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Compensatory mitigation in marine ecosystems: Which indicators for assessing the "no net loss" goal of ecosystem services and ecological functions?

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ABSTRACT

Recent years have seen increasing interest in the concepts of compensation and ecosystem services. Regulation systems in the United States dealing with environmental protection (Superfund Act, Oil Pollution Act, National Environment Policy Act, Clean Water Act, Endangered Species Act, etc.) require those responsible for damage to ecosystem services to compensate for it "physically" and restore these services for the benefit of the entire population. This article, using simple indicators of compensation identified in the literature, attempts to analyze what types of ecological compensation are adopted, how performance is assessed, how standards on ecological equivalencies are adopted, and what are the costs of this compensation. To perform this analysis, compensatory measures carried out during the last ten years in the case of coastal and marine ecosystems in Florida have been addressed. The results show that: analysis criteria for the equivalencies between ecosystem services lost due to damage and ecosystem services gained due to compensatory measures are questionable; most compensation monitoring is for a relatively brief period of time and the data obtained during this period may be insufficient for assessing the net effect of the compensatory measure; the weaknesses regarding criteria for the equivalencies and the uncertainty about the relevant time-scale can be counter-balanced by increasing the area of compensation, a problematic solution at best.

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1. Introduction

In the US, two regimes of compensatory measures can be identified for marine ecosystems: the first is the "Damage Assessment, Remediation and Restoration" regime, which is used for unauthorized impacts (accidents), especially for the Superfund Act (1986) and the Oil Pollution Act (1990); the second is the "Environmental Impact Statement" regime, which provides rules for authorized impacts, especially for the National Environment Policy Act (1969), the Clean Water Act (1975) and the Endangered Species Act (1973).

The first, based on the natural resource damage assessment (NRDA) procedure, requires primary and compensatory restoration measures after environmental damage [1]. The second requires avoiding, mitigating, or compensating for the impacts resulting from a project.[1] In connection with these major laws, several other acts and rules can be mentioned: MSA (Magnuson–Stevens Act, 1996), MPRSA (Marine Protection, Research and Sanctuaries Act), RHA (Rivers and Harbors Act of 1899), NHPA (National Historic Preservation Act), Coastal Zone Management Act, Coral Reef Task Force, and National Fish Habitat Action Plan.

However, the assessment of the effectiveness of compensatory measures for marine ecosystems remains scarce and patchy [2] in comparison with other types of ecosystems such as wetlands [3–8].

Two US states have developed advanced approaches to ecosystem equivalencies (ESE) for the marine and coastal environment – Florida and California. This article is based on the Florida example.

Two main methods for determining ESE coexist in Florida, the Habitat Equivalency Analysis[2] (HEA) [1,9] and the Uniform Mitigation Assessment Method[3] (UMAM). The core issue addressed in this paper is how to reach a better understanding of the way equivalencies should be estimated through these

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[1] The goal of the procedure is to avoid negative ecological impacts, reduce negative impacts that cannot be avoided, and compensate for any remaining significant negative ecological impacts.

[2] http://www.csc.noaa.gov/coastal/economics/habitatequ.htm.
[3] http://www.dep.state.fl.us/water/wetlands/mitigation/umam.htm.

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methods for assessing the effectiveness of compensatory measures in coastal and marine ecosystems, using a simple list of indicators.

The level of equivalencies can be estimated with a simple equation, distinguishing four types of indicators [1,10]:

$$V_I A_I I(1+r)^{-tI} = V_R A_R R(1+r)^{-tR}.$$

- V_I is the value of the ecosystem or function impacted and V_R the value of the ecosystem or function compensated.
- I is the intensity of impact and R the intensity of compensation.
- $^{-tI}$ is the time-scale of the impact and $^{-tR}$ the time-scale of the compensation.
- r is the discount rate.[4]
- A_I is the number of acres impacted and A_R the number of acres compensated.

On the basis of the indicators used to calculate the ESEs, it has been attempted in this paper to carry out an analysis of the compensation system. This analysis uses the example of compensatory measures for the coastal ecosystem in Florida. It focuses on the "intensity," the "area," the "time-scale," and the "discount rate" indicators, since "values" are considered as constant.[5] Another indicator has also been taken into account, the "cost of compensation" associated with these ESE. Lastly, using these indicators it has been asked whether the assumption of equivalency is validated and whether ecosystem or function is truly compensated for.

To carry out this work, a reports review related to this state has been carried out (Florida EPA, www.dep.state.fl.us). In addition, several interviews were conducted in Florida in February 2010 with the main stakeholders responsible for compensatory procedures (Table 1): the National Oceanic and Atmospheric Administration (National Marine Fisheries Service), the US Army Corps of Engineers (USACE) team, the Department of Environmental Resources Management of Miami-Dade, scientists (mainly marine ecologists) interested in compensatory programs, one county project manager, two ecological engineers from two coastal engineering firms responsible for compensatory programs, the Florida Department of Environmental Protection (F-DEP), and the Fish and Wildlife Service (F-FWS Division of Marine Fisheries Management) [11].

2. Intensity: the indicator of equivalency

2.1. Description

In both the HEA and UMAM models, the concepts of "ecosystem services" and "ecological functions" are important: using them makes it possible to assess the equivalencies between the level of impact and the level of compensation. Ecosystem services are defined as "the benefits people obtain from ecosystems" [12]. The MEA suggests the following classification of ecosystem services: cultural services provide recreational, aesthetic, and cultural (spiritual) benefits; regulatory services are obtained through the regulation of ecosystem processes and affect climate, floods, disease, waste, and water quality; provisioning services obtained from direct exploitation of resources by human beings such as food, water, timber, and fibers; supporting services such as soil formation, primary productivity, and nutrient cycling, are the basic ecological functions at the root of biotic processes.

Functions and services are calculated in "Discounted Services per Acre and per Year" (DSAY) for HEA and in "value of function" for UMAM [1,11], but are not distinguished by types as in the MEA report.

In the compensatory procedures, the main assumption is that lost ecosystem services or functions are equal to the level of ecosystem services or functions gained as a result of the compensatory measures. Indicators are thus necessary to assess the impact and to assess the ESE obtained between the losses and the gains acquired through the compensatory measures, as well as to estimate the costs associated with these compensatory measures (Table 2).

However, procedures for developing these indicators of ESE are not the same for the HEA and the UMAM. Their assessment processes are summarized in Table 3.

2.2. Effectiveness

Up until now, indicators of ESE have been based on social standards regarding what is important to compensate local stakeholders for in order to limit social conflicts. Thus, the main goal was to counterbalance the losses sustained by divers and recreational fishers and to maintain the flow of recreational ecosystem services supplied by marine biodiversity. Hence compensatory measures were often based on the deployment of a specific type of artificial reef (boulder reefs)[6] (Table 4) that efficiently provides a high level of abundance of large fishes but does not respect real equivalency criteria relative to the original habitat, which was suited to small fishes [14,15].

Indeed, artificial boulder reefs were not necessarily designed to offset the loss of other ecosystem services, especially regulation and support services, delivered by biodiversity, and were not designed to compensate for the loss of certain habitats such as seagrass, shallow sand bottom, and natural hardbottom [16]. Recent monitoring of the similarity between artificial boulder reefs (Fig. 1), module reefs (Fig. 2), and natural reefs impacted, highlights the non-equivalence between these habitats [14,17].

Thus, as noted by Spieler et al. [17], "the mitigation reef unquestionably provides a habitat that is suitable for fish colonization. However, this habitat differs dramatically in size and appearance from the area impacted and creates an environment that is not similar to that of the natural hardbottom. Different habitat characteristics produce different assemblages [18]. Further, it is not clear what impact mitigation reefs have on the ecology of the sand habitat, and what ecosystem services are altered, at the site where they are deployed." For instance, a restoration procedure based on artificial reefs led to the replacement of soft coral (Octocoralia) by hard coral (Scleractinia) in benthic communities and of Pomacentridae and Labridae by Haemulidae in fish communities [15]. What does this mean for the production of ecosystem services and functions? Scleractinia assemblages are reef builders and might provide new habitats for new species. This might be a good opportunity for increasing the total level of marine biodiversity and ecosystem services. However, Scleractinia and Octocoralia are structurally different, provide differing refuge, and concomitantly display different

[4] Discount rate is the "social rate of time preference, which reflect society's willingness to shift the 'consumption' of public goods (such as natural resource services) over time" (Dunford, [1], p. 62).

[5] This assumption is much debated because preferences are heterogeneous and ecosystem values change over time [10]. One primary condition underlying the assumption of constant value is that compensatory measures should benefit those who have suffered damage (see "Intensity" section below).

[6] Between 1985 and 2004 the 18 compensatory projects associated with beach renourishment and harbors and waterways improvement were based on the deployment of compensatory artificial reefs [13]. Among the 12 compensatory projects adopted in Florida since 2005, 9 are based on reef deployment, 2 on seagrass transplanting, and one on mangrove replanting (Table 4).

Table 1
List of stakeholders interviewed and their role in compensatory procedures.

Organizations	General description	Compensation for impact of future project (authorized)	Compensatory restoration after damage (unauthorized)
National Oceanic and Atmospheric Administration(National Marine Fisheries Service [NMFS] and National Ocean Service [NOS])	Federal organization for marine management	Advisory and control Designations and protection for essential fish habitats: Fishery Management Councils, Interstate Fish Commissions	Leader of trustees Advisory and control Office of Response and Restoration (Damage Assessment, Remediation, and Restoration Program, DARRP)
US Army Corps of Engineers	Federal organization in charge of authorization and permit issuance	Final decision to authorize and issue permits: – Federal authorization *Section 103 prohibits dumping of trash and sewage in US waters* *Section 10 All Structures or Work in the navigable waters of the US* *CWA* (*section 404*)	Final decision to authorize and issue permits: – Federal authorization *Section 103* *Section 10* *CWA* (*section 404*)
Florida Department of Environmental Protection	State organization for marine management and authorization	Final decision to authorize and issue permits: – Water quality certification (WQC) *Environmental Resource Permit or Joint Coastal Permit* (*state procedure*), *with the note that it is for work in state waters/sovereign submerged lands authorization*). *NEPA* (*section 404*) – Marine Protection, Research, and Sanctuaries Act	Final decision to authorize and issue permits: – Water quality certification (WQC) *Environmental Resource Permit or Joint Coastal Permit*
***Department of Environmental and Resource Management**[a]	County organization for marine management and permit issuance	– Water quality certification (WQC) *Environmental Resource Permit or Joint Coastal Permit* (*state heading*, *with the note that it is for work in state waters/sovereign submerged lands authorization*). – CZ Certification=Coastal Zone (Management) Certification	– Water quality certification (WQC) – CZ Certification
Fish and Wildlife Service/Florida FWS	Federal and state organization for game fisheries management	Advisory and control Fishery Management Plans Threatened or endangered species (ESA) MSA (EFH) Fish and Wildlife Coordination Act	Advisory and control Fishery Management Plans Threatened or endangered species (ESA) MSA (EFH) Fish and Wildlife Coordination Act
Private firms in charge of implementing compensatory measures	Marine expert	Collect and organize data from various acts and rules (NEPA and CWA) to define and design the project to obtain authorization and permits for an applicant	Collect and organize data from DARRP to define and design ecological restoration
Scientist compensatory measures	Marine biologist, scientific expert	Data and expertise	Consulted for: Data and expertise Experimental protocol
City environment manager	Coastal management	Data	Consulted for: Data and coastal management

[a] Subsidiarity with FDEP.

Table 2
Description of indicators used in compensatory measures.

Indicators	Underlying concept	Unit of equivalency	Justification for the use of these indicators
Value of ecosystem services and functions	Utility, welfare, well-being	No unit of value since it is considered to be constant most of the time[a]	Proximity of the site impacted to the site of compensation (people who suffer injury are the same ones who benefit from restoration)
Area	Spatial compensation	Acre/square meter	The ratio used depends on the method of restoration used and degree of uncertainty about the probability of its success
Intensity	Ecosystem services or functions	Ecosystem services lost (in percentage); functions lost (mark=*f*(function losses))	Assessment of the level of destruction and of restoration in two sites with an equivalency (or a similarity)
Time-scale	Time required for ecosystem renewal	For the HEA, time required for ecosystem services renewal; for the UMAM, time lag corresponding to time required for full function to be gained by the restoration project (from 1 to 3.91)	Scientific knowledge, monitoring
Discount rate	Preferences for present	Most of the time around 3% for the HEA; no discount rate for the UMAM	International convention on the discount rate

[a] By "value" is meant "economic value" and not the ecological "function value" referred to above with respect to the UMAM method.

Table 3
Differences between the HEA and UMAM equivalence assessment procedures.

	HEA	UMAM
Step 1=intensity	Scoring (percentage of total services per year)	Scoring (rank of total functions without reference to unit of time)
Step 2=area	Assessment of service losses percentage of services*surface=Services/acre/year (SAYs)	Assessment of functional losses FL=surface lost*rank of functions for the impacted area
Step 3=discount rate	DSAYS (discount rate*SAYs)	No discount rate
Step 4=equivalency	Compensation assessment (delta between DSAYS for site damaged and DSAYS for expected site and type of restoration)	Compensation assessment (delta between rank for site damaged and rank for expected site and type of restoration)
Step 5=uncertainty and time factor	No risk factor or time factor since the percentage of services is estimated for each year	Relative function gains (delta/[time lag*risk factor])
Step 6=measure of compensation	Surface to compensate for=DSAYS lost/DSAYS gained	Surface to compensate for=Functional losses/relative function gains

Table 4
Compensatory projects in marine areas, Florida 2005 onwards (*F*-Department of Environmental Protection).
Source: Pioch, 2010.

Year	Project name	Type of impact	Type of compensatory measure	Surface area in acres	Cost of the compensatory project in $	Cost in $/acre
2005	Sarasota/Venice Beach	Beach renourishment	Artificial reefs	7.3	5100,759	698,734
2006	Collier County	Beach renourishment+channel dredging	Artificial reefs	1.09	850,000	779,817
2006	Longboat Key	Channel dredging	Artificial reefs+seagrass planting	1	93,181	93,181
2007	Gasparilla	Beach renourishment	Artificial reefs	0.9	98,790	109,767
2009	Blind Pass	Channel dredging	Mangrove planting	0.6	16,140	26,900
2006–2007	Indian River County	Beach renourishment	Artificial reefs	3.8	3728,500	981,184
2009	Blind Pass	Channel dredging	Seagrass planting	1	132,347	132,347
2008–2009	Hillsboro	Channel dredging and beach renourishment	Artificial reefs	1.6	1250,000	781,250
2010+	Broward-Mid Reach	Beach renourishment	Artificial reefs	4.8	7100,000	1479,167
2010–2011	Juno	Seawall construction	Artificial reefs			
2010+	Ocean Ridge	Beach renourishment	Artificial reefs			
–	South Lake Worth Inlet	Channel dredging	Seagrass planting			
Mean				**2.454**	**2041,080**	**564,705**

Fig. 1. Boulder reef.
Source: Sylvain Pioch, 2010.

ecological trends. Likewise, although members of both families may feed on plankton, Pomacentridae are mainly dependent on algal forage, whereas Haemulidae are primarly benthic carnivores [18].

In addition, artificial boulder reefs seem to be attractive for predators of juveniles and could thus contribute to disturbing a major ecosystem regulation service, that is, trophic regulation in the fish community [17]. This may be why juveniles are less abundant in these artificial habitats than in natural habitats. It is also possible that these artificial boulder reefs fail to provide another major regulation service, the nursery function. The proxy used to assess equivalency is critical as well. Species richness, diversity, density, abundance, evenness, major family constituent, size of individuals, and so on, can be used for estimating ESE and lead to different equivalencies [14,15,19]. In monitoring benthic communities and fish communities, the equivalency is not the same: for example, it has been shown that fish abundance or species richness can be greater with "boulder reefs" than with "module reefs" or "natural reefs," but benthic population density can be higher with "module reefs" or "natural reefs" [13,16].

The similarity of physical criteria also appears to be important: depth and current conditions, substrata, and shape of the structures of "boulder reefs" are all different from those of natural reefs. The restoration community will thus be different from the natural one.

It is possible to conclude that even if the compensatory measures are really founded on a service-to-service equivalency, the categories of ecosystem service that are compensated are not the same as those that have been impacted. In particular, the destruction of ecosystem regulation and support services is

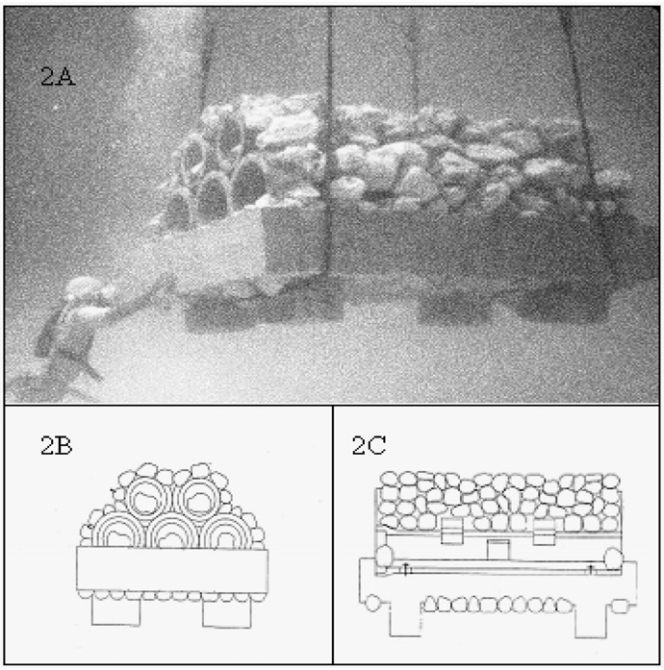

Fig. 2. Module reef.
Source: Sathe et al. (2010), p. 4.

compensated for, above all, by the production of ecosystem recreational services.

This approach to mitigation results from the fact that the economy of Florida is highly dependent on tourism, including diving and recreational fishing.[7] There is also a historical path dependency, as previous compensation projects based on boulder reefs provide some "social" and "legal" precedents which have been shared and collectively well accepted, whereas there are not many clues to the efficacy of alternative measures of restoration (replanting, other types of effective artificial reefs, and so on).

However, it appears that things are changing, as is brought out by a number of signs. Above all, a variety of options for compensating for damage – creation, restoration, enhancement, and preservation – is possible, and their efficacy is taken into account in the ESE assessment procedure. Thus, equivalence ratios allow weighting options which are assumed to be more or less relevant for compensation (Table 5).

In addition, the UMAM method has been recently preferred to the HEA method because the HEA is alleged to underestimate the area subject to compensation (personal communication with South Florida Water Management District, Environmental Resource Permitting Division). To counter this underestimation of compensatory measures, the UMAM takes into account several factors not used in the HEA approach. As stated in 62-345.100, FAC, the intent of the UMAM "is to fulfill the mandate of subsection 373.414(18), F.S., which requires the establishment of a uniform mitigation assessment method to determine the amount of mitigation needed to offset adverse impacts." Further, "to determine the value of functions provided by impact and mitigation sites, the method incorporates the following considerations: current condition (see subsection 62-345.500(6), F.A.C.); hydrologic connection (see paragraph 62-345.400(1)(d), F.A.C.); uniqueness (see paragraph 62-345.400(1)(f), F.A.C.); location (see subsections 62-345.400(1) and 62-345.500(7), F.A.C.); fish and wildlife utilization (see paragraph 62-345.400(1)(h), F.A.C.); time lag (see subsection 62-345.600(1), F.A.C.); and mitigation risk (see subsection 62-345.600(2), F.A.C.)." Next, the Florida law listed basic criteria for assessing the efficacy of a compensatory restoration project: proximity, mimicking, and functional equivalencies.

First, the compensatory project must be close to the place where the impact occurred – at a minimum in the same county. This requirement is designed in accordance with a landscape approach, by locating the compensation in a similar habitat, and is intended to deliver the compensatory ecosystem services to the population who lost them through the impact. It is thus in accordance with the assumption of constant value for the ecosystem services impacted and the ecosystem services restored through the compensation project.

Second, it is necessary to fulfill mimicking criteria: that is, the compensation project is to be based on the same habitat as the ecosystem impacted. For example, it would not be acceptable to compensate for the destruction of seagrass by coral transplanting or to substitute shallow soft bottom for hard bottom. New artificial reefs are now used in a way that fulfills more completely the mimicking criteria required by law, and efforts have been made recently to improve compensation measures (see for example [20]). The "module reefs" mentioned above seem to restore the similarity of natural habitat required for benthic and fish communities more effectively [14].

Third, it is necessary to monitor multiple species for 3 to 5 years, rather than a single species indicator, in order to gather information on both the community scale and the functional scale. Indicators are more and more based on the functional aspects of marine biodiversity. For example, according to a standard protocol, "Benthic ecological assessment for marginal reefs" (BEAMR), functional equivalency is estimated based on 19 functional groups [21]. Equivalency is reached when the restoration program displays between 70% and 90% similarity with functional groups in the natural habitat[8] [3]. If this equivalency is not obtained during the period initially foreseen, it is necessary either to increase the size of the restoration project or to continue the monitoring in order to show that the impact has been truly compensated for. The problem here is that most of the time the functional groups are based only on sessile biodiversity with short life-cycles.

Last, it is possible to mention that many methods of restoration are now being tested that should help in the future to increase the success of restoration plans for biodiversity and ecosystem services conservation [13,21–25].

3. Time-scale and discount rate: The incentive indicator

3.1. Description

The HEA's model places time at the center of its ESE analysis. Time has an ecological role, as the level of ecosystem services produced by a habitat increases over time. Several assumptions are needed in order to estimate the ecosystem services production function over time. It is necessary first to estimate the "project life span" and "maximum ecological service level" of the habitat when its maximum potential is reached. The "project life span" provides a time limit in the calculation (more or less a human lifetime) and the "maximum ecological service level" underscores the assumption that restored habitat cannot supply

[7] "With 76.8 million visitors in 2004 (a record number), Florida is the top travel destination in the world. The tourism industry has an economic impact of $57 billion on Florida's economy" (http://www.stateofflorida.com).

[8] "A common practice for restoring perennial tidal wetland restoration was to use a performance standard of 70–90% vegetative cover by the end of five years, which they considered to be 'scientifically sound'." [3, p. 68].

Table 5
Ratios for the methods of compensation.
Source: Pioch, 2010.

Compensation measures	Definition	Habitat impacted	Ratio of unit of compensation: unit of damage (Florida law X.3.2.1.1)	Examples of measures
Creation	A new habitat is created near the site impacted	Seagrass and coral reefs	2:1 (2 units created for 1 destroyed) to 4:1	Hard bottom=artificial reefs+coral transplanting
		Mangrove, marshes	2:1 to 5:1	Seagrass (planting)
		Halophyte or estuarian vegetation	1.5:1 to 4:1	Planting of halophyte plants Deployment of oyster reef
Restoration (on the site impacted)	A damaged habitat is restored near the site impacted	Seagrass, coral reefs	2:1 and 4:1	Same as for creation
		Mangrove, marshes	2:1 to 5:1	
		Halophyte or estuarian vegetation	1.5:1 to 4:1	
Ecosystem enhancement	Enhancement of ecological functioning through improvement of environmental conditions	Seagrass, coral reefs	4:1 to 20:1	Hard bottom cleaning
		Enhancement of wetlands	4:1 to 20:1	Improvement of water quality with water treatment Creation of moorings for avoiding anchorage Destruction of invasive species
Preservation	Habitat protection near the site impacted	Seagrass and coral reefs		Creation of a marine protected area or mitigation banking area
		Mangrove, marshes	Around 60:1	
		Halophyte or estuarian vegetation		

the same level of ecosystem services as a natural one (the maximum level of ecosystem services production is always less than 90%). Next, it is necessary to define the "year to maximum services" and to shape the production function. The year to maximum services is the time required for the ecosystem to be able to deliver its full potential for the production of ecological services (depending on the type of ecosystem), and the shape of the production function is based on assumptions regarding relations between time and ecological productivity – asymptotic relation, linear relation, logistic relation, and so on.

Time also has an economic role: for each unit of environmental service earned, a "discount rate" reflecting the "preference for the present" is applied to each benefit per year. The discount rate is applied to physical ecological units and not to monetary economic values. The model thus offers a trade-off between ecological dynamics and individual preference for the present, and makes it possible to calculate the optimal rates of production of ecosystem services. The level of compensation will thus depend on the ecological indicators used to specify the ecosystem services production function and the level of discount rate adopted.

The UMAM does not explicitly take time into account in the assessment. Time is estimated through a "time factor" (from 1 to 3.91) that allows for the adjusting of the ratio of equivalencies. For the UMAM, the final goal is to obtain an ecological equivalency with respect to different functional groups, not to obtain an equivalency between the total amount of DSAYS (Discounted Service-Acre Years) gained and DSAYS lost. If the impacted habitat will need a long period of time for restoration, the time factor is high and the area required for compensation will increase (see next section).

3.2. *Effectiveness*

An important source of variability in the compensation project is the indicator used to assess the success of restoration projects. Indeed, the indicator used to characterize "ecological services improvement" can be based on long life-cycle species or short life-cycle species. As noted above, for a long time the main category of ecosystem services restored in Florida was the recreational one. The presence of some large fish taxa at the compensation site was sufficient to claim that the restoration project had succeeded, and the abundance of these taxa could be taken as a measure of success. In this case, the deployment of boulder reefs was enough to compensate for loss of ecosystem services. However, ecosystem regulation and support services are not taken into account by this type of measure. It thus may well be important to assess compensation using new indicators such as the functional groups that make it possible to monitor ecosystem regulation and support services, as required in the UMAM. Yet even though the UMAM is focused on the functional groups, and can be considered more robust than the HEA, most of the indicators used are based on short life-cycle species (e.g., coral reef animals with short life-cycles), using a short-term monitoring system (from 3 to 5 years) to observe the ecological response to restoration measures. Another problem is that the metrics used to implement indicators are typically coverage and richness, not the size of individuals; using these metrics, it is easy to observe ecological response in the short term.

In addition, a major problem with the time-scale, for HEA or UMAM, is the real capacity of long-term monitoring. Currently, monitoring compensation measures is carried out over 3 or 5 years and is mainly focused on "keystone species" that can be observed at the end of this period.

Several long-term monitoring programs have been launched in Florida to assess the effect of compensation measures based on the deployment of artificial reefs [14,15,17]. These restoration programs aim to compensate for the impact of a beach renourishment project on benthic and fish communities. Several things have been observed:

- The level of variability of benthic and fish assemblage through time can be higher on artificial reefs than on natural reefs, which can be a sign of lower resilience [26].
- In one study, the similarity between benthic communities of artificial reefs and natural reefs increased substantially over

4 years but stabilized between year 5 and year 8 and started to decrease in years 9 and 10. Apparently there is no straight-line "natural path" leading to ecological equilibrium.
- Some benthic groups such as corals are very sensitive to the structure of the materials used for compensation.
- There is a difference in fish abundance between the artificial reef and the natural hardbottom it replaces.
- Opportunistic species can be very abundant during the first years and become less so after two years.
- There is great dissimilarity in fish assemblages between artificial reefs and natural reefs, even after 10 years.
- Even when functional groups are similar, the species that can be observed after 10 years are not identical, for benthic or fish assemblages.
- What is best for a benthic assemblage (as seen on the module reef) after 10 years is not necessarily the best for fish assemblages (boulders).

Two major conclusions of these studies are: that time is needed to understand how ecological restoration based on compensation measures works (or fails to), and that no "natural convergence" toward a "natural equilibrium" on compensation reefs can be observed. Another major conclusion is that it is possible to observe an increase in ecological similarity between natural and artificial habitat over 5 years, but see a decrease in similarity during the next 5 years. This means that conclusions about the efficacy of compensation measures and ecological dynamics – of convergence or divergence – will differ significantly depending on the time-scale of the monitoring.

The main assumption used to explain the persistence of this difference is that the artificial reefs deployed at this specific site do not mimic the structure of natural reefs. Another explanation is that there exists a historical path dependency that is impossible to recreate through compensatory measures, since the natural habitats have information related to long-term ecological interactions embedded in their ecological structures [26].

4. Area: The adjustment indicator

4.1. Description

The size of the area of compensation depends on the ratio of equivalence between ecosystem services or function lost and ecosystem services or function gained (Table 5). This ratio is calculated using several input variables. These input variables for the equations are (1) the type of habitat impacted, (2) the method of compensation used, and (3) the level of uncertainty regarding the compensation project.

(1) It is clear that the type of habitat impacted has central importance in the assessment of ESE. For example, coral reefs or sponges with long life-cycles are difficult to restore and are both subject to a high ratio of equivalency.
(2) The goal of the compensation measure is considered to be its adequacy to the impact observed (Table 5). Thus, "creation" and "restoration" are viewed as better goals than "ecosystem enhancement," because the latter is not specifically devoted to a target habitat. The worst is a goal of simple "preservation," which is not accepted because it does not fulfill the criterion of no net loss.
(3) The level of uncertainty associated with the restoration project can have a significant impact on the ratio of equivalence, especially in the UMAM, which takes into account a "risk factor" (from 1 to 3) in the calculation. The level of uncertainty concerns everything: the technique of restoration (e.g., replanting coral reefs vs. deployment of artificial reefs), the time required for renewal of ecosystem services or function (e.g., well understood and short-term vs. long-term and debatable), the planning of management and maintenance, the risk of failure to accomplish the goal.

For the HEA, uncertainty is not taken into account in the assessment itself. However, in the NRDA procedure, if the project of restoration does not achieve the goals previously set for it, it is possible to demand an additional compensation measure and to invest 20% more of the cost of the project in a new restoration phase. These are called contingency costs, and represent the cost of adjustments related to project uncertainties [2].

In brief, the greater the richness of the habitat impacted, the degree of inadequacy of the compensation measure, and the uncertainty of the chances of success of the compensation measure, the greater the number of hectares needed to compensate for one hectare impacted (higher the ratio of equivalence).

4.2. Effectiveness

It is important to note that these ratios are highly subjective and based on old conventions that do not have a genuine scientific foundation. Basically, they provide the input variables that make it possible to adjust the size of the compensation area. The problem is that increasing the size of the area does not necessarily increase the chance of its success. Unfortunately, this is the only parameter on which it is possible to intervene.

Under this adjustment procedure, all projects are accepted even if their chances of success are very poor. This is clearly the chief limit of this ESE method for measuring compensation efficacy: merely taking into account the quantity of surface compensated for leaves out of account the quality of the compensation project. However, this method provides a strong economic incentive to avoid or mitigate the initial impact of a project development: a high ratio is costly for project managers, since it is expensive to increase the amount of compensation, a fact that should encourage them to seek avoidance or mitigation rather than be forced to compensate.

5. Indicators of costs

5.1. Description

The costs of restoration can be divided into several categories: the material costs, which are the costs of the physical capital used for compensation, for example artificial reefs; the monitoring costs, which are the costs incurred in monitoring the efficacy of the compensation measures (for example monitoring the level of colonization of benthic communities); the administrative costs of the design and supervision of the compensatory project (for example the time of the experts employed by federal organizations such as the NOAA or DEP, the cost of licenses to deploy materials used for compensation).

It is simple to assess these costs for unauthorized natural damage since they will be estimated at the end of the NRDA procedure, after restoration projects have been carried out [1] (Table 4). In contrast, the cost assessment for an authorized impact resulting from a development project is more complex, since it requires pre-assessment. In fact, compensation costs depend on several parameters that are difficult to estimate before the project is implemented. Stakeholders have thus adopted a convention for assessing the costs of compensation related to environmental impact assessments: they use the cost of boulder reef deployment, even if the compensation will not be based on

this kind of restoration. This can be a source of problems when it comes time to implement the compensatory measure, as the cost originally estimated and the accounting cost of the compensatory project can be quite different.

For artificial reefs, these costs break down as follows:

- 70% for materials costs
- 25% for monitoring costs
- 5% for administrative costs

5.2. Effectiveness

What has been observed in the field is that the economic incentive to avoid or mitigate rather than compensate, as previously noted, does not in fact work. Compensation is always preferred to avoidance and mitigation, since it is easier to take those additional costs into account in a business plan for a project developer.

In recent years all the costs listed above have increased. The cost of materials has increased because it is necessary to develop better artificial reefs. The cost of monitoring has increased since intensive underwater monitoring is needed, not simply a count of fishes available for sport fishing. The administrative costs have also increased because the supervising efforts required are more extensive.

Unfortunately, the increased funds allotted to compensation are used to deploy more and more boulder reefs, which have been shown to be inadequate to restore the ecosystem services destroyed by beach renourishment impacts [14,15,17,19].

However, it is possible to emphasize that this incentive system, based on the ratio of equivalency, works well for encouraging "creation" and "restoration" and avoiding the "preservation" option when compensation measures are chosen. Preservation has never been used for marine compensation since it is too costly, with a ratio of 60:1 (Table 5).

6. Conclusion and discussion

To improve the quality of the discussion of restoration projects among the stakeholders, it would be useful to develop more detailed indicators regarding the ESEs. Coming back to the initial equation $(V_I A_I I(1+r)^{-tI} = V_R A_R R(1+r)^{-tR})$ in which the different indicators for assessing equivalency are specified, what can be concluded?

As noted above, "V" is constant and "r" is conventionally fixed at 3% [10]. In this paper, the equivalencies between (1) I and R, (2) A_I and A_R, and (3) tI and tR have been analyzed.

(1) Using the indicator of intensity provides information about the equivalencies between losses due to impact and gains due to compensation. The criteria for the equivalencies are questionable, especially as the proxy for ecosystem services and functional groups is subject to debate. However, it can be noted that even if the equivalency seems not to be achieved at this stage, many efforts have been adopted in recent years to improve it, especially through the use of new official standard criteria for assessing it (the mimicking and in-kind criteria and functional similarity).

(2) Using the indicator of time-scale provides information about the efficacy of the measure. Most compensation monitoring is very brief (around 3 years) and the results obtained in this period of time may be insufficient for assessing the net effect of the compensatory measure. Long-term analysis demonstrates the intrinsic limitations of compensation measures, that is to say the impossibility of truly compensating for damage not only to biodiversity itself but also to ecosystem services. Artificial boulder and module reef habitats, used to compensate for the impact of project development in this case study, do not deliver the same ecosystem services, are suspected of being a source of disturbance for the fish community, and seem not to support a resilient ecosystem.

(3) Using the indicator of area helps us to understand better how a compensation measure can be adjusted in order to take into account the limitations of the measures adopted, especially regarding the chance of success of the measure, the type of habitat to be restored, the long-term dimension of the monitoring, and so on.

In conclusion: because V and r are considered to be constant, because it is difficult to determine an equivalence between I and R, and because tI and tR are clearly difficult to approximate, the entire rationale for compensation is based on the ratio of equivalency between A_I and A_R, the only easily controllable parameters for state decision-makers. The main limitation of this rationale is the fact that these indicators are substitutable. Basically, you may have a very poor level of intensity and a great deal of uncertainty about the relevant time-scale, and then transfer these weaknesses to the area indicators, thus giving them significant weight in the calculation of the equivalency. In this situation it is almost impossible for state decision-makers to refuse a compensation project, since it is always possible for the project manager to increase the area of the compensation.

Compensatory measures might become more sophisticated through an improved level of monitoring, but this is not currently happening. In addition, the cost of compensation measures has become higher and higher in recent years, but the increased funds allotted to compensation are used to deploy more and more boulder reefs, which have been shown to be inadequate to compensate ecosystem services destroyed by authorized impacts.

Why is this? Several explanations can be advanced. First, there is a significant lobby of recreational fishers, divers, and boulder reef manufacturers. Second, the courts show a preference for decisions that have been well received in the past, based on existing case law, and believe that boulder reefs meet with social consensus and avoid conflict. In addition bureaucrats do not want to take any risk if a conflict arises over compensatory measures and do not want to test new options considered as a source of risk for their careers. Finally, maybe the main problem is the lack of a real "environmental champion" in charge of defending the environment interest. Without such an actor, consensus regarding compensatory measures is always oriented toward specific stakeholders interest and not toward environmental goals.

In this situation, even if the capacity for technical innovation is high and the funds are available, it is difficult to use them because of the existing political, social, and legal consensus in Florida on the use of boulder reefs to compensate for impacts.

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