opportunities are greater if the measures of several projects can be shared on the same site (see below). Furthermore, as the notion of technical constraints is closely linked to the cost of implementing the measure, the choice of the site with the least technical constraints will also present the best financial cost/environmental benefit ratio.

The estimation of benefits in terms of use and exploitation of renewable natural resources (fisheries, tourism, scientific, etc.) also provides information to be considered when examining the compensation site. Historic data on previous exploitation of potential sites, particularly fisheries and outstanding marine physical features (canyons, caves, fall offs, etc.) will provide arguments in favour of the chosen site. Specific measures aimed at improving connectivity between fragmented habitats will also be very effective in improving the potential for exploitation of sites with ecological discontinuity (causeways, ports, finger piers, etc.) and difficulties in replenishing stocks.

Finally, **the financial aspect,** often highly dependent on other criteria previously discussed, is a predominant factor in choosing the compensation site. The financial aspect of the measure, which is usually based on the cost per square metre of the restored surface, determines the total surface area of the possible restoration that will be higher when the square metre cost is lower. The choice of the site with fewer restoration costs per square metre will thus enable the implementation of either the largest compensation measure or the least expensive.

This selection method could be presented in table form with criteria in columns and potential sites in rows. Each criterion can be assigned a score or a metric (0 = weak, 1 = average, 2 = strong) and the rows summed, thus attributing each potential site with a total score; enabling the identification the site with the highest potential for compensation regarding the defined criteria.

3.1 Contractual arrangements for compensation

Project Managers are responsible for choosing the most appropriate providers and determining contractual arrangements for compensation measures. The request for authorization to occupy a marine area belonging to the State, for a period to be established, should be established within the framework of an EIA, following the validation of the measure adopted by the project manager. Drawing up contract specifications regarding the implementation of possible technical aspects of the measure (underwater works, maritime and site capacity, etc.) and scientific follow-up to assess the level of success (number of years to be monitored, interventions and competencies required, assessment methods, etc.) should also be requested by project managers within the framework of the EIA.

3.1.1 Identification of a steering committee

The **first criterion** required when making contractual arrangements for the specified measure is **the identification of a steering committee**, recognized for its experience and/or its legitimacy in the area of compensation measures. This steering committee could, for example, be a regional fisheries organization, in the case of the submersion of artificial reefs for fisheries or government agencies involved in coral transplantation from a port, etc. This may also be the project owner who caused the residual impacts.

The Steering Committee's role would include the issuing of tenders for the implementation of compensation measures and scientific follow-up during the regulatory monitoring period (preferably a manager of natural areas or MPAs). At the end of this period, the role of the steering committee can be delegated to a management structure, over a designated period.

3.1.2 Financial validity of the measure

The second criterion required in contractual arrangements is **the financial validity of the measure.** This involves an exhaustive examination of the costs for implementation, scientific follow up and the management and quantification of potential benefits from the measure during the regulatory period. All financial estimations must be budgeted and presented, breaking costs down for each budget line and indicating sources of funding.

Even though the majority of funds for the measure would come from the project which caused the degradation, other sources of project funding can be considered. These other sources can, for example, correspond to an extension of the measure's objectives such as the installation of a mooring device on an artificial reef, or the sharing of the work site built to achieve economies of scale such as a park of artificial reefs funded through several compensation measures.

Such methods for the implementation, management and valuations should, to the extent possible, take precedence. This is even more important, as sharing often increases the importance and effectiveness of the compensation measure.

3.1.3 Ecological and scientific competence of the team

The competence of the team members involved in drafting contracts is a key element in the project's acceptance or refusal. This team must be recognized by State authorities (government bodies) as competent in the required fields and must have the necessary experience and the ability to anticipate potential challenges involved in the implementation of the different measures. Collaborating with a university or researchers from other institutions would also be beneficial, so as to offset possible shortfalls in scientific expertise on the part of the entity carrying out the EIA. Detailed curricula vitae of experts participating in the contracts drafting should be annexed to the EIA.

3.1.4 Responsibility and control

Responsibility and control should also be included in the contractual arrangements for compensation. These relate to obligations regarding the protocols used, outcome objectives and monitoring of success. The responsibility for implementation, monitoring and assessment of the measures' levels of success falls on the project manager.

The criteria for the selection of the compensation site (as described in the previous section) should be summarized and easily accessible. A table presenting results of the SWOT analysis of each suggested site will provide a clear and pertinent summary of the steps that led to the selection of the most appropriate site.

The project manager must also provide some guarantees regarding work implementation and the compensation program. He/She should commit to returning the site to a state corresponding to conditions detailed in the assessment for compensation of the project's significant residual impacts. In certain cases, the manager must also commit to ensuring that each planned measure is reversible and that work undertaken can be dismantled, extracted or rearranged with a view to returning the site to its initial state, if the compensation measure's objective is not achieved; as in the case of artificial reefs, for example.

Ecological restoration or reconstruction techniques implemented with the aim of achieving the compensation measure objectives, must be fully described in order to allow them to be evaluated by a scientific committee. The assessment of the measure's expected performance will include information on similar projects carried out in other parts of the world. When the measure is the first of its kind and is highly experimental, a research programme should be associated with it, in order to determine its efficacy. This is extremely important for cases in which benefits have not been previously documented.

Monitoring should occur via scientific monitoring events for which the protocols are clearly outlined. The methods employed must be proportionate, realistic and directly relevant to the compensation objectives declared in EIAs. Established objectives should be presented in a qualitative and a quantitative manner. Causal links between measures taken and expected improvements in the project's success indicators should be detailed in a table. These indicators must be associated with thresholds representing the compensation measure's quantitative objectives. The timeframe for achieving objectives should also be specified and justified in light of established scientific and environmental criteria.

It is as important to consider the risks associated with the non-achievement of the objectives as the measure's success. These risks might appear in the form of a natural catastrophe (cyclonic events, coral bleaching, proliferation of Acanthaster, volcanic eruption, etc.) or a human induced disruption, beyond the responsibility of the area's management authority (oil spill, mudslide, shipwreck, etc.), or the result of an inappropriate technical decision or error by those responsible. Mentioning these risks provides the opportunity to establish the orders of magnitude of the measure taken (mechanical, ecological, socioeconomic resistance) and the potential for adaptive management. This should be scaled in accordance with rare climatic events, likely to take place during the measure's desired performance period (maximum 10-year or 100-year values).

Finally, the terms should be established for the transfer of information to a delegated management body that will implement the measure at the end of the regulatory monitoring period. This management body could, for example, be a natural areas manager, a nature protection association, a fishers' union or a city council service. The measure's steering committee could also offer its own services as the delegated management body and continue the activity for as long as the measure requires managing. This time frame will be either to ensure the ecological compensation role or for the duration of the authorization for the temporary occupation of the Public Maritime Domain (PMD). Renewal of this authorization should be sought until such time as compensation objectives have been achieved and are sustainable. A request for the extension of the temporary occupation period could also be made if necessary. The delegated body could also seek the assistance of an external independent oversight body, represented, for example by a consulting firm, a scientific committee or a group of experts.

3.2 Types of compensation measures

The choice of compensation measures (once compensation objectives of species composition, structural and functional losses of impacted ecosystems are met) is left up to the project manager. No known regulations exist to specify the type of compensation measures to be carried out to meet these objectives.
If confronted with a given residual impact for which there are no known or possible restoration techniques, a targeted scheme to improve knowledge on the project's impacts (on the condition that it studies the links between conservation issues, pressures and impacts of the activity and associated restoration methods) can be accepted as a compensation measure (specific procedure for the marine environment). This chapter presents examples of the three types of compensation measures most frequently carried out in coral reef environments (Chipeaux et al., 2016).

3.2.1 Territorial conservation measures

In a terrestrial environment, the project manager can propose the acquisition of a given natural space for, management, conservation and scientific monitoring with a view towards compensating for the residual impacts of a project.

The question of heritage conservation is, however, a problem from a compensation perspective and it is therefore necessary to show that the conserved site would deteriorate in the absence of conservation (so as to show the conservation advantages) and that conservation would not have been undertaken, other than the compensation activity (Levrel et al., 2015).

In a marine environment, with the PMD that is not subject to limitation, this type of territorial measure involves the creation of a Marine Protected Area (MPA). The petitioner can propose the creation or an extension of a MPA and provide (financial or logistical) resources for its management (Figure 13). However, it falls on local authorities to designate the MPA's perimeter and define its management procedures. For example, the creation of a marine reserve could reduce poaching, protect resources and limit threats to the coral reef.

It is important to note that in the majority of MPA categories (marine nature park, area adjacent to a national park, etc.) the protection goal does not exclude other objectives, particularly managed economic development such as ecotourism and fishing associated with the area.

It is worth also recalling that the principle of additionality, applied to already existing public policies and that the creation of the MPA must be accompanied by management measures in order to be accepted as a compensation measure. The project manager must thus propose, through agreement with local stakeholders, a management plan describing the objectives of this protected area as well as management measures and an action plan.

Unless the project manager is a local authority, it is common for the managing body to possess neither the competence nor the authority to programme and ensure the effective management of a MPA. It is therefore more effective to relegate such tasks to a natural area manager (community, association or public body), that will commit to implementing activities involving communication, supervision, awareness raising, protection, knowledge enhancement and monitoring.

The establishment of MPAs as compensation measures, however, faces several challenges. There is the danger that compensation measures can be substituted for the conservation role played by public bodies. To avoid this, the requirement that no "public" reserve project exists on the chosen compensation site at the time of the EIA, should be instituted. Furthermore, from the perspective of the functionality of degraded ecosystems, one should choose a site with degraded ecological functions as close as possible to those likely to exist due to the project, and to bring about restoration after establishment and management of the reserve. A quantitative estimation of the gains, which is extremely difficult to determine experimentally (pers. com. Hay, 2016), is also required.

Figure 13: West entrance of the Nouvelle Route du Littoral (NRL) in Reunion Island (© M. Pinault). The prime contractor (Réunion Region) proposes as a first compensation measure the «definition and management of an area of protection of remarkable marine habitats». It has therefore set itself the objective of protecting a marine site with a minimum area of 150 hectares.

Another limitation is the management and financing capacities of MPAs by public authorities:

1. The required skills (scientific, management, etc.) and staffing are not always available in the public service.,
2. Private sector financing is increasingly being looked to as a means of negating minimal/fluctuating financing by Governments. However, this may raise issues of public accounting and the availability of funds for a specific objective

3.2.2 Acquisition of offset credits

Offset credits have been available from mitigation banks since the 1970s in the USA and currently represent 26% of compensation measures (Vaissière et al., 2017).

A mitigation bank is a private or mixed institution that brings together offset credits held by private or state entities to sell them for future development projects (Figure 14). Operators of mitigation banks (mitigation bankers) establish environmental offsets to improve the environmental status of natural sites (not MPAs) that are managed by them. Natural asset reserves are created in restoring or creating an environment that has a high ecological value. Inherent costs are considered to be an investment (Figure 15).

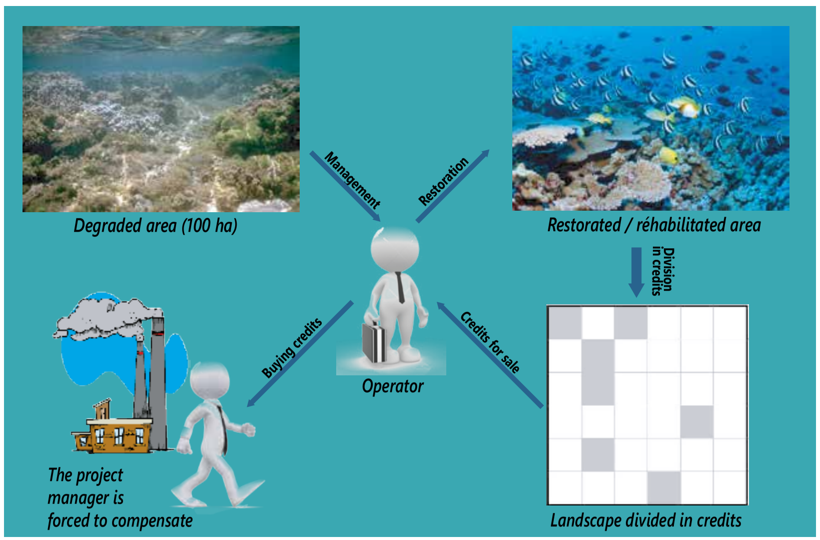


Figure 14: Principle of natural asset reserves (source Chabran, 2011)

Offsets then appreciate when sold to developers who must compensate for their impacts on the same habitats or species targeted by the bank, under regulators´ (in ´the USA with an Interagency Review Team) supervision through public policy framework (rules and acts). The mitigation bank system thus enables the sharing of several compensation projects and the anticipation of their future needs. Reserves of natural assets provide interest in avoiding a net transitional loss of biodiversity, functionalities and ecological value. They somewhat anticipate concerted actions, beneficial to natural environments prior to any impact of development schemes (Figure 15).

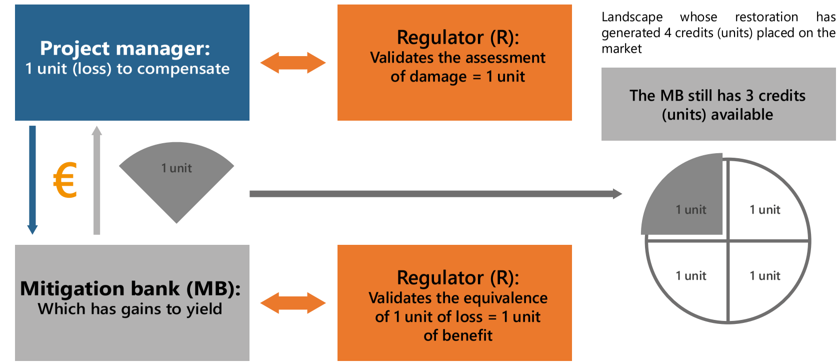


Figure 15: Scheme simplifying the mechanism binding an operator (mitigation bank or Mitigation Banking - MB on the figure) with a Contractor (C) bound by a contract of purchase of units of natural assets (credits) validated by the State (R for Regulator).

The procedures and monitoring of compensation measures by project managers are thus facilitated (Figure 16).

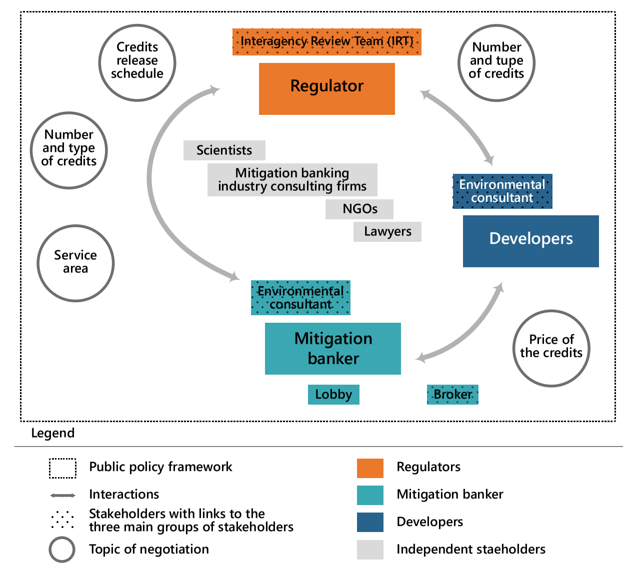


Figure 16: The stakeholders and the topics negotiation in a wetland mitigation bank (in Vaissière, Levrel and Pioch, 2017).

However, this system has encountered strong opposition on principle, particularly regarding those project managers, with the means to purchase natural assets, thus acquiring the "right to destroy". The underlying idea is that the creation of a market for natural assets implies the monetarization of nature. Additionally, the sustainability of a site and sound environmental management are to be ensured by the operator, requiring the establishment of a strict legal framework and control (Chabran & Napoléone, 2012).

3.2.3 Restoration of degraded natural environments

According to Moreno-Mateos et al. (2015), the aim of environmental restoration is to: *"place an ecosystem that has been degraded or destroyed, within its historical context, that corresponds to a moment or a period in the past, that has been chosen to represent a reference ecological state".*

In practice, the choice of this period to represent a reference ecological state (initial state) should be based on environmental as well as societal factors: What functions are to be restored – identical to those destroyed or new ones that are socioeconomically desirable and meet society's expectations? This depends on the historical context and the documents chosen to define this period (related to the study of ecosystems or their exploitation - fishing, tourism, etc.). Although this question goes beyond the scope of this handbook, it thus appears that the notion of initial state is a subjective estimate, which can be influenced by the availability of documents and the choices of the project steering committee.

Prior to detailing the primary techniques to be utilised, a summary of definitions related to the restoration of projects involving degraded environments is set out below.

The Society for Ecological Restoration (SER, 2004) defines **the ecological restoration** of an environment as: *"any process aimed at facilitating the restoration or repair of a damaged ecosystem to a reference condition."*

More precisely, it can be defined as the process of accompanying and assisting in the restoration of an ecosystem that has been degraded, damaged or destroyed (Clewell & Aronson, 2013). The aim is for the environment to develop naturally after restoration activities (without other artificial interventions) through self-regeneration processes.

Ecological rehabilitation (close to ecological restoration) is a process that helps re-establish functions of a damaged ecosystem, although not all functions of the reference system may be met (vs real restoration projects). The aim is generally to re-establish productivity or, more frequently, the provision of ecosystem services (Clewell & Aronson, 2010).

Finally, in the case of ecosystems that are too degraded, **reassignment** is proposed to modify the ecosystem for purposes completely different from those contemplated in its reference condition (Aronson et al., 2007). Its aim is often linked to social expectations: protection of an emblematic species, aesthetics, etc.

We note that the **protection or conservation** of an environment is envisaged, within this framework, only in the absence of any form of degradation, but does not constitute a repair action *stricto sensu* of nature. Protection can fall within the field of ecological restoration, but this approach requires careful handling. Environmental gains (added value) are often weak, and can be problematic when the solution is proposed as a compensation measure.

Protecting a site that is already functioning correctly presents a problem when calculating the equivalence between net gains and losses linked to degradation, as gains will be non-existent or very weak (see Chapter on compensation). But it is also equally clear that after degradation, the protection of a healthy ecosystem enables the repair of some environmental components without direct human intervention.

The procedures and monitoring of compensation measures by project managers are thus facilitated (Figure 16).

SER definitions	State bodies / management
Restoration (towards a reference condition)	Restoration
Rehabilitation (from a reference condition)	Improvement/rehabilitation
Reassignment (no reference condition)	Creation
Conservation (no degradation of reference condition)	Protection / preservation

Table 11: Ecological restoration and relationships according to SER and State Bodies' definitions (the X refers to "no correlation")

Environmental engineering involves environmental management and the design of sustainable development schemes inspired by or based on mechanisms that govern ecological systems (self-organization, diversity, heterogeneity, resilience, etc.). This activity aims to restore or create sustainable, and thus stable and autonomous ecosystems, which have an intrinsic natural value and potential for people (Chocat, 2013).

From a technical perspective, restoration and creation call for the application of environmental engineering techniques that vary according to the required level of intervention in habitats and species (Pioch et al., 2017). Restoration is more demanding and therefore more difficult to implement than creation, as it requires a thorough knowledge of how ecosystems function (marine environments are little understood). Of course, if we can identify the cause of the loss or degradation of the habitat, repairing the damage should result in successful restoration. With creation, all the factors that are necessary for the establishment of the new habitat have to be identified. These processes often involve a series of tests to validate techniques prior to their possible development on a larger scale (experimentation phases are often fundamental).

Improvement and protection techniques are mainly undertaken to halt degradation and prevent future pressure, in order to improve or maintain a reference condition. In the case of marine environments, Elliot et al. (2007) refer to passive approaches with weak human action on the ecosystem (leaving nature to repair itself), compared to active actions involving more interventionist environmental engineering. In fact, these measures focus more on the sources of degradation (waste, uses, etc.) than on techniques aimed at restoring species or repairing degraded habitats (Borja et al., 2010).

In any project dealing with compensation, the following options should be considered in this order of priority: restoration, creation and, as a last resort, conservation (as potential gains are smaller). However, it should be recalled that all these measures are effective only within a regulatory framework and with the available resources to ensure their enforcement; in other words, only if it is possible to adopt a policy capable of assessing projects' impacts, anticipating future pressure, and/or stopping them.

[11] In Florida, regulators only allow mitigation credit for preservation of a habitat if the unavoidable destruction of the habitate is otherwise imminent.

3.2.4 Research and scientific programmes

A programme to enhance scientific knowledge is acceptable in the case of compensation measures, only if it studies the links between conservation issues, the pressures and impacts of the activity concerned and the associated restoration methods. When possible, this option enables problems to be overcome when there is a lack of knowledge of the environment or the techniques aimed at its restoration. It is usually associated with one or several concrete measures (environmental engineering, creation of reserves, management enforcement, etc.) and plays a role in their evaluation.

3.3 Environmental engineering methods adapted to coral reefs

It is important to recall that the best compensation schemes often achieve barely 70% of established objectives, and very rarely 90% in the case of simple ecosystems. In addition, the time required to reach these objectives can be relatively long (5–8 years, and perhaps more, but feedback is limited due to short monitoring periods). There is thus always a risk of net loss to be considered when scaling compensation (foresee slightly increasing ratios) (Moreno-Mateos et al., 2012).
This chapter briefly summarizes some of the primary techniques (of the 24 listed by Jacob et al. (2017)) developed in the world (see Annex 2). However, this list is far from exhaustive and new methods are developed annually with the aim of improving environmental integration of submerged structures or materials (Chipeaux et al., 2016). Nevertheless, when determining which of these techniques should be used in compensation measures, it is important that the issue of intellectual property be addressed, as techniques are often patented by the companies responsible for their development. The development of new techniques, inspired by previous experience and adapted to the specific requirements of the site is preferable, due to the sometimes extremely high costs of operating rights of patented techniques.

3.3.1 Transplantation of coral

Coral transplantation involves fixing previously collected coral fragments or entire colonies to different kinds of hard substrates (concrete, coral skeletons, glass plates, metal, etc.) (Figure 17). The primary objectives in transplanting coral are: to save what would otherwise be destroyed and to improve the quality of the recipient reefs in terms of live coral coverage, biodiversity and structural complexity (topographic roughness).

This objective can be broken down into four specific objectives:

1. increase coral coverage and biodiversity,
2. support the recruitment of coral larvae through the presence of mature transplants,
3. foster the survival of rare and threatened coral species when their habit is destroyed,
4. increase roughness and shelter in bare areas.

Figure 17: Transplantation programme carried out on the threatened species Acropora palmata in the Caribbean and study of transplant growth during a period of 5 years (© Coral Restoration Foundation Bonaire)

Deciding to use coral transplantation as a compensation measure will depend on the nature and origin of the degradation suffered by the natural environment . This technique is adapted to the replacement of dead or broken colonies due to acute deterioration to accelerate the natural regeneration process or to build resilience. In contrast, it is useless transplanting colonies into zones where prevailing conditions are unfavourable for coral development or are likely to reappear (even if briefly) on a frequent basis.

It is therefore suitable for episodes of physical damage, short-term and accidental pollution, the proliferation of *Acanthaster planci* the past use of explosives or to acute coral bleaching episodes (on the condition that these disruptions do not occur frequently). However, transplantation is unsuitable for areas where there is any sort of chronic discharge. Furthermore, the high cost of transplantation can make it unsuitable for large impacted areas.

The key benefit of transplantation as a restoration tool lies in the speed with which it can be carried out (no net loss due to a delay between implementation of the measure and achievement of objectives). As soon as they have been fixed, transplants are able to grow, lay and offer shelter to associated species (fishes, crustaceans, echinoderms, etc.).

Transplanting is also of considerable scientific interest. Experimental research programmes have thus been carried out, particularly on the resistance to the coral-zooxanthellae relationship, genetic fluxes and on the adaptation of colonies to environmental changes.

A research programme however, cannot take the place of a compensation measure, unless it is followed by a larger-scale application aimed at restoring lost ecological functions. Studies available on coral transplantation are often limited to short term temporal and small spatial scales and, in the majority of cases, no controls have been established to enable comparisons on the effectiveness of the restoration. Methods of transplantation, extraction and host sites appear to strongly influence the risk of failure.

Greater success is likely when there are as many physical, chemical and environmental similarities as possible between the host and extraction sites. If transplantation takes place on sites exposed to wave action, a large proportion of transplants may become detached, even if they were fixed securely. In such a case, damage will be caused to the host site (and should be included in calculating of compensation). The level of consolidation of the substrate, exposure to wave action, and frequency and direction of storms and hurricanes on host sites are elements that will determine the level of success of the transplantation.

The loss of genetic diversity can also result in the failure of this technique. The population of a given species of coral presenting greater genetic diversity is more resistant to disease and temperature fluctuations (Dixon et al., 2015). Certain types of coral, such as branched *Acropora* spp. reproduce naturally via cuttings, while others, such as massive encrusting colonies, use this mechanism only rarely (Harriott & Fisk, 1988). When transplantation is carried out, each transplant will have the same genome as the mother colony. The analysis of different populations indicates that the use of ten donor colonies, randomly chosen within the host population, would conserve 50% of its genetic diversity, while 35 colonies would conserve 90%. The sampling of a minimum of ten colonies would thus appear to be a reasonable objective (Shearer et al., 2009).

The stress caused by the collection of colonies from extraction sites can also result in a number of issues related to the health of coral colonies. Clark & Edwards (1995) state a stagnation of coral recovery rate on the extraction site for a one to two year period following the collection. There is also the risk of contributing to coral disease on wounds caused on source colonies as well as the potential spread of contaminated fragments towards distant host sites. Particular attention should thus be paid to sample-collecting methods, inventorying disease and its percentage rate of prevalence so as to provide an estimation of the health status of the source population and of the risk of contamination (Rinkevich, 2005).

Furthermore, even with careful handling, transplanted colonies tend to present higher death and lower fertility rates than undisturbed colonies, at least during the months following transplantation. Transplants are usually more susceptible to disease, bleaching and exposure to *Acanthaster planci* or parrotfish. However, this sensitivity varies between species; massive, encrusting species demonstrate less sensitivity than those that rapidly grow, such as *Acropora* spp. (Auberson, 1982; Plucer-Rosario & Randall, 1987; Yap et al., 1992). Very small cuttings also appear to be more fragile and have higher mortality rates that large ones. Cuttings with a minimum size of 5–10 cm have the best chance of success. The balance between mortality and regeneration potential by fragmentation should thus be carefully assessed for each site and each species to be transplanted (Highsmith, 1982).

Finally, if natural ecological successions are not considered, transplantation will fail. Indeed, when a reef is formed, not all species colonize it simultaneously. Pioneer species, with a relatively short lifecycle but a high fertility rate such as *Pocillopora* spp. in the Indo-pacific region, install themselves first, followed by more competitive species, such as *Porites* spp., that are often larger but slower growing with lower fertility rates. Thus, transplanting *Pocillopora* spp. to a highly structured environment might not be a wise choice, as these transplants would be expected to die rapidly. A study of the ecological structure of the host site would therefore be required, so as to better adapt the species to the constraints linked to interspecific interactions (Moberg & Rönnbäck, 2003).

For example, in New Caledonia in 2009, a compensation measure imposed on a private mineral extraction company following the construction of a port in a reef zone was aimed at saving coral reef colonies threatened by development and their use in the restoration of 2,000 square metres of damaged reef. Approximately 2,000 coral colonies which were representative of the threatened area of different growth types, were collected and transported (20–30 minutes) in containers exposed to air but regularly doused with seawater. These transplants were cemented to the natural limestone

rock at three different sites. The resources necessary for the restoration of 2,000 square metres of reef involved a team of three marine biologist divers, a land assistant (preparation of cement mortar on the surface and logistical assistance), a boat and diving equipment. Of the 25 days in the field, a third of the time was spent on preparing field campaigns, logistics and local transport, and two thirds spent on restoration activities, choosing the site, collection and transplantation and basic monitoring. The cost of materials was € 14,000 and salaries € 36,000. The monitoring of transplanted corals is scheduled for twice yearly (cool season and hot season) over a five-year period.

One month after transplanting, signs of growth were found at the base of the transplanted colonies. After 30 months, results showed the survival rate to be 90% and the growth of transplanted colonies could no longer be distinguished from natural colonies. The success of the operation on the third site was less however with mortality rates of 50% on transplants. This example shows the high variability in success of these types of operations, particularly with regard to the environmental conditions of the host site.

3.3.2 Submersion of artificial reefs

According to the Food and Agriculture Organisation (FAO) the term Artificial Reef (AR) refers to: *"a submerged (or partly exposed to tides) structure deliberately placed on the seabed to mimic some functions of a natural reef, such as protecting, regenerating, concentrating and/or enhancing populations of living marine resources. This includes the protection and regeneration of habitats. It will serve as habitat that functions as part of the natural ecosystem while doing "no harm"."* Few authors, expand the definition to all materials disposed on the seabed (Duval & Duclerc, 1986) (Figure 18). This definition is in line with our requirements of intention and functionality.

However, it does not include submerged structures that have been deliberately placed for specific objectives, which do not include mimicking natural habitats, such as breakwaters, anchorages, cables, pipelines, marine research equipment or platforms. This is even though such structures fortuitously imitate certain functions of the natural environment. Nonetheless, they can often be upgraded by an effort of eco-conception or eco-design, to reduce their negative impact and enhance their ecological integration (Pioch, 2017; Pioch et al., 2017).

For European projects, the Financial Instrument for Fisheries Guidance (FIFG) recommends scientific follow up over a 5 year period, to assess the performance of all ARs (Pary, 2004). However, different studies show that 5 years might not be an adequate time frame for monitoring, as communities on artificial reefs do not always reach a steady state by this time and continue to evolve (Dalias & Scourzic, 2008; Pinault, 2013).

Figure 18: Scientific assessment of an artificial reef in La Possession (Réunion Island) (© G. Marquis)

The potential offered by the submersion of ARs may also contribute to protection against coastal erosion and marine flooding, as well as fisheries development, economic profitability (recreational or educational diving), biodiversity conservation or environmental knowledge, and particularly the colonization processes of a virgin habitat (Pioch, 2008).

The environmental benefits depend on circumstance and involve an increase in:

1. substrates available for coral reef organisms,
2. structural complexity,
3. post-larval installation and recruitment,
4. species richness,
5. connectivity between sites,
6. alternative sites for diving as well as public awareness raising (Pinault, 2013).

The diversity of AR architecture and volumes allows them to be used in the functional restoration of ecosystems on rocky substrates, through the design of habitats that mimic conditions, which attract targeted species to the degraded habitat (void ratio, structural complexity, height, edge effect, etc.).

ARs can, for example, replace the nursery function of certain species or allow the colonization of high densities of crustaceans of interest to fisheries (lobster, crabs, spiny lobster, etc.). However, they are not adapted to the restoration of habitats with ecological and geomorphological structures that are too complex to be replaced by a substitute artificial environment, such as coral reefs. The high cost of underwater deployment can also make them unsuitable for the replacement of large areas of degraded habitats.

The primary advantages of ARs are:

1. the reversible character of their submersion (even though retrieval is more expensive than submersion),
2. their durability (depending on the materials used),
3. their capacity to replace an ecological function that has been lost or degraded and to stimulate the production, under certain conditions, of more biomass than the host site prior to its development.

On the other hand, assessments of ARs are often incomplete and anthropocentric (diving, fisheries interest, recycling of bulky materials, etc.), with few studies addressing questions of ecological connectivity and continuity between natural and artificial habitats. Furthermore, the development of this technology is slow and costly, mainly due to a fragmented understanding of interactions between species and their habitats. In general terms, although the use of ARs has increased over the last two decades, a gap remains between the publics' perception and demand, and scientific knowledge of the how ARs work (Pinault, 2013).

There are constraints associated with the development of AR networks such as physical deterioration, the destabilization of anchorages, unintentional breakwater effects that result in downdrift beach erosion, the abandonment of structures by fish or dangers posed to navigation, that are intimately dependent on the environmental characteristics of the submersion site.

These conditions are related to the **slope of the terrain,** which influences strongly fish assemblages. The slope has also an effect on the stability of the structures that, exposed to wave action, can be subject to a variety of complex hydro-sedimentary phenomena. It is thus recommended that ARs be installed on slopes of less than 9° and between 0.3° and 0.5° on wave-battered coastlines (Miyazaki & Sawada, 1978).

The **submersion depth** affects both the biological community and productivity of structures, particularly due to the energy of wave action and light penetration. It also influences the size and type of fish species, with larger fish occupying deeper water, and coral and algae colonisation, with shallower waters providing more suitable conditions for growth (Pinault, 2013). Depth is important in terms of maritime security. A minimum above ARs is required (Bragoni, 1980), or ARs are to be lower than the highest existing natural relief in the vicinity (Darovec et al., 1975). ARs positioned below or above appropriated depths do not produce optimal results (Nakamura, 1985).

In Florida, beach nourishment projects can result in the burial of nearshore hardbottom (limestone rock outcrops) that provide important substrate for new growth algae and habitat for larval fish. They also support some octocorals and small colonies of *Siderastrea* spp. In order to replicate these lost habitats, it is necessary to construct low relief ARs in shallow water.

Martin Seeling, F-DEP, Florida

While all **geomorphological habitats** can theoretically accommodate manufactured structures, it is widely recognized that sandy or sandy-silty bottoms are better adapted to ARs (Bombace, 1983). Soft sediments of low cohesion, which tend to be fluid (clay, silts), are to be avoided due to the risk of siltation and the clogging of micro-habitats (Mathews, 1981). Hard substrates also do not favour the installation of dense populations of large fish. This could be due to their relief (bathy topography), which can partially hide the AR structures and thus reduce their attractiveness. It is thus preferable to choose compact, soft seabed (sand or small pebbles), with a thickness of 2–3 m above hard substrate (Hardy, 1983).

Fish appear to prefer **productive natural areas rather than artificial ones** (Kakimoto, 1979). It is therefore not ideal to choose a site that is already productive or in close proximity to healthy natural formations as ARs risk being abandoned by mobile populations, particularly fish. In addition, the placement of an AR too close to a healthy natural habitat could disrupt rather than restore lost functions and compromise regulatory clearance for the project. In 1967, during an experimental fishing exercise conducted within 1,850 m of an AR range, approximately half of fish were caught within a 370 m radius. Flat-bottomed areas at least 750 m from natural reefs should thus be selected according to Chang (1980). This is one suggestion however, as the optimal distance depends to a large extent on the environmental characteristics of the site and the species involved. ARs can however, be organized into small, compact groups or "villages" ranging from few metres to tens of metres apart. This type of arrangement is often preferable to a diffuse arrangement as it enables savings to be made on submerged materials, with each "village" representing a habitat with a surface area that far exceeds the sum of the surface areas of each AR.

The hydrodynamic effect of **wave action** strongly influences the integrity of structures and their colonization by organisms. It is the factor that primarily affects the biological community and productivity of structures (Katoh & Itosu, 1980). It destroys the epifauna and impacts the colonization of mobile organisms (Russell, 1975). Waves can also disturb sediments, thus increasing water turbidity, smothering and the corrosive effect of sand on ARs (Bragoni, 1980). This action is considerably amplified during cyclones/hurricanes. ARs should therefore not be exposed to strong wave action.

There are a variety of different opinions, from various studies, about the impacts of **currents** (tidal and general currents) on the AR settlement process. It appears that strong currents (above 1–3 knots) have the same negative impacts as wave swell (Russel, 1975). However, ARs that are too sheltered by the coast always lead to poor outcomes (Henocque, 1982). Exposure to moderate currents is thus recommended.

Finally, the **choice of materials and the architecture** strongly influence both the structure's mechanical resistance to deterioration and burying, as well as the ability of the AR to imitate natural ecological functionality; thus complying with one of the objectives of restoration (Pinault, 2013). It is therefore recommended to give preference to tough materials (concrete, with proportionated bolts, bracings and anchorages, etc.) and an architecture that does not present major resistance to currents in an area potentially exposed to violent, and/or sporadic wave action such as caused by hurricanes and storms. Particular attention should be given to the design and development plans of ARs, prior to any firm commitment being given to a project involving the submersion of materials (Pinault, 2013).

In 2008 in La Reunion, small ARs made of recycled material (electricity poles and concrete pipes) were submerged to compensate for the overfishing of deep-sea fish. The aim of these structures was to promote the recovery of stocks of small fish of interest to fisheries, by improving connectivity between their essential habitats. Four structures each measuring between 10–20 m3 were submerged, separated at 68 m along the -25 m isobaths. This programme complemented a park of three ARs submerged in 2002 at a depth of 15 m on the same site.

The conception, assembly, storage, transport and submersion of the five structures cost € 80,271 and scientific monitoring over a five-year period, including initial state, € 105,831, representing more than half of the overall cost of the operation. This monitoring contributes to the financing of a CIFRE thesis as part of the consulting firm responsible for the scientific follow up of ARs. This work reported on the positive effect of the ARs on the ecological continuity between coastal alluvial pebble sea beds (fish nurseries) and rock outcrops at sea, traditionally exploited by fisheries 700–1,000 m from the coast and separated by a vast sedimentary basin at the bay head.

3.3.3 Capture and post-larval fish culture

Post-larval capture and culture (PCC), which has started in Polynesia in the 1990s, is based on the capture of reef fish when they return in large numbers to the coast and their subsequent farming. The technique involves the collection of post-larval reef fish during the most appropriate period (highly seasonal) using a range of different devices (bongo nets and Neuston nets, light traps, etc.).

Larvae are then identified and separated on sorting tables prior to being placed in specific tanks for the nursery and growing-out period (Figure 19). In a natural environment, the majority (over 95%) of several million post-larval fish arriving at the coast each night fall prey to predators (Durville, 2002); therefore, the impact of the capture of several thousand post-larvae each night with environmentally-friendly devices can be considered negligible (Petit, 2010).

Figure 19: Capture by light trap and culture of post larvae in aquariums during the Zoé mission conducted in 2013 in Guadeloupe (© Ecocean)

A variety of destinations await these post-larval fish, once they have reached the juvenile stage, including the aquarium market, food markets, or re-seeding/seeding overexploited marine areas or the ARs respectively. The latter destination is primarily utilised for compensation measures.

The aims of compensation PCC are to:

1. support the resilience of certain fish populations by reducing the predatory pressure in the nursery colonization phase,
2. foster vulnerable species with a low reproductive capacity (grouper, demersal fish),
3. ensure the continuous colonization of growth ARs-type artificial nurseries.

However, the PCC cannot be considered a sustainable compensation measure as its benefits disappear once human intervention is discontinued. It can therefore only serve as compensation for a transitory impact or to accelerate the colonization, for example, of a recently submerged AR.

The ex situ component of the selection and growing stages of post-larvae is a crucial aspect in the choice of PCC as a compensation measure. It can be implemented as a compensation measure, which is carried out while works are underway; in other words, while the ecosystems of the study area are exposed to the project's maximum effects, including temporary effects linked to the construction site (turbid plumes, noise, congestion, etc.). PCC can also promote the acceleration of natural resilience processes, post-environmental impact with a view to ensuring no net biodiversity loss. For example, this method is appropriate in compensating a temporary breakdown in ecological continuity due to congestion on a building site (filtrating dams, oil filtering booms, piles, finger piers, etc.) or the initial planting of artificial structures to serve as nurseries. On the other hand, it is not appropriate for the durable replacement of a deteriorated ecological function, as it does not foster ecosystem autonomy or sustainability.

The primary advantage of this method as a compensation measure is the control over the procedure involving the capture of individuals and their release into a natural environment. This control enables a precise assessment of the survival rate, growth and thus the benefits of the measure up until the seeding of host sites. The control of the survival of released individuals, however, presents considerable challenges, specifically with the migration rate with respect to natural mortality and predation. The primary limitation of this method is the unsustainability of effects on ecosystems. It can momentarily boost certain natural mechanisms, but it cannot replace or sustain these over time.

As in the case of other methods presented, certain conditions for implementation will ultimately determine the operation's level of success. Among these conditions is the need for knowledge of the factors involved in post-larvae **habitat selection** for colonisation. Each reef fish species selects its first habitat according to its own specific mechanisms (Pinault et al., 2015). Some select topographic characteristics (height of surface irregularities, slope, depth, etc.), others prefer exposed sites or those protected from wave action, while others seek mobile or unstable habitats such as coastal pebbles or seagrass. Habitats, whether natural or artificial, where juveniles will be released after growing-out, must conform to the selection criteria for the species or risk the loss of recruits as they move towards more suitable habitats.

Another aspect to be considered is the knowledge of the biological cycles of target species. The majority of reef fish start their lives with an oceanic larval stage. Passing through this stage allows the colonization of new coastal habitats and promotes connectivity between populations and thus species survival (Crochelet et al., 2013). After having colonized nursery areas, some species rapidly migrate to deeper habitats (Dahlgren & Eggleston, 2000). Ensuring **ecological continuity** between essential habitats of collected species will raise the probability of success in the recruitment of individuals released into natural adult populations. This continuity can, at the same time, be accompanied by an AR submersion campaign (Pinault, 2013).

In cases of re-seeding overexploited areas or newly submerged artificial structures, **farming conditions** that promote the rapid adaptation of juvenile fish to the natural environment when they are released should be favoured. The choice of a feeding system which requires research into the nutritional sources and/or a period of restocking the natural environment will help both the re-adaptation and the competitiveness of individuals released into natural juvenile populations (Lecaillon, 2015). Indeed, apart from the risk of predation, access to food can also be a limiting factor and result in both intra- and inter-specific interactions likely to disadvantage farmed fish.

A prior survey of **juvenile densities** on potential release sites will enable the selection of those sites with the lowest densities thus allowing higher growing rates (Dahlgren et Eggleston, 2000).

In La Reunion, a study programme on the post-larval colonization of reef fish was based on the use and development of PCC. In 2007 the La Reunion Natural Marine Reserve [RNMR under its French acronym] was established to ensure the management of the natural area associated with coral reefs and their resources. The success of such a process over time requires basic knowledge on the environment and associated populations so as to better understand how the ecosystem functions and to propose appropriate management measures.

The study programme was integrated into this process in order to provide MPA managers with information required for improved understanding of the renewal of fish populations and proposing lines of action both for the conservation and the development of fisheries resources. Knowledge acquired on the biology of reef species also provides data essential for the use of hydrodynamic models, in order to highlight current patterns that can impact the dispersion of larvae during their oceanic stage. Together with genetic and otolith analyses of fish, these models have provided a better understanding of the origin of larval flux of interest to Reunion (local or regional origin).

3.3.4 Eco-design of coastal infrastructures (Green marine construction)

An eco-designed (or eco-conception) coastal infrastructure - CI - (viaduct pier, shells of sea walls, breakwaters, anchorage clamps, moorings, scour-protection mats, etc.) is a project that incorporates ecosystem conservation objectives into its functions at the same level of study and prioritization as the usual technical, economic or social objectives. Eco-design is thus part of the design of a project from the earliest stages (preliminary design or feasibility studies), when defining the functions of the structure and its ecosystemic objectives. It is based on the idea that the materials submerged as part of large projects, can serve a secondary ecological integration purpose (following some complementary adaptation such as covering, casting, perforation, etc.) (Pioch et al., 2011). This secondary purpose can range from simply helping with the colonisation of structures to the restoration of complex ecological functions. The earlier these modifications are taken into account, the higher the compatibility between durability or mechanical resistance objectives of CI and the attraction of organisms allowing greater achievement (Figure 20).

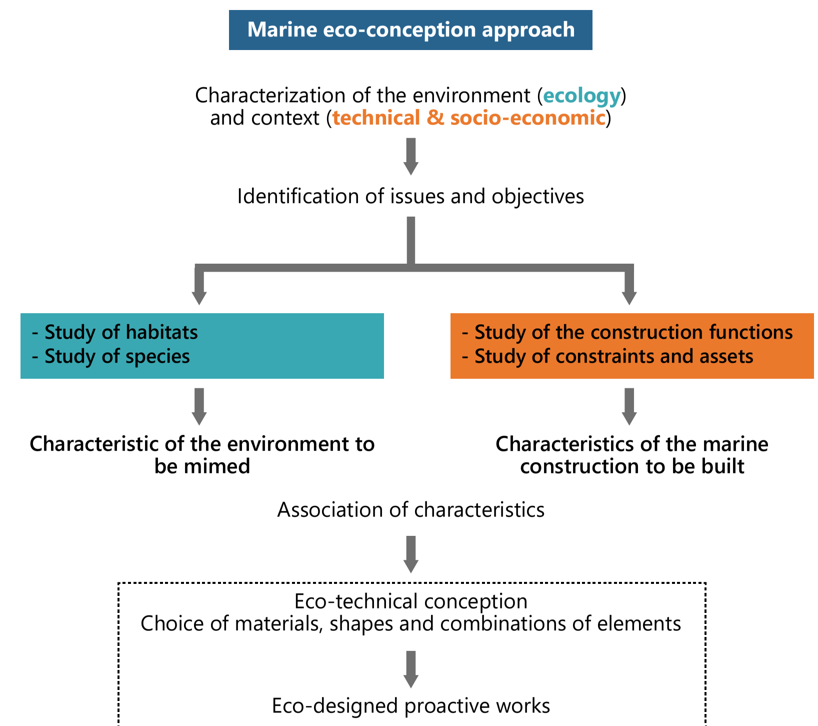


Figure 20: From concept to eco-design project (Pioch)

The conservation objectives of the eco-design relative to the impacted ecosystems have to take into account, at least, the identified impacts on the ecosystem, but can and should go well beyond that. The design should take into account, as much as possible, the integration of the infrastructure with the environment and which natural habitats, processes, or components thereof are affected, which habitats to preserve or re-establish, and how to incorporate creation of such habitats in the design conceptualization phase, taking into account both a conservation of habitats and minimization of impacts. Mitigation hierarchy, avoidance, reduction and, finally, offset proposals and adaptation actions are not central to eco-design, although they must also be fully taken into account by a specific 'Environmental Impact Assessments'. Similarly, the notion of 'no net loss', an effort to balance losses by increasing biodiversity or productivity to offset project-related impacts, is integrated into eco-design. This is because even when every effort is made to avoid, minimize and offset the impacts of construction, human activities can or will inherently negatively impact biodiversity to some extent.

Jacob et al. (2017) has shown that these activities are mainly related to port infrastructure and coastal defense, waste water collection and discharge, and sediment dredging and disposal. The idea, that damages resulting from human activities must be balanced by equivalent gains, is a necessary step in the right direction, but is not completely sufficient and can still be improved upon. Indeed, eco-design of a structure should not be defined solely in response to anticipated or unavoidable impacts, but should include ecosystem conservation objectives as well.

Consideration of the ecosystem requires an intellectual approach integrating many parameters. In particular, the notion of "habitat" is a key concept for population development.

When a new CI construction takes place in a natural area, it will create a new habitat (at a minimum as a hard substratum supporting settlement), with a colonization of every submerged surface being in direct proportion to the surface area of the deployed structure (assuming the deployment is not a biocide). Habit is somewhat arbitrarily divided into micro-habitat and macro-habitat with a division of about centimetric to pluricentimetric (cf. Figure 21).

Concern and scale	Design	Mainstream consideration
Micro-structure material (μ)		- Concrete implementation - Physic-chemical - Biological interaction - Colonization
Micro-structure external (cm)		- Mold for concrete - Colonization - Bio mimicking
Macro-structure (cm to m)		- Mold for concrete & implementation - Hydrodynamic - Artificial reef / habitat function - Bio mimicking

(photos @ JC Souche)
Figure 21: Submerged concrete: from micro-structure (material) to macro-structure (form design)

It has been established that artificial structures which have rougher surfaces, more closely matching natural topography will experience better colonization than smooth concrete surfaces. The presence of ledges, ridges and crevices has also been found to have some influence on improving the colonization and biodiversity of artificial marine structures. At microscopic and macroscopic scales of material and structures, the more roughness heterogeneity is the better good habitat for smaller organisms is provides as a refuge.

The eco-designed habitat elements typically do not require any special maintenance, like the rest of the structure, because, similar to ecological restoration (SER, 2004), the natural auto-regeneration processes should be favored. These processes should not generate any human interventions a posteriori.

In the end, three main questions have to drive CI eco-designed projects:

1. What are the ecosystem functions that the structure will support?
2. What habitats will be impacted by the project?
3. How could the current ecosystem functions, both locally and regionally, be maintained or developed?

An eco-based design also needs to mimic the original habitat as closely as possible, guided by the following principles: 1) to improve the ecological integration of its surfaces by bio-mimicry/nature-based solutions with naturally occurring ecosystems, and 2) to create complexity at micro-, meso-, and macro-habitat levels (create support for fauna, flora, juveniles and adults) (Figure 21).

Of course, creating artificial habitat can also facilitate the spread and support population growth of invasive exotic species. Thus, if the infrastructure also causes an areal impact or footprint on the sea-bed, this sea-bed area typically cannot be replaced. However, if one looks at the footprint from the perspective of surface area, then replacement is possible with material of higher roughness, i.e., boulders versus sand. Likewise, ecosystem services can be replaced, but seldom with full equity.

The specific objectives of eco-design projects within the framework of reduction or better integration measures can involve:

1. fostering the colonization of structures by benthic flora and fauna, and particularly coral,
2. providing shelter for lobsters, groupers, octopuses and other cave-dwelling organisms,
3. creating or restoring a nursery area,
4. restoring / creating or improving natural ecological continuity (blue network).

The eco-design choice can be driven by the positive image conveyed by the environmental integration of a large project's infrastructure. It is nonetheless desirable that the main motivation of the project manager is the achievement of quantifiable environmental objectives rather than acceptance by the general public. These measures can also, under certain implementation conditions, result in an interesting cost-benefit ratio for the project manager.

Eco-design is particularly adapted to:

1. reduce a longitudinal or transversal breakdown of ecological continuity,
2. restoring / creating nursery areas often affected by development projects due to their coastal location,
3. developing new fishing or hunting sites (fish, crabs, lobsters, octopuses, etc.),
4. restoring / creating deteriorated coral reefs.

The realistic scope of possibilities can therefore be identified and incompatible or poorly developed scenarios can be discarded at an early stage, according to systemic approach, involving large stakeholder opinions (Figure 22).

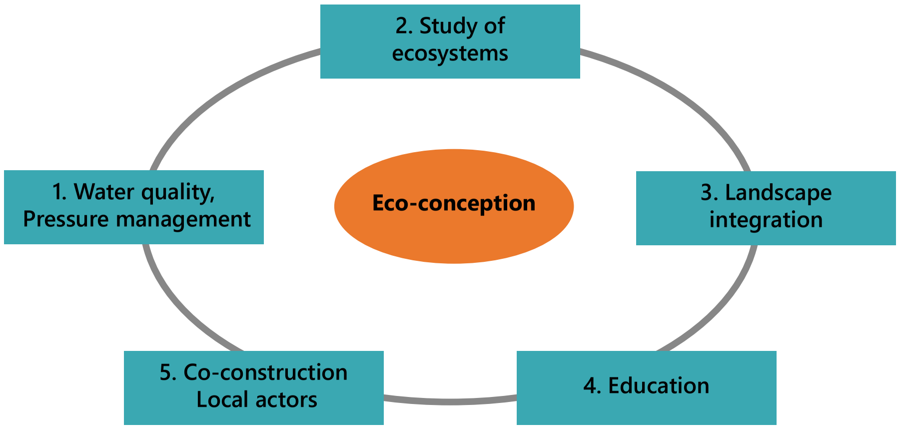


Figure 22: Principles for the implementation of an eco-designed maritime development project

Example 1: an experimental ballast system was established in Mayotte along 2.6 km of submerged drinking water pipelines linking the islands Grande Terre and Petite Terre located in a PMA (Figure 23).


Figure 23: Installation work for eco-designed pipelines in Mayotte in 2009 (© L. Cadet)

The installation of 200 of these ballasts has enabled the creation of more than 1,500 m3 of habitats in a lagoon ecosystem. Following the first positive results (increase in biodiversity and fish density, attachment of benthic organisms) observed in Mayotte, this solution has also been successfully applied on the island of Reunion, particularly as far as fish and lobsters are concerned. These preliminary experiences show that the colonization of this type of work is 10 times greater than a traditional installation. To date, 350 of these ballasts are under construction or being submerged around the world (Pioch et al., 2011).

Example 2: In 2013, in Deshaies (Caribbean area, France), 71 eco-designed mooring were disposed. The two main objectives were :

1. A mooring buoy programme to prevent the future damage to corals from anchoring
2. A unique coral propagation technique that helps to restore damage from past activities using the concrete block used for the mooring.

Local habitat mimicking, endangered species as well as functional targets have to be specified to guide the design of the concrete blocks, for ecological performance. From technical aspect, the material durability, stability and mooring system have to be adapted to the boat size and the hydrodynamic parameters. Finally, aesthetic considerations for landscape integration have to be developed (Figure 24).


Figure 24 : Eco-designed mooring system in Caribbean coral ecosystem in 2013 (Pioch)

Ecological assessment show from 5 to 10 times more species diversity, between a classical concrete block (cubic) and eco-designed mooring (Bigot, 2010). Young corals grow on rough parts. The additional construction costs are between 1 and 20%, depending upon the design. Mooring fees in Europe average between 9 and 60$/day, depending on boat-size. The life expectancy of the eco-designed block is approximatively 50 yrs.

3.3.5 Other methods existing or under development

Recent progress regarding the regulation of compensation measures and the advent of environmental engineering as a fully-fledged discipline are elements that have contributed to the proliferation of proposals for the restoration and rehabilitation of increasingly complex ecosystems. These proposals involve experimental projects, for which all the conditions for success are not yet completely in place, and are as diverse as the submersion of substrates comprising fragments of coralline algae that promote the attachment of coral larvae, the establishment of coral nursery farms, and electrodes stimulating coral growth. These non-exhaustive examples illustrate the considerable creativity in research in the field of reef restoration.

These techniques are also considered for coral reef associated ecosystems, in particular seagrasses and mangroves, on which several cutting and transplanting techniques are currently being tested. Mangrove reforestation campaigns, isolating propagules within protective tubes that facilitate the growth of young shoots protected from predators (Riley Encased Methodology – REM), were developed in the Caribbean since 2010 and provide encouraging results (Figure 25). Many attempts to transplant Posidonia oceanica have also been tested in the Mediterranean, some of which have promising results.

The aim of these techniques, often in experimental stages or employed in conjunction with other restoration methods (coral growth electrodes integrated in ARs or eco-design structures), is often to accelerate natural colonization processes (particularly coral) of degraded habitats. The example of artificial mangroves is aimed at rebuilding a complex ecological function that allows both improvements to water quality and a nursery role.

The implementation of these innovative methods tends to:

1. increase knowledge and facilitate the use of natural mechanisms involved in the restoration processes,
2. integrate devices to accelerate natural colonization processes in more conventional compensation measures,
3. develop new environmental engineering tools for the future.

Since 2014 and within the framework of a port extension project in Martinique, 270,000 m3 of 360,000 m3 of earth, rock and other bulk materials derived from the project are used as fill for the creation of a mangrove. The project's experimental facet involves specially tailored scientific monitoring in collaboration with a university research team. This monitoring should allow for a comparison of success rates of planting by species, population densities, their reclamation condition and the exact composition of sediments. It should also evaluate the factors that limit the development of seedlings, so as to propose possible adjustments.

Figure 25: Young growing mangrove still in its protective tube in 2010 (© REM)

The port will take charge of a doctoral student working on the mangrove ecosystem with this process to be led jointly with the Antilles Guyane University.

These measures have been estimated to cost € 95,000 for monitoring in the field over a three-year period, and €100,000 for financing the thesis. Given the uncertainties involved relating to the initiative's success, the EA recommends completing the case with a presentation of feedback on other similar trials in Martinique, and describing the long-term management and monitoring procedures, allowing the project to be continued until a functional mangrove is achieved.

4 IMPLEMENTATION AND MONITORING OF COMPENSATION MEASURES

4 IMPLEMENTATION AND MONITORING OF COMPENSATION MEASURES

We have seen that the objectives of compensation measures can be quite different, even though they all involve repairing ecosystems degraded by the residual impact of projects. Many regulations dictate that project managers return the site to a state at least equivalent to that of the original status and compensate for net losses during the construction phase. The assessment of the success or failure of these objectives must therefore be based on reliable qualitative and quantitative methods, in order to compare them with the evaluation of losses, described in previous chapters.

4.1 Planning the monitoring of compensation measures

The project manager is under obligation to demonstrate the success of restoration measures undertaken, or in the case of failure, to show that the resources committed and references used are trustworthy so as cover issues of liability. Monitoring is therefore a crucial component. From a regulatory perspective, the concept of monitoring varies and there are different obligations depending on the type of compensation measures chosen.

As has been seen in chapters dealing with loss assessment procedures, after avoidance and reduction measures have been taken, the evaluation of gains following the implementation of compensation measures relies on a rigorous protocol for the monitoring of relevant indicators in both space and time.

As compensation is undertaken to restore functions that have been altered by the project, indicators of deterioration and restoration can be considered as identical. Thus, the monitoring of compensation measures, should be carried out independently of an EIA, with different contractors from those involved in the estimation of losses and should be completed in close conjunction with the monitoring of loss assessment. The greater the similarity between the assessment methods of gains and losses, the better the reliability of comparisons.

The monitoring of compensation measures should utilise the same benchmarks as those in loss assessments, particularly those based on a complete analysis of the initial status, considering the series of indicator variables monitored. This initial status analysis is often neglected in impact assessments that generally rely on a large-scale focus and a rapid, semi quantitative description of some standard variables (coral coverage, relative fish density, etc.).

The monitoring of compensation measures must also consider the time estimated to achieve the expected results of the restoration. For example, it makes little sense to monitor the colonisation of a viaduct pier by corals on a monthly basis after submersion, knowing that the growth rate of these organisms is between millimetres to several centimetres a year. On the other hand, monitoring will most often be required for several years prior to achieving the expected results. Thus, the duration and frequency estimation and the number of monitoring activities for compensation measures is often a tricky issue and are often carried out over a too a short period of time for the established objectives to be documented.

4.2 Medium- and long-term management of compensation measures

In France and its territories, once the scientific monitoring is completed in accordance with the authorisation requirements, site management can be delegated to a management body (a public body managing the MPA, a local community or a nature conservation organization, a regional fisheries and fish farming committee, marine reserve, etc.).

This body will generally be designated from the moment the implementation measure is initiated and will be chosen based on the benefits expected from the compensation (fisheries, ecological functionality, biodiversity conservation, etc.). This body will be responsible for managing the benefits of the measure in a sustainable manner, whether these involve extractive, non-extractive or non-use values over the entire authorized period of occupation of the PMD, and with the possibility of renewing the Temporary Authorization to Occupy (TAO) request or concession if necessary. Prefectural orders also provide regulatory support for their sustainable management. Although the creation of a MPA does not require a TAO or a concession, it does require a prefectural or ministerial decree, which seems to be the only way to guarantee the sustainability of a compensation measure in a marine environment beyond 10 or 20-year periods (providing management and monitoring measure are also sustained).

Feedback on experiences showing benefits resulting from the management of compensation measures, both medium- and long-term, are however rare, although the measures carried out theoretically are the responsibility of the project manager until the time that the impact is at least completely compensated for (no net loss principle). In conclusion, there is a need to prioritize development projects' avoidance and reduction measures, and for compensation measures, for which conditions for success and benefits over the medium- and long-terms are still not clear, to be considered only as a last resort.

BIBLIOGRAPHY

Aronson, J., Renison, D., Rangel-Ch, J. O., levy-tacher, S., Ovalle, C., del Pozo, A. (2007). Restauración del Capital Natural: sin reservas no hay bienes ni servicios. Revista Ecosistemas, 16(3).

Auberson, B. (1982). Coral transplantation-an approach to the reestablishment of damaged reefs. Kalikasan-The Philippine Journal of Biology, 11(1), 158-172.

Barnaud, G., Coïc, b. (2011). Mesures compensatoires et correctives liées à la destruction de zones humides. Revue bibliographique et analyse critique des méthodes. Rapport ONEMA, MNHN. 104 p. http:/spn.mnhn.fr/spn_rap- ports/archivage_rapports/2012/SPN%202012%20-%201%20-%20 RappFinalCompensationZHOnemaMnhnCoic- Barnaud24-11-11.pdf

Bas, A., Jacob, C., Hay, J., Pioch, S., Thorin, S. (2016). Improving marine biodiversity offsetting: A proposed methodology for better assessing losses and gains. Journal of environmental management, 175, 46-59

Bayraktarov, E., Saunders, M. I., Abdullah, S., Mills, M., Beher, J., Possingham, H. P., Mumby P.J., Lovelock, C. E.(2016). The cost and feasibility of marine coastal restoration. Ecological Applications, 26(4), 1055-1074.

BBOP & UNEP (2010). Mitigation Hierarchy. Business and Biodiversity Offsets Programme & United Nations Environment Programme, Washington DC, USA.

Bennett, A.F. (2003). Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation. IUCN, Gland, Switzerland and Cambridge, United-Kingdom, 254 p.

Bezombes, L., Gaucherand, S., Kerbiriou, C., Reinert, M. E., & Spiegelberger, T. (2017). Ecological Equivalence Assessment Methods: What Trade-Offs between Operationality, Scientific Basis and Comprehensiveness?. Environmental Management, 1-15.

Bombace, G. (1983). Observations sur les récifs artificiels réalisés le long des côtes italiennes. Journée Etudes Récif artificiels et Mariculture suspendue, Cannes, Rapport et Procès-verbaux des réunions de la Commission Internatio- nale pour l'Exploration Scientifique de la Mer Méditerranée C.I.E.S.M.M. (1982), 15-20.

Borja, Á., Elliott, M., Carstensen, J., Heiskanen, A. S., van de bund, W. (2010). Marine management–towards an in- tegrated implementation of the European Marine Strategy Framework and the Water Framework Directives. Marine Pollution Bulletin, 60(12), 2175-2186.

Bigot L., (2010). Suivi écologique de la pose d'une conduite d'eau potable entre Petite et Grande Terre (Ile de Mayotte). Expertise environnementales. Rapport EQUILIBRE pour le compte d'EGIS Eau.

Bragoni G. (1980). Les récifs artificiels. Analyses et résultats de quelques expériences. Mémoire de Maitrise de Bio- logie Marine. Université de Nice. 56 p.

Buffard, A. (2015). État des lieux des techniques d'ingénierie écologique répondant aux besoins de réduction ou de compensation des impacts d'aménagement en milieu marin et côtier. Rapport de stage de fin d'études de Master 2. EPHE - Centre d'Ecologie Fonctionnelle et Evolutive - CNRS / CREOCEAN Montpellier.

Burel, F., Baudry, J. (1999). Ecologie du paysage: concepts, méthodes et applications. Ed. TEC & DOC. Chabran f. (2011). État de l'art de la compensation écologique par l'offre. Le cas de la première Réserve d'Actifs

Chabran F. (2011), État de l'art de la compensation écologique par l'offre. Le cas de la première Réserve d'Actifs Naturels leprojet Cossure. Rapport UR Ecodéveloppement – SAD INRA, ISARA-Lyon"

Chabran F., Napoléone C. (2012). Les conditions du développement des banques d'actifs naturels en France. Développement durable et territoires. Vol. 3, n°1. 14 p.

Chang, K.H. (1980). Toward the sea farming - Artificial reefs in Taiwan. In Proceedings of a Symposium on aquacul- ture in wastewater. National Institute for Water Research, pp. 0-14, Pretoria, South Africa.

Chevassus-au-louis, B., Salles, J.B., Bielsa, S., Richard, D., Martin, G., Pujol, J.l. (2009). Approche économique de la biodiversité et des services liés aux écosystèmes. Contribution à la décision publique. Rapport du Centre d'Analyse Stratégique - CAS. 378 p.

Chipeaux, A., Pinault, M., Pascal, N., Pioch, S. (2016). Analyse comparée à l'échelle mondiale des techniques d'ingé- nierie écologiques adaptées à la restauration des récifs coralliens. Revue d'Écologie (Terre et Vie), 71(2), 99-110.

Chocat, B. (2013). Ingénierie écologique appliquée aux milieux aquatiques. Pourquoi ? Comment ? Ouvrage collectif piloté par l'ASTEE sous la coordination de Bernard Chocat, et soutenu par l'Onema. 357 p.

Clark, S., Edwards, A.J. (1995). Coral transplantation as an aid to reef rehabilitation: evaluation of a case study in the Maldive Islands. Coral reefs, 14, 201-213.

Clewell, A.F, Aronson, j. (2013). Ecological restoration: principles, values, and structure of an emerging profession. Island Press.

Commissariat Général au Développement Durable - CGdd (2013). Lignes directrices nationales sur la séquence éviter, réduire et compenser les impacts sur les milieux naturels. 229 p.

Crochelet, E., Chabanet, P., Pothin, K., Lagabrielle, E., Roberts, J., Pennober, G., Lecompte-Finiger, R., Petit, M.(2013). Validation of a fish larvae dispersal model with otolith data in the western Indian ocean and implications for marine spatial planning in data-poor regions. Ocean & Coastal Management, 86, 13-21.

Dahlgren, C.P., Eggleston, D.B. (2000). Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology, 81(8), 2227-2240.

Dalias, N., Scourzic, T. (2008). Suivi scientifique des récifs artificiels de Capbreton, Soustons / Vieux-Boucau, Mes- sanges / Azur / Moliets. Année 3 - 2008. Contrat ALR & OCEANIDE. OCEANIDE publ. Fr. 78 p.

Darovec, J.E., Carlton, J.M., Pulver, T.R., Moffler, M.D., Smith, G.B., Whitfield, W.K., Willis, C.A., Steidinger, K.A., Joyce E.A. (1975). Techniques for Coastal Restoration and Fishery Enhancement in Florida. Florida Marine Research. Publication, 15, 0-32.

Dixon, G.B., Davies, S.W., Aglyamova, G.V., Meyer, E., Bay, J.K., Matz, M.Y. (2015). Genomic determinants of coral heat tolerance across latitudes. Science, 348, 1460-1462.

Durville, P. (2002). Colonisation ichtyologique des platiers de La Réunion et biologie des post-larves de poissons coralliens. Thèse doctorale, Université de La Réunion & Université de Perpignan. 170p + annexes.

Duval, C., Duclerc, J. (1986). Evaluation des impacts des aménagements récifaux sur la faune halieutique et son exploitation. FAO Fish Report, 357, 167-175.

Elliott, M., Burdon, D., Hemingway, K.L., Apitz, S.E. (2007). Estuarine, coastal and marine ecosystem restoration: confusing management and science – A revision of concepts. Estuarine, Coastal and Shelf Science, 74(3), 349-366.

Facon, M., Pinault, M., Obura, D., Pioch, S., Pothin, K, Bigot, l., Garnier, R., Quod, J.P. (2016). A comparative study of the accuracy and effectiveness of Line and Point Intercept Transect methods for coral reef monitoring in the southwestern Indian Ocean islands. Ecological Indicators, 60, 1045-1055.

Fennessy, M.S., Jacobs, A.D., Kentula, M.E. (2007). An evaluation of rapid methods for assessing the ecological condition of wetlands. Wetlands, 27, 543–560.

Forman, R. T., Godron, M. (1986). Landscape ecology. Jhon Wiley & Sons, New York. 619 p.

Gardner, T.A., Barlow, J., Parry, I.T.W., Peres, C.A. (2007). Predicting the Uncertain Future of Tropical Forest Species in a Data Vacuum. Biotropica, 39, 25-30.

Hardy, L. (1983). Expérience pilote «récifs artificiels» à Palavas les Flots. Rapport technique, CEPRALMAR. 28 p. Harriott, v.j., fisk, d.A. (1988). Coral transplantation as a reef management option. In Proc 6th int coral Reef Symp. Vol. 2, 375-379.

Henocque, Y. (1982). Le Japon et son aménagement côtier : les récifs artificiels marins en 1982. Maison Franco-Japonaise. 7p. Highsmith, r.C. (1982). Reproduction by fragmentation in corals. Marine ecology progress series. 7, 207-226.

Jacob, C., Buffard, A., Pioch, S., Thorin, S. (2017). Marine ecosystem restoration and biodiversity offset. Ecological Engineering

Jacob, C., Quétier, F., Aronson, J., Pioch, S., Levrel, H. (2014). Vers une politique française de compensation des impacts sur la biodiversité plus efficace : défis et perspectives. VertigO - la revue électronique en sciences de l'environnement [En ligne], Volume 14 Numéro 3 | Décembre 2014, mis en ligne le 16 janvier 2015, consulté le 21 avril 2015. URL : http:/vertigo.revues. org/15385 ; DOI : 10.4000/vertigo.15385

Kakimoto, H. (1979). Artificial fish reef in Japan sea coastal regions. In Proceedings of a Symposium on Aquaculture. Tokyo, Japan, 103-109.

Katoh, J., Itosu, C. (1980). Study on artificial reef from the view point of environmental hydraulic engineering. Bulletin of the Japanese Society of Scientific Fisheries, 46(12), 1445-1456.

Kirsch, K.D., Barry, K.A., Fonseca, M.S., Whitfield, P.E., Meehan, S.R., Kenworthy, W.J.,Julius, B.E. (2005). The Mini-312 Program - An expedited damage assessment and restoration process for seagrasses in the Florida Keys National Marine Sanctuary. Journal of coastal Research, 109-119.

Lebègue, D., Hirtzmann, P., Baumstark, I. (2005). Le prix du temps et la décision publique: réunion du taux d'actualisation public. La Documentation française. Commissariat général du Plan.

Lecaillon, G. (2015). La PCC, une solution d'avenir. http:/www.ecocean.fr/elevage-raisonne/la-pcc-une-solution-davenir/

Levrel, H., Pioch, S., Spieler, R. (2012). Compensatory mitigation in marine ecosystems: which indicators for assessing the "no net loss" goal of ecosystem services and ecological functions?. Marine Policy, 36(6), 1202-1210. http:/esanalysis.colmex.mx/ Sorted%20Papers/2012/2012%20FRA%20USA%20-CS%20USA%20FL,%203F%20Phys.pdf

Levrel, H., Frascaria-Lacoste, N., Hay, J., Martin, G., Pioch, S. (2015). Restaurer la nature pour atténuer les impacts du déve- loppement Analyse des mesures compensatoires pour la biodiversité. Ed. Quae. 320 p.

Lewis, R. R. (2009). Knowledge overload, wisdom underload. Ecological Engineering, 35, 341–342. Maron, M., Hobbs, R.J., Moilanen, A., Matthews, J.W., Christie, K., Gardner, T. A., keith, D.A., lindenmayer, D.B., McAlpine,

Maron, M.; Hobbs, Richard; Moilanen, A.; Matthews, J.W.; Christie, K.; Gardner, T.A.; Keith, D.A.; Lindenmayer, D.B.; Mcalpine, C.A. (2012). Faustian bargains? Restoration realities in the context of biodiversity offset policies. Biological Conservation, 155, 141–148.

Mathews, H. (1981). Artificial reefs site: selection and evaluation. In Proceedings of a Conference on Artificial Reefs in Florida. St. Petersburg, Florida, 50-54.

Mechin, A. Pioch, S. (2016). Une méthode expérimentale pour évaluer rapidement la compensation en zone humide. Rapport ONEMA. 85 p.

Miyazaki, C., Sawada, T. (1978). Studies on value judgement of fishing grounds with natural fish reefs and artificial fish reefs, 1: Relations between natural fish reefs and artificial ones. Journal of the Faculty of Marine Science and Technology, Tokai Uni- versity, 11, 71-78.

Moberg, F., Rönnbäck, P. (2003). Ecosystem services of the tropical seascape: interactions, substitutions and restoration. Ocean & Coastal Management, 46, 27-46.

Moreno-Mateos, D., Power, M.E., Comín, F.A., Yockteng, R. (2012). Structural and functional loss in restored wetland eco- systems. PLoS-Biology, 10(1), 45. http:/www.plosbiology.org/article/fetchObject.action?uri=info:doi/10.1371/journal. pbio.1001247&representation=PDF

Moreno-Mateos, D., Meli, P., Vara-Rodríguez, M. I., Aronson, J. (2015). Ecosystem response to interventions: lessons from restored and created wetland ecosystems. Journal of Applied Ecology, 52(6), 1528-1537.

Nakamura, M. (1985). Evolution of artificial fishing reef concepts in Japan. Bulletin of Marine Science, 37(1), 271-278. Nicet j.b., Porcher M., Pennober G., Mouquet P., Alloncle N., denis y., Gabrié C., dirberg G., Malfait G., Nicolas A., Pribat b.,

Ringelstein J., Tollis S., Quod J., Andréfouët S. (2015). Aide pour la réalisation et la commande de cartes d'habitats norma- lisées par télédétection en milieu récifal sur les territoires français. Guide de mise en œuvre à l'attention des gestionnaires. IFRECOR. 73 p + annexes.

Nouvelle route du littoral – Nrl (2013). Nouvelle route du littoral sécurisée avec TCSP. Demande de dérogation relative aux espèces protégées au titre de l'article L411-2 du Code de l'Environnement. Mémoire complémentaire en réponse aux avis émis sur le dossier du 29 mars 2013. 80 p. http:/www.la-reunion.gouv.fr/IMG/pdf/Memoire_comple_aux_avis_emis_cle8bcbca. pdf

Pary B. (2004). Récifs artificiels en Languedoc-Roussillon : des outils originaux d'aménagement de la bande côtière. Rapport CEPRALMAR. 13 p.

Petit, M. (2010). Promotion de la filière post larves en Polynésie française. Stratégies appliquées à l'entreprise BoraEcoFish. Composante 2A - Projet 2A6 Tourisme durable en Polynésie française. Rapport CRISP. 49 p.

Pinault, M. (2013). Évaluation de la fonctionnalité de récifs artificiels à vocation non extractive, dans un contexte d'ha- bitats naturels fragmentés – Côte nord-ouest de l'île de La Réunion. Cybium, 37 (4), 262. http:/sfi.mnhn.fr/cybium/ numeros/2013/374/08-RT%20Pinault.pdf

Pinault, M., Quod, J.P., Galzin, R. (2015). Mass-settlement of the Indian Ocean black-tip grouper Epinephelus oceanicus (Lace- pède, 1802) in a shallow volcanic habitat following a tropical storm. Environmental Biology of Fishes, 98(2), 705-711.

Pioch, S., (2017). Vers une nouvelle gouvernance côtière entre aménagement et environnement ? La compensation des im- pacts de l'homme sur l'environnement dans les projets d'aménagements maritimes. Mémoire d'HDR, Université Paul Valéry Montpellier 3. 315 p.

Pioch S., Garidou, E, Carlier A. (2017). Ingénierie écologique et restauration des milieux marins. Etats des lieux dans les AMP et bilan critique. In « Maintien des fonctions essentielles pour le devenir de l'humanité » ; AAMP coord., Springer (éd.).

Pioch S., Jacob C., Bas C. (2015a). « L'Unified Mitigation Assessment Method : une méthode intégrée de notation des fonctions écologiques ». In Restaurer la nature pour atténuer les impacts du développement Analyse des mesures compensatoires pour la biodiversité. Levrel, Frascaria, Hay, Martin et Pioch (eds), Quae, 320p.

Pioch S., Barnaud G., Coïc B. (2015b). « Liste des méthodes de dimensionnement des mesures compensatoires pour les zones humides ». In Restaurer la nature pour atténuer les impacts du développement. Analyse des mesures compensatoires pour la biodiversité. Levrel, Frascaria, Hay, Martin et Pioch (eds), Quae, 320p.

Pioch, S., Kilfoyle, K., levrel, H., Spieler, R. (2011). Green marine construction. Journal of Coastal Research, Special Issue 61, 257-268.

Pioch, S. (2008). Les habitats artificiels : élément de stratégie pour une gestion intégrée des zones côtières ? Essai de méthodologie d'aménagement en récifs artificiels adaptés à la pêche artisanale côtière. Thèse de doctorat de l'Université Paul Valéry, Montpellier III, France et Tokyo Univeristy of Marine Science, Tokyo, Japon. 288 p.

Plucer-Rosario, G., Randall, R.H. (1987). Preservation of rare coral species by transplantation and examination of their recruit- ment and growth. Bulletin of Marine Science, 41(2), 585-593.

Rinkevich, B. (2005). Conservation of coral reefs through active restoration measures: recent approaches and last decade progress. Environmental science & technology, 39, 4333-4342.

Russel, B.C. (1975). The development and dynamics of a small artificial reef community. Helgoländer Wissenschaftliche Mee- resuntersuchungen, 27(3), 298-312.

Samson, M. S., Rollon R.N. (2009). Restoration of coral populations in light of genetic diversity estimates. Coral Reefs, 28, 727-733.

Society for ecological restoration – Ser - international Science & Policy Working Group (2004). The SER International Pri- mer on Ecological Restoration. www.ser.org & Tucson : Society for Ecological Restoration International. 15 p. https:/c.ymcdn. com/sites/www.ser.org/resource/resmgr/custompages/publications/SER_Primer/ser-primer-french-2004.pdf

Souche, J.C., Le Saout G., Salgues, M., Pioch, S. (2017). Effect of concrete with bio-active admixture on marine colonisation in mediterranean environment. Matériaux et techniques, Vol. 104, No. 3.

Stowers, J.F., Fehrmann, E., Squires, A. (2000). Seagrass scarring in Tampa Bay: impact analysis and management options. In: Seagrass Management: It's not just nutrients! Proceedings of a Symposium St. Petersburg, Florida (p. 47).

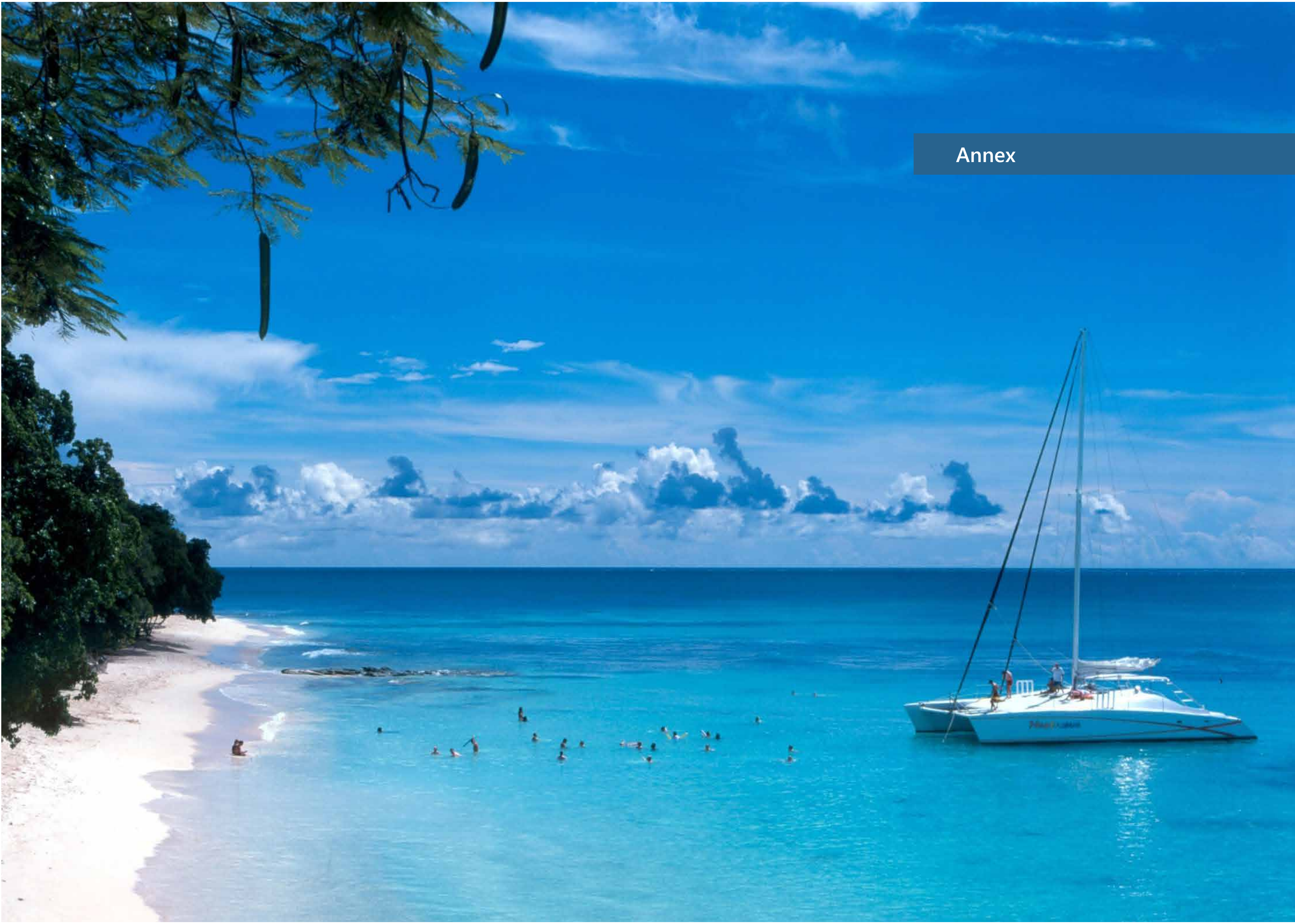
UNEP (2002). Environmental Impact Assessment – Training Resource Manual,The United Nations Environment Programme.

Vaissière A.C., Levrel H., Pioch S. (2017). Wetland mitigation banking: Negotiations with stakeholders in a zone of ecological-economic viability. Land Use Policy, 69, 512-518

Wilkinson, C. (2008). Status of coral reefs of the world: 2008. Townsville (AUS), Global Coral Reef Monitoring Network (GCRMN) and Reef and Rainforest Research Centre (RRRC). 296 p.

Yap, H.T., Alino, P.M., Gomez, E.D. (1992). Trends in growth and mortality of three coral species(Anthozoa: Scleractinia), inclu- ding effects of transplantation. Marine ecology progress series. 83(1), 91-101.

Annex



Annex I

MERCI-COR EXAMPLE

In Reunion Island a sewage outfall was proposed for construction in the vicinity of a coral reef ecosystem (). The outfall would extend from on shore out to a depth of around 2m (, grey arrow) and expected to cause both physical and chemical impacts.

The **footprint,** of the impacted area (direct impact) is 40 m² (20 m length x 2 m width, for the pipe and blocks) or **0.004 ha.**

The **buffer zone** is about 100 m around the impacted area (pipe), determined via a hydrodynamic model (turbid plume).

The area is **1.568 ha**

The ecosystem consists only of corals (and associated flora and fauna) on rocky substratum (no soft bottom, seagrasses) see pictures in Figure 1.

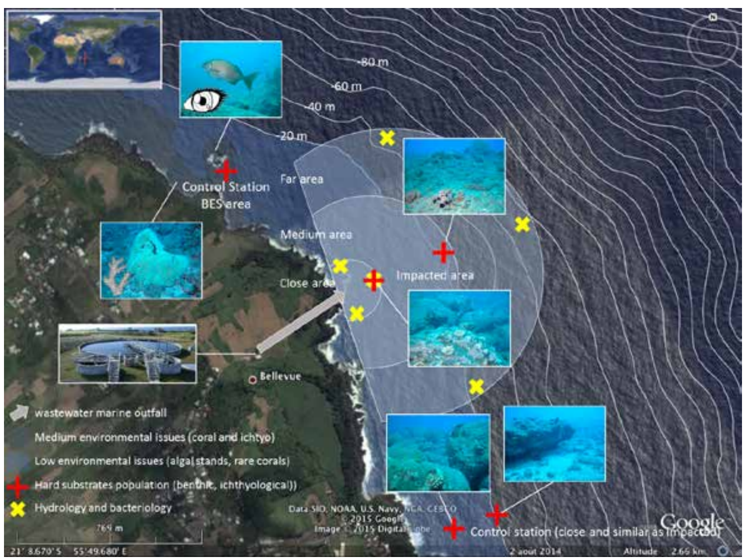


Figure 26: Map of the project and environmental stakes

The Mitigation Hierarchy was followed during the EIA:

Avoidance - sewage outfall pipe moved away from the healthiest coral ecosystems areas and water treated to the tertiary level (potable water).

Reduction - coral removal from the area where concrete blocks will be installed for transplantation in the compensation area.

Compensation – A compensation area is proposed to the North of the project (), geographically immediately adjacent (same eco-region) but negatively impacted by anthropogenic activities. It will be the recipient site for transplanted corals from a coral nursery and the impacted site.

The project consists of transplanting corals reared in local nurseries to the compensation area, to enhance the existing ecosystems which were damaged by unsustainable fishing and physical damage. Educational programmes, and management measures (eco-moorings, enforcement, training etc) will also be implemented to minimise any future negative impacts from unsustainable fishing and other activities. These will be carried out in partnership with local environmental agencies, financed by the applicant (as an accompanying measure).

Figure 27: Compensation area in Blue (North) and impacted area in Red (south)

A reference reef (best ecological state) is located to the North (eye symbol in Figure 1).

5 monitoring stations were established within and around the impacted area (red crosses), with 5 associated water quality survey stations (yellow crosses)..

Part I of MERCI-COR method, for the pre-impacted and the pre-compensation site follows. The aim is to check the ecosystems equivalence, in terms of biophysical and socio-geographical components, from impacted and compensated areas (qualitative assessment):

PART I – Qualitative description of the study site (impacted)
Mr. C. Durand/ EXO-SET LTD/2017

Name or number of the study area	*Name or number of study site*	*File number*
Sainte-Rose	STEP Ste Rose	N°STR17-001

Code of classification of use and type of ground cover	*Other classification (optional)*	*Impacted or compensated site*	*Surface of the study site*
Sugarcane agiculture/ Diffuse urbanization		Impacted	39 Ha

Watershed reference	*Class of affected watershed*	*Protection status of the area*
Waterbody n°LC03	Good	None

Geographical relationship and hydrological connection with other waterbodies	
Probably connected with Mauritius and adjacent areas for larval recruitment	
Description of the study site	
Volcanic cliffs and sloping rocky bottoms. Moderate biological concentration zone with high diversity but low fish densities and low coral hard cover. Despite very heavy precipitation, the waters are generally clear and of good quality. Present and past marine uses mainly concern traditional small-scale fisheries, mostly informal and targeted to small bottom species (groupers, snappers) and pelagics (tuna, sea bream, swordfish). The probable ecological connections with the adjacent areas and Mauritius, about 200 km offshore, make it an area influenced by meso-scale biological processes (larval recruitment, migrations, displacements, etc.).	
Environmental characteristics of areas adjacent to the study site	*Rarity of habitats/species in study site compared to bio-geographic species pool*
The area north of the LC03 water body is located under the influence of the main river systems of the island (East River) with more turbid waters throughout the year. In the south, there is the area of the recent lava flows of the Piton de la Fournaise that have remarkable ecological origins	**Rarity of habitats on a regional scale (the only active volcano in the region), although the flows of the study area, which are relatively old, are not particularly remarkable.**
Ecological functions provided by the habitats for the recorded animal species	*Has the study site already been subject to compensatory measures?*
All functions are provided by habitat other than larval recruitment of pelagic origin	**No**
Remarkable species likely to be present from bibliographic elements	*Species protected or included in a list of vulnerable species likely to be present on the study site*
Proven presence of endemic species	**Marine turtles and marine mammals frequently observed on site**
Species whose presence is established on the study site by direct or indirect (skeleton, test, carapace, burrows, tumuli, etc.) visual census	
Refer to the many previous reports and studies on the study area or adjacent areas.	
Characteristic features of the study site and adjacent sites, not previously mentioned	
No important human activity. The commune is rural, mainly agricultural.	
Name of the organization in charge of the environmental impact assessment	*Date of completion of the study (field period, reporting date)*
EXO-SET	**20/01/2017**

PART I – Qualitative description of the study site (compensated)
Mr. C. Durand/ EXO-SET LTD/2017

Name or number of the study area	*Name or number of study site*	*File number*
Sainte-Rose	STEP Ste Rose	N°STR17-001

Code of classification of use and type of ground cover	*Other classification (optional)*	*Impacted or compensated site*	*Surface of the study site*
Idem		Compensated	250 Ha

Watershed reference	*Class of affected watershed*	*Protection status of the area*
Idem	Idem	Fishing Reserve

Geographical relationship and hydrological connection with other waterbodies	
Idem	
Description of the study site	
Idem	
Environmental characteristics of areas adjacent to the study site	*Rarity of habitats/species in study site compared to bio-geographic species pool*
Idem	**Idem**
Ecological functions provided by the habitats for the recorded animal species	*Has the study site already been subject to compensatory measures?*
Idem	**Idem**
Remarkable species likely to be present from bibliographic elements	*Species protected or included in a list of vulnerable species likely to be present on the study site*
Idem	**Idem**
Species whose presence is established on the study site by direct or indirect (skeleton, test, carapace, burrows, tumuli, etc.) visual census	
Idem	
Characteristic features of the study site and adjacent sites, not previously mentioned	
Idem	
Name of the organization in charge of the environmental impact assessment	*Date of completion of the study (field period, reporting date)*
EXO-SET	**20/01/2017**

1 - IMPACTED AREA

A/ Score before impact (project), in pre-impacted area

Table **1**: **Site location and landscape score** - 0.004 ha **footprint**

Carried out also for the ***Biological and Physical environments .***

Remember that the **score** is from **0-10**, while the metric indicates different ranks -

- **Rank 0** => minimum score (null)
- **Rank 1** => scores of 1 to 4/10 (low)
- **Rank 2** => scores of 4 to 7/10 (average)
- **Rank 3** => scores of 7 to 10/10 (strong)

Indicators	*Score*	*Metric*
Site location and landscape		
a. Are the uses identified in the areas adjacent to the study site a risk for the species of fauna and flora present on the study site?	2	«0. Areas adjacent to the study site are highly urbanized, have a high industrial, port or 0. Areas adjacent to the study site are highly urbanized, have a high industrial, port or agricultural activity or high capacity (> 30000PE) or non-compliant wastewater treatment plant. 1. Areas adjacent to the study site are moderately urbanized and have limited agricultural and industrial activities. They may have a fishing or pleasure port with a limited footprint (<15ha). 2. Areas adjacent to the study site have diffuse urbanization, with agricultural activities far from the coast and little or no industrialization. They may have a very limited coastal shelter (<1ha). 3. Areas adjacent to the study site are very little or not urbanized, free from industrial, port and agricultural activities, but they may have a low capacity and compliant wastewater treatment plant.
b. Are habitats with the highest conservation stakes of the study site exposed to other impact factors than those of the study project?	1	0. Habitats are chronically subjected to domestic, petrochemical, chemical, organic, superheated or desalinated discharges. 1. Habitats receive treated discharges (environmentally compliant) from diverse activities of small and medium sizes or are subject to intensive exploitation of their natural resources. 2. Habitats are only subjected to a moderate exploitation of their natural resources without altering the ecological balance (trophic, size and maturity structures, etc.). 3. Habitats and their natural resources are only exposed to very low exploitation rates or to sources of pollution far removed from the study site.
c. Can exchanges between habitats within and outside the study area be made freely and easily (ecological continuity)?	5	0. Habitats are fragmented and exchanges between habitats within and outside the study site are constrained by an artificial barrier (dykes, harbor walls, etc.). 1. Habitats are fragmented and separated by large sedimentary areas but no artificial barriers constrain exchanges between habitats within and outside the study site. 2. Habitats are continuous but exchanges between habitats within and outside the study site are constrained by a natural (estuary, pass, isthmus) or small artificial barrier. 3. Habitats are continuous and there are no geographic barriers to exchanges between habitats within and outside the study site.
d. Do the areas adjacent to the study site have the full range of habitats necessary for the life cycle of fauna and flora species present on the study site and are these habitats large enough to allow for the renewal of their populations?	9	0. Adjacent areas contain no habitat essential to the life cycle of the species present on the study site (nursery, growth, reproduction, feeding). 1. Adjacent areas contain certain habitats that are essential to the life cycle of the species present on the study site, but their size is insufficient for the renewal of their populations. 2. Adjacent areas contain certain habitats that are essential to the life cycle of the species present on the study site and sufficiently large for the renewal of their populations. 3. Adjacent areas contain all the habitats essential for the life cycle of the species and these habitats are large enough to allow the renewal of their populations.
e. Is the study site likely to benefit adjacent areas by one of its essential ecological functions (spillover effect)?	5.5	0. The species present on the study site do not have sufficiently structured populations (density, size classes, maturity) to allow the rapid colonization of adjacent areas. 1. Some ubiquist species present on the study site have sufficiently structured populations to colonize adjacent areas. 2. Some populations of species characteristic of specific habitats (non pioneer species) present, on the study site, structuration rates allowing the colonization of the adjacent areas. 3. Certain populations of remarkable species (keystone species, ecosystem engineer, etc.) present, on the study site, structuration rates allowing the colonization of the adjacent areas.
f. Is the study site likely to benefit from adjacent areas by one of their essential ecological functions (source zones)?	8.5	0. With the exception of larval recruitment of pelagic origin, the renewal of populations present on the study site does not benefit from any ecological function offered by the adjacent areas. 1. The renewal of the populations present on the study site benefits from the ecological functions offered by the adjacent areas on an optional basis. 2. The renewal of the populations present on the study site benefits from at least one ecological function offered by the adjacent areas. 3. The populations present at the study site can fully benefit from the ecological functions offered by the adjacent areas for their renewal.
g. Is there a proven risk of invasive (Acanthaster planci), toxic (Gambierdiscus toxicus), epizootic (corals, fish, etc.) or epiphytic species (mangrove, seagrass, algae) on the study site or on the adjacent areas?	9	0. The study site is affected by frequent epizootic / epiphytic events or exotic / toxic species proliferations (on bibliographic basis). 1. Some events have been recorded in the past and proliferation conditions are present on the study site but only rare and recent observations of small groups or isolated individuals testify to this. 2. No large-scale events have been reported in the past in spite of the presence of some recent observations of isolated individuals, but the conditions of proliferation are present on the study sites. 3. No epizootic / epiphytic event or exotic / toxic species proliferation have been reported in the past and the conditions necessary for the occurrence of these phenomena are not present on the study site.
TOTAL 1	40	
AVERAGE (/ 10)	6	

1 Site location and landscape = 6.0
2 **biological environment** = 5.7
3 **physical environment** = 6.7

Total average Pre-impacted area (AIM: Average index of Indicators Measurement) = **6.13/10**

B/ Score after impact (construction), in post-impacted area

1 - **site location and landscape** = 5.65
2 - **biological environment** = 5
3 - **physical environment** = 5.5

Total average post-impacted area (AIM: Average index of Indicators Measurement) = 5.38/10

Delta of losses (impacted area) for the footprint is: 6.13 - 5.38 = **0.75**

C/ and D/ Scores before and after (construction), in impacted buffer zone area

We carried out the same process for **the buffer zone**, (pre-impact / post-impact) and the result is:

Delta of losses (impacted area) for the buffer zone is: 6 – 5.8 = **0.2**

2 - COMPENSATION AREA

Using the same tables of indicators.

A/ Score before compensation, in pre-compensated area

1 - **site location and landscape** = 8
2 - **biological environment** = 6
3 - **physical environment** = 6.5

Total average (AIM: Average index of Indicators Measurement) = 6.83/10

B/ Score after compensation, in post-compensation area

1 - **site location and landscape** = 8.1
2 - **biological environment** = 6.5
3 - **physical environment** = 6.8

Total average (AIM: Average index of Indicators Measurement) = 7.13/10

The delta of gain (compensation area) is: 7.13 – 6.83 = **0.3**

3 - MULTIPLICATION FACTORS

In the compensation area, multiplication factors have to be added (adjustment parameters).

R = The Risk factor is moderate, many scientific experiences for coral reef transplantation are referenced, and the table of risk can be easily filled = 1.5 / 3

T = The Time factor should be considered around 10 to 15 years for coral transplants, to reach full functionality (scientific assessments of coral transplantation are available), with management measures: 11 to 15 years = 1.46

The losses scores have to be added:

Footprint losses:
Impacted area Footprint x Δ impact = 0.004 x 0.75 = 0.003

Buffer zone losses:
Impacted area Buffer x Δ impact = 1.568 x 0.2 = 0.3136

Total Losses Impacted area:
0.003 + 0.3136 = **0.3166**

4 - SIZING THE COMPENSATION AREA

The compensation area needed to comply with the quantitative equivalence requirement can be calculated as follows:

$$\text{Compensation area} = \frac{\text{Impacted area x } \Delta \text{ impact x R x T}}{\Delta \text{ compensation}}$$

The compensation area is directly proportional to the impacted area and impact intensity, as well as to the risk and time delay.

The compensatory area (coral transplantation enhancement) should be:

$$\text{Compensation area (ha)} = \frac{0.3166 \times 1.5 \times 1.46}{0.3} = \mathbf{2.31}$$

-> **Compensation area (ha)**, that has to be restored to offset the sewage outfall project is **2.31 ha.**

-> **The ratio, between losses and gains**, is **1.47.** (2.31 ha compensated / **1.572 ha impacted)**

Annex 2

Description of the marine ecosystem ‘restoration’ techniques currently available in the world literature, in 2017 (in Jacob, C., Buffard, A., Pioch, S., & Thorin, S. (2017). Marine ecosystem restoration and biodiversity offset. Ecological Engineering).

Table 1
Description of the marine ecosystem ‘restoration’ techniques currently available in the literature.

Technique	Principle	References
Coral reefs		
Transplantation	Most common restoration technique, involving the transplantation of coral colonies, juveniles or fragments to a natural or artificial substrate. Usually, epoxy is used to attach the coral to natural or artificial (e.g. concrete, steel rods) hard substrates.	Abelson (2006), Gomez et al. (2011), Kolinski and Helton (2006), Omori and Iwao (2014) and Tortolero-Langarica et al. (2014)
Transplantation of nursery-raised corals	Breeding of coral larvae or fragments before transplantation. Larvae, ova and embryos are directly collected with a funnel net or by the installation of artificial substrate near the colonies. Fragments are removed from natural colonies or retrieved from the seafloor. Nurseries can be raised on artificial substrates such as concrete, slate or nets.	Amar and Rinkevich (2007), Mbije et al. (2013), Rinkevich (2014) and Schopmeyer et al. (2012)
Electro-stimulation	Mineral accretion by electrolysis to improve the growth of transplanted juveniles or the colonization by larvae. A low continuous current encourages the deposit of minerals present in seawater.	Sabater and Yap (2002) and Schuhmacher et al. (2002)
Artificial reefs	Increasing the available hard substrate for natural colonization of coral larvae (must be located close to a healthy and productive coral reef).	Al-Horani and Khalaf (2013) and Thanner et al. (2006)
Seagrass meadows		
Transplantation	Removing the rhizome or entire plant from a seagrass donor and transplanting it to a natural or artificial substrate (e.g. cement base or grid) by attaching it with various methods (e.g. epoxy glue, props, hooks, staples, elastic bands or shells) manually or using a machine. *Posidonia oceanica* (Neptune grass), *Posidonia australis, Posidonia coriacea, Amphibolis griffithi, Posidonia sinuosa, Zostera marina* (eelgrass), *Halodule wrightii* (shoalgrass), *Thalassia testudinum* (turtlegrass), *Syringodium filiforme* (manatee grass)	Bastyan and Cambridge (2008), Bell et al. (2008), Lee and Park (2008), Paling et al. (2001) and Zarranz et al. (2010)
Sowing	Seeding using seeds from a donor seagrass meadow (harvested from the seafloor by divers or by an underwater mower). These can be seeded directly on the site manually or mechanically, diffused (through ‘buoys’), or cultivated in a laboratory until germination and then planting the young seedlings directly in the sediment on webs or on a prop. *Cymodocea nodosa* (slender seagrass), *Z. marina, T. testudinum.*	Bell et al. (2008), Marion and Orth (2010) and Zarranz et al. (2010)
Electro-stimulation	Mineral accretion by electrolysis to improve the growth of transplanted shoots. A low continuous current encourages the deposit of minerals present in seawater.	Vaccarella and Goreau (2012)
Micro-propagation	Cloning plants axenically from terminal buds to produce a large number of clonal offspring. *Ruppia maritima* (beaked tasselweed), *H. wrihhtii, T. testudinum, S. filiforme*	Ailstock and Shafer (2006)
Macroalgae beds		
Transplantation	Most common restoration technique. It involves attaching adult or juvenile thalli using epoxy glue, polyurethane foam or hooks on a natural or artificial substrate. Transplantation can be undertaken on coastal structures when populations are too remote for natural colonization (e.g. *Cystoseira barbata, Cystoseira amentacea*).	Carney et al. (2005), Falace et al. (2006) and Perkol-Finkel et al. (2012)
Sowing	Sowing of sori directly after harvesting them or the outplanting of spores or microscopic sporophytes grown in laboratory cultures on a substrate. It is also possible to induce the fertility of male or female gametophytes to produce microscopic sporophytes.	Carney et al. (2005) and Terawaki et al. (2003)
Artificial reef	Increasing the available hard substrate for natural macroalgae colonization.	Reed et al. (2006)
Ichthyofauna		
Postlarval Capture and Culture (PCC)	Restocking ecosystems to boost biodiversity and fish density for fishing purposes.	Gerard et al. (2008)
Artificial reef	Creating an artificial reef to replace some of the degraded functions (e.g. as a habitat or feeding zone) or ecosystem services (e.g. fish provision) or to increase connectivity (e.g. to improve recruitment of species with limited dispersal).	Brickhill et al. (2005), Jordan et al. (2005), Pastor (2008) and Seaman (2007)
Artificial algae	Imitating the size, shape and density of natural macroalgae (e.g. *Cystoseira* spp. or *Sargassum* spp.). Artificial algae can be made out of polypropylene, polyethylene or nylon and attached to an artificial reef with a steel and epoxy anchor to replace the habitat function of macroalgae in zones where environmental conditions prevent natural recovery.	Fernández et al. (2009)
Invertebrates: bivalves (oyster, scallop, abalone, mussel, giant clam), crustaceans (lobster), sea fans		
Transplantation	Transplanting adults from another site. It is used for some bivalve mollusks (*Pinna nobilis*, noble pen shell and *Tridacna spp.*, giant clam).	Katsanevakis (2009) and Linares et al. (2008)
Planting hatchery-raised juveniles	Releasing cultured larvae to rebuild stocks.	Arnold (2008), Dinnel et al. (2009), Gerard et al. (2008), Hansen and Gosselin (2013) and Tettelbach et al. (2013)
Artificial reef	Creating an artificial reef to replace some of the degraded functions (e.g. as a habitat or feeding zone) or ecosystem services (e.g. crustacean provision) or to increase connectivity (e.g. to improve recruitment of species with limited dispersal).	Behringer and Butler (2006) and Chapman (2012)
‘Green’ marine construction		
Modification of concrete surface: This facilitates species colonization by targeting ‘ecosystem engineers’, which influence other species by altering environmental conditions and by providing habitats and other resources (Jones et al., 1994; Jones et al., 1997 In: Harley, 2006) (e.g. barnacles in intertidal zones).		
Surface texture	Modifying the texture of a construction by methods such as making grooves in the surface of the concrete or by including shells, fiberglass, natural fibers or	Coombes et al. (2015) and Omori and Fujiwara (2004)

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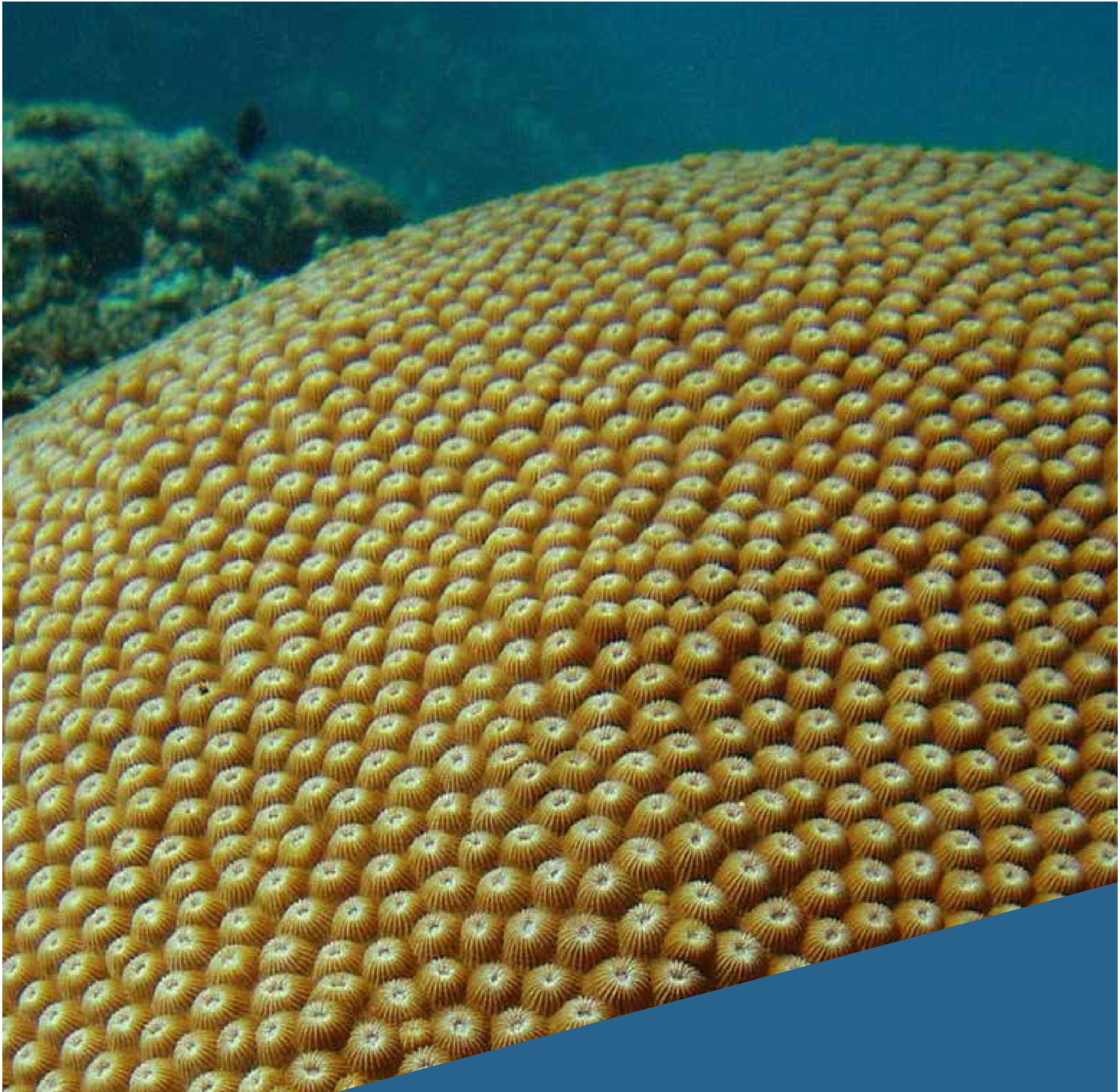
Table 1 *(continued)*

Technique	Principle	References
	porous granulates in the cement, or by attaching small structures to artificial constructions to improve colonization.	
Artificial cavities	Creation of cavities of different sizes at different heights in a dike. These cavities can be integrated in the design of a dike or added to pre-existing dikes.	Browne and Chapman (2014), Chapman and Blockley (2009) and Firth et al. (2014)
Creation of specific structures: This technique exists mainly in pilot projects (e.g. micro-habitats to restore habitat or nursery functions and semi-floating dikes to minimize physical footprint).		
Marine sediment remediation		
Bioaugmentation (*ex situ* and *in situ*)	Addition of exogenous bacteria or inputs that stimulate microbial activity by providing oxygen, nutrients or chemical products (e.g. gaseous hydrogen, acetate, lactate or alcohol). This technique can be used to degrade organic or inorganic oxidized pollutants or to reduce accumulated sediments in ports (bio-dredging). It does not require sediment excavation.	Haines et al. (2003) and Prince (1997)
Electro-oxidation (*ex situ*)	Using electro-osmosis to cause pollutants to migrate and to precipitate through a membrane via the action of an electric field generated by electrodes (pollutant recovery is required after migration as the pollutants are not degraded).	Virkutyte et al. (2002)
Electro-biostimulation (*ex situ*)	Using an electrical current to stimulate microbial activity, allowing organic pollutants to be degraded by bacteria more quickly than in natural conditions. Electrodes placed in contaminated sediment act as electron donors to cause degradation through a reduction reaction (for chlorinated chemical products) or act as electron acceptors to cause degradation through oxidation reaction (for hydrocarbons). It does not require sediment excavation.	Li and Yu (2015) and Lu et al. (2014)



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