Using habitat equivalency analysis to balance the cost-effectiveness of restoration outcomes in four institutional contexts

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# Abstract

One of the Aichi Biodiversity Targets adopted in 2010 in Nagoya, during the tenth meeting of the Conference of the Parties, is to restore at least 15 per cent of degraded ecosystems (target 15) by 2020.

At the national scale, with a given amount of resource available for financing public investment in the restoration of biodiversity, it is difficult to priorizing alternative restoration projects. One way to do it is to assess the level of ecosystem services delivered by these projects and to compare them with their costs. The challenge is to be able to propose a common unit of ecosystem services in order to compare between them these projects, carried out in different institutional contexts (application of environmental laws, management of naturel reserve, production of specific services for local population, etc.).

The aim of this paper is to assess how it is possible to use the Habitat Equivalency Analysis (HEA) as a tool to evaluate ecosystem services provided by various restoration projects developed in different institutional contexts. This tool was initially developed to quantify the level of ecosystem services required to compensate non-market impacts coming from accidental pollution in US. In this paper, HEA is used to assess cost-effectiveness of various restoration projects with regard to different environmental policies, using some case studies based in France. This work was conducted on four different case studies: (1) the creation of a market for wetlands both as mitigation credits and lagoon systems for filtration, (2) the public acceptance of a project of port development, (3) the rehabilitation of marshes to mitigate nitrates loadings to the sea and (4) the restoration of streams in a protected area.

Our main conclusion is that HEA can provide a simple tool to clarify the objectives of restoration projects, help to make a link between costs and effectiveness of these projects and then to carry out trade off, without requiring an important amount of human or technical means.

# Keywords

Wetland restoration ; Equivalency tool ; Ecosystem services; Cost-effectiveness

# Introduction

One of the Aichi Biodiversity Targets adopted in 2010 in Nagoya by the Parties, during the tenth meeting of the Conference of the Parties, is to restore at least 15 per cent of degraded ecosystems (target 15) by 2020.

At a national scale, with a given amount of resource available for financing public investment in the restoration of biodiversity, it is difficult to priorizing restoration projects. One way to do it is to assess the level of ecosystem services delivered by alternative projects, and/or alternative actions within these projects, and to balance these levels with the costs of these projects/actions. The challenge is to be able to propose a common unit of ecosystem services in order to compare between them these actions/projects with regards to different institutional contexts (application of environmental laws, management of naturel reserve, production of specifics services for local population, etc.).

The aim of this paper is to assess how it is possible to use the Habitat Equivalency Analysis (HEA) as a tool to evaluate ecosystem services provided by alternative restoration projects developed in alternative institutional contexts. Recent publications have highlighted how it is possible to use equivalency tools in order to provide valuations of ecosystem services in biophysical units (Dumax et Rozan, 2011; Vaissière et al., 2013). These publications, however, are based on hypothetical case studies. The goal of this paper is to assess the applicability and the reliability of HEA for carrying out cost-effectiveness analysis of restoration projects carried out in different places in France during the last years.

The first section of this paper will be dedicated to the presentation of the method and the economic arguments that defend its broader use. We will, in the second section, present the results of its application in four restoration projects in France, based on different institutional goals, and finally discuss these results in the third section.

In this paper we want to determine if HEA can be used in the context of other institutional objectives. As we aim at valuing ecological service gains associated with restorations projects/actions that would not take place in the context of compensation, we need to adapt the procedure to calibrate the HEA method to each restoration action.

# Material and method

## The use of the HEA in the NRDA procedure

The NRDA procedure has been created in 1986 with the CERCLA law, also known the *Superfund Act*. This procedure help assessing the level of damages after an accidental pollution and allowing to calculate how much the polluter will have to pay for these damages.

The NRDA procedure is based on several steps: « Trustees[[1]](#footnote-1) » are informed that an environmental impact occurred ; negotiations between polluter and trustees ; evaluation to assess the spatial scale of the damage, the intensity of the impact, the primary restoration actions to carry out on the impacted site, the recovery time of the impacted ecosystems ; call for tender is launched by the trustees for compensatory projects allowing to compensate the temporary losses of ecosystem services ; reception of the proposals and ranking of the projects[[2]](#footnote-2) ; payment of the primary and compensatory costs by the polluter plus the costs of the procedure.

The *primary restoration* allows to accelerate the speed of ecological recovery on the impacted site (ecological gains are assessed by the surface A in the figure 1). But, even if this action allowed to recover the initial good ecological state of the ecosystem, there is still a temporary loss of ecosystem services (corresponding to the surface B in the figure 1) which required *compensatory actions* in order to have a « no net loss of ecosystem services ».



Figure 1: The impacts and the primary restoration

At the end of the 80s, the challenge was to know how evaluate the “no net loss of ecosystem services”. Initially, the assessment of the surface B was based on contingent valuation method (CVM) allowing to estimate the values of the non-market impacts (Mazzotta et al., 1994; Jones et Pease, 1998). The rationale of this method was to get a monetary value corresponding to the social cost of the injuries that the polluter would have to pay. Then, this amount had to be used for restoration actions in order to produce ecosystem services for the population as a whole, as mentioned in the Oil Pollution Act (OPA). However, it appeared quickly that the implementation of this method had to face two main challenges: collecting information on preferences regarding both environmental damages and environmental restoration projects was very costly; the CVM was deeply debated in the community of economists (Bateman et Willis, 1999; Arrow et al., 1993; Kahneman & Ritov, 1994; Kahneman et al., 1998) and then strongly contested by the polluters[[3]](#footnote-3). The consequence of these problems was that, at the end of the 90s, the monetary valuations were less and less accepted by the court of justice for estimating the non-market impacts of environmental pollution (Thompson, 2002).

Acknowledging that the CVM method was too costly and no more accepted by the court of justice, the NOAA (National Oceanic and Atmospheric Administration) created the HEA tool in 1995, which left the value equivalency criteria to adopt a biophysical ecosystem services unit criteria (Bruggeman et al., 2005 ; Dunford et al., 2004 ; Roach and Wade, 2006 ; Thompson, 2002; Zafonte and Hampton, 2007). The equivalency is then considered through the biophysical restoration required in another site on which it is possible to get an ecological lift, in order to compensate the ecosystem services lost, assuming that the calculation of the biophysical equivalency help to « determine whether restoration actions make the public whole for injuries due to the spill » (Mazzotta et al., 1994, p.174). At the end, the assessment of the amount of money that the polluter has to pay is based on the cost of restoration actions allowing to have the biophysical equivalencies in ecosystem services units.

The losses coming from the impacts and the gains coming from the compensation are calculated in discounted services per acre and per years (DSAYs). In US, the discount rate adopted is 3%. It is also used a ratio which allow to weight the value of the ES gains vis-à-vis the ES lost, for example if the restoration happened in a low population area whereas the impact was in a high population area or if the techniques of restoration are not sound enough.

The rationale of the HEA can be described through Equation (1) (Dunford et al., 2004 ; Zafonte and Hampton, 2007 ; Levrel et al., 2012 ; Vaissière et al., 2013) and is observable on Figure 2 if we assume that surface C has to be equal to the surface B in order to have a no net loss of ES. HEA quantifies gains and losses as Discounted Services Acres Years (DSAYs).

$V\_{I}A\_{I}I\_{t}(1+r)^{-T\_{I}}= V\_{R}A\_{R}R\_{t}(1+r)^{-T\_{R}}$ (1)

***VI*** is the value of the ecological services on the impacted site and ***VR*** is the value of the ecosystem services on the compensatory restoration site.

***AI*** is the surface impacted, the damaged area and ***AR*** the surface compensated, the restoration area.

***It*** is the intensity of damage and ***Rt*** the intensity of restoration. They vary according to time and this variation is called recovery function on the impact site and maturity function on the restoration site.

***r*** is the discount rate.

***-TI*** is the time scale of the impact and ***-TR*** is the time scale of the compensatory restoration.



FIGURE 2 - Changes in ecological services provision on sites of injury and compensation (adapted from Vaissière et al., 2013)

Behind these changes, some assumptions have to be pointed out (Dunford et al., 2004; Roach et Wade, 2006 ; Zafonte et Hampton, 2007) : the unit of reference to calculate equivalency becomes the ecosystem service (ES) and it assumes that humans derive utility from natural resources in proportion to the ecosystem services they provide. As such, the services from restoration projects designed for compensation, should provide approximately the level of utility expected to reach the objective of compensation of public loss from the injury (Roach and Wade, 2006). At the end, the restoration costs become a proxy of the social cost of the non-market impacts even if it is recognize that the “replacement costs are a poor cousin to theoretically correct welfare-based measures of economic damages” (Unsworth et Bishop, 1994, p.38.

## Calibration of the HEA

According to the equation (1), it is assumed that *VI* and *VR* are some constant variables. In addition, *AI* and *AR* are easy to estimate since it is only an area to calculate. Only two parameters are more difficult to define.

The first important issue for the calibration is the question of the measurement of the level of ecosystem services lost with the impact (*It****)*** and gained with the compensation (*Rt*) through a specific metric. As it is hard and costly to measure all components of an ecosystem, HEA relies on the use of a metric. Generally, the choice of metric is oriented toward an ecological parameter that is representative of the damaged habitats and/or natural resource. This metric is central in the process as it will be used for the determination of losses resulting from damage and the gain associated to compensatory restoration. Thus HEA results will be very sensitive to this choice (Strange et al., 2002, Vaissiere et al., 2013). As we can see on Table 1, various metrics can be found in the literature depending on the type of ecosystems and the targeted services or functions. From the observation of the metric, HEA measures ecosystem services as an estimated percentage. Quantification of gains is conducted in perspective of the level of services on the site of injury in its baseline condition.

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| --- | --- | --- | --- |
| **Source** | **Ecosystem** | **Targeted function or service** | **Choice of metric** |
| Fonseca et al. (2000) ; Bell et al. (2008) | Seagrass | Food source, shelter, sediments stabilisation and nutrients cycles | Seagrass density (number of roots per unit of surface) |
| Strange et al. (2002) | Salt marsh  | Primary production | Biomass |
| Habitat | Canopy structure of vegetation |
| Soil development and biogeochemical cycling | Organic matter  |
| Support of food chain | Infauna |
| Secondary production | Shellfish and fish density |
| Milon and Dodge (2001) | Coral reef | Habitat | Reef surface |
| Sperduto et al. (2003) | Seabirds | Bird population | Abundance |
| Penn and Tomasi (2002) | Salt marsh | Habitat | Qualitative observation, expert judgement and specific species abundance |
| French McCay and Rowe (2003) | Coastal species  | Habitat participation to food web | Primary or secondary production |
| Cacela et al. (2005) | Estuary | Sediments quality | Toxic element concentration and effects on biota |
| Bruggeman et al. (2005) ; Scribner et al. (2005) | Unspecified | Habitat at metapopulation scale | Abundance and genetic variability |
| Roach and Wade (2006) | Coastal wetlands | Habitat | Establishment of a model to estimate impacts of chemicals  |
| Damages on wildlife (birds, mammals and reptiles) |

Table 1 - Review of possible metrics for HEA and their associated ecosystem and ecological services in the scientific literature

A second key parameter is the time scale and the discount rate. The time-scale is based on the dynamics of the ecological recovery in the impacted site (*TI*) and in the compensatory site (*TR*). The application of a discount rate (*r*) reflects the “social rate of time preference, which reflects society’s willingness to shift the ‘consumption’ of public goods (such as natural resource services) over time” (Dunford et al., 2004, p. 62). In this case, discounting is not applied on the monetary value of ecological services but directly to the biophysical quantity of ecological services. In the case of NRDA procedures, a discount rate of 3% is generally applied and the time reference is usually based on the year of the impact (NOAA, 1997).

## The adapted HEA

Compensation can be considered as an institutional objective that will change according to the nature of the impact but above all according to the legal references which specify the ecological goals to achieve.

In the adapted HEA, the idea is to adopt a baseline depending on the institutional/legal frame in which the assessment makes sense: the good ecological status for the European Marine Strategy Framework Directive (MSFD) or the Water Framework Directive (WFD), the no net loss for the Environmental Liability directive and so on.

All these elements are of key importance for the application of the method and they are all taken from observations of the damages on natural resources. Table 2 summarizes how the expansion of HEA has been carried out in order to be applied to other types of institutional goals (Table 2).

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|  | **HEA for compensation** | **Translation in a broader use** |
| Institutional context | Natural Resource Damage Assessment | Multiple (Water Framework Directive, Marine Strategy Framework Directive, Positive actions, Compensation...) |
| Actor responsible for restoration | The party responsible of the impact | Multiple (Private investor, public actor, NGO...) |
| Value of services | Possible use of ratio to frame compensation options | Possible use of ratio to frame restoration options  |
| Choice of metric | Depending on the nature of the impact to compensate | Depending on the nature of the objective for restoration |
| Baseline for measurement | Initial level of ecological services on impacted site | Reference level of ecological services to produce |
| Time reference | Time of the impact | Time of the initiation of the restoration planning |

Table 2 - Calibration of HEA for the expansion of its use

In this paper we will apply HEA to the valuation of actions of restoration of ecosystem services in perspective of their institutional goals. This work will rely on case studies from four sites in France. A discount rate of 3% is used for the adapted HEA. The year of reference will be based on the institutional frame and we will calculate all projects on a 25-year period.

## Study sites

Site selection resulted from cooperation with a public agency specializing in water and aquatic ecosystem management, the ONEMA (The French National Agency for Water and Aquatic Environments) and Water Agencies. We selected four different case studies in France taking place in different institutional contexts (Figure 3, Table 3).

We start with the simplest case study and continue with the more complex study. The Port 2000 case study and the Libellule zone case studies allow to compare different actions of restoration for a same project. At the end, the idea is to be able to compare both restoration projects and restoration actions in a same projects in order to carry out our analysis at two different level of investments.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Vurpillères stream** | **Kervigen marsh** | **Environmental measures of Port 2000** | **Libellule® zone** |
| **Geographical context** | Labergement-Sainte-Marie Pop. 1,000Franche-ComtéContinental | Châteaulin and Porzay and surrounding communities Pop. 15,000BrittanyOceanic | Le Havre Pop. 300,000Upper NormandyOceanic | Saint-Just and Saint-Nazaire-de-Pézan Pop. 3,068Languedoc-RoussillonMediterranean |
| **Goal of the restoration project** | Ecological restoration of Vurpillères stream  | Avoiding green tides | Acceptance of the ecological impacts coming from the extension of the Port of Le Havre in the Seine estuaries | Creating a market for environmental mitigation or natural water treatment system  |
| **Type of action** | Restoration of meanders in the stream | Producing a service for assimilative decrease of nitrogen | Home-birds (shorebirds):creation of an island in the sea, creation of a resting place on dune-Production of mudflats:creation of a meander | Creation of a wetland at the outlet of a sewage treatment plant |
| **Size of projects** | 1.1 km of stream | 22 ha | 45 ha for the resting place1.5 ha for the island300 ha for the meander | 1.5 ha |

Table 3 - Presentation of the four case studies



FIGURE 3 - Location of the four case studies in France

# Results

This part will present the application of HEA to the calculation of the gain of ecological services associated with each of our projects (synthesized in Tables 7 and 8). As we assume that HEA is a good tool for valuation of a project according to its institutional context and objectives, we will have to present each project.

The details for the calculation of DSAYS in each project are provided in Supplementary Material.

## Vurpillères stream

The Vurpillères stream is located in the upper Jura mountains, in the Nature Reserve (NR) of Lake Remoray. It is a little over one kilometer long, supplied by a watershed with no anthropogenic activity. It crosses low marshes and peat lands. In the 1960s, with the aim of draining the marshes for agriculture, the stream was channeled. Without releasing usable land, this rectification resulted in a loss of diversity of habitats and species. When the Nature Reserve was established in 1980, public access to the wetlands was completely banned and in 1997 the first management plan enabled the reserve manager to launch the restoration of Vurpillères stream (Figure 4).

Valuation of this restoration project was conducted using HEA. For calibration of the model we used information on monitoring of small invertebrates of the communities: plecoptera, trichoptera and ephemeroptera. Monitoring on the restored stream was conducted in 1993, 1998, 2002 and 2007 (Redding, 2009). We chose the species’ richness of these communities as a metric for the calculation; and the number of species at the last observation (2007) as a baseline, assuming that the stream had reached its initial level of services. The application of HEA for the calculation of gains gave 5.79 DSAYs between 1997 date of the project and 2022.

In the same way, we can calculate the loss associated to the channelization of the stream in 1966 with HEA. We obtain a total of 25.95 DSAYs lost. This underlines that the restoration of ecosystems never takes into account the temporal loss associated with past impacts. In the case of Vurpillères stream, compensation of total losses would have implied a project 4.5 times larger.

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| --- | --- | --- | --- |
| **Objective for valuation** | **Metrics**  | **Determination of baseline** | **DSAYs** |
| Restoration | Species’ richness of communities plecoptera, trichoptera and ephemeroptera | Dissolved oxygen in the Or lagoon. | 1.26 |

Table 4 - Application of HEA to measure the environmental gains in the Vurpillères stream



FIGURE 4 - Aerial view of the Vurpillères stream (Image Google Earth -GeoEye 2013)

## Kervigen marsh

The Kervigen marsh is located in the bay of Douarnenez in Brittany. It is a 22-hectares marsh separated from the sea by a coastal dune. It is crossed by the river Kerharo, whose watershed is known for its intensive agriculture. In the 1960s, adjustments were made to drain the swamp for agriculture. This led to the rectification of the river and the raising of the dune. However, agricultural activity ceased in 1975. In 1990, because of the intense exposure of Douarnenez Bay to green tides, Kervigen marsh became the subject of an experiment to take advantage of its performance in purifying nitrates. The success of this experiment led to the acquisition of land from the local government and the establishment of a rehabilitation program: restoration of the dune and diversion of part of the flow of the river into the marsh with the installation of two systems of sluices for water level management (Figure 5).



FIGURE 5 - Aerial view of Kervigen marsh (Image: Google Earth - DigitalGlobe 2013)

Facing the high purification capacity of the marsh, a broad program of restoration has been included in the nitrate mitigation strategy of the watershed of the Douarneney bay. This program aims at reducing by 50 tons per year the quantity of nitrate in the bay with marsh rehabilitation. We will use this objective for the calibration of HEA for valuation of the Kervigen marsh.

Purification performances of the Kervigen marsh varies between 2 and 4 kg per day per hectare, as the marsh is used 110 days per year (when the water level in river is high enough to allow fish circulation despite deviation in the marsh). Calculation of ecological gains using HEA gave us 0.079 DSAYs and 0.158 DSAYs for performances of 2 and 4 kg per day per hectare respectively.

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| --- | --- | --- | --- |
| **Objective for valuation** | **Metrics**  | **Determination of baseline** | **DSAYs** |
| Nitrate mitigation | Purification performances of 2 kg per day | Objective of 50 tons per year | 0,079 |
| Nitrate mitigation | Purification performances of 4 kg per day | Objective of 50 tons per year | 0,158 |

Table 5 - Application of HEA to measure the environmental gains in the Kervigen marsh

The strategy of restoration fixes an objective of reduction of 50 tons of nitrate per year, this can be considered as a deficit of ecological services: if nothing is done 100% of services will be lost, corresponding to 18.41 DSAYs between 2012 and 2037. Considering the gains associated to the Kervigen marsh rehabilitation we can propose discussion on the different strategies for restoration of marshes (Table 4). Using HEA we can determine the need of restoration to reach 50 tons of nitrate reduction. We can see that changing the time limit for the objective will change the total surface of project, because of the application of a discount rate that gives preference for services produced in 2012, rather than later.

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| --- | --- | --- |
| **Strategy for marsh restoration** | **Surface to restore per year** | **Total surface to restore** |
| Objective in 2012 | 234 ha | 234 ha |
| Objective in 2015 | 64 ha | 254 ha |
| Objective in 2020 | 33 ha | 294 ha |

Table 6 - Dimensioning restoration plan according to different strategy scenario for a selected performance of 2 kg.day-1.ha-1

## Environmental measures of Port 2000

The Seine estuary refers to the part of the river that is subject to tidal influence. It is a densely populated region and home to a variety of economic activities. The estuary is characterized by the presence of a high biological diversity (birds, fish, etc.) and included in the Natura 2000 network. It is also protected by the existence of the Nature Reserve of the Seine Estuary. Because of the construction of Port 2000, the Le Havre harbor had to set up two types of environmental measures to offset impacts on local biodiversity: compensatory measures and accompanying measures.

Compensatory measures that focused on the creation of a resting place on dune - a resting area of 45 ha consisting of a basin subject to tidal influence and a large dry area - and an islet resting place - an islet of 5 hectares at low tide which is reduced to 1.5 ha and three smaller islets at high tide (Figure 6). As the objective of the islet is to welcome shorebirds at high tides, we retain the surface of 1.5 ha in all calculations. These measures were designed to compensate for the destruction of a disused deposition chamber which had been colonized by seabirds - particularly shorebird species.

Among the accompanying measures we study a rehabilitation project of mudflats. This project involved the creation of an artificial meander to restore 100 ha of mudflats which had undergone a decrease of their surface area at a rate of 20 hectares per year since 1980.

We applied HEA to value these projects in two different ways, first considering the compensatory measures and second considering accompanying measures (Table 5).

First we focus on the valuation of the two compensatory measures: the repositories for shorebirds. Valuation of projects using HEA is similar to its initial use in the NRDA framework, with the difference that the impact is not accidental and temporary but authorized and permanent. As a result, the objective for valuation of both repository area and islet is the compensation of loss of habitat for shorebirds. According to data availability, we used the global population of shorebirds in the estuary as metric. In 1997, objectives were set for compensatory restoration to compensate loss of population of shorebirds due to port development. We used data produced by Wetland International on observation of the shorebirds population on the estuary (Aulert et al, 2009) between 1985 and 2007. Works of Port 2000 were finished in 2005, we then assume that after this year, all evolution of the shorebird population at the scale of the estuary will be due to compensatory measures. As we do not have available information after 2007, we have to make assumptions on the maturity curve associated to the intensity of restoration. We assume that because of the last adjustment and good management practice, compensation measures will work and that shorebird population will recover its 1997 level in 2011 with a linear growth from 2007 to 2011. We can then calculate the gains associated to both repositories between 2005 and 2030 using HEA, result is of 0.131 DSAYs.

Considering the accompanying measure, the objective of the project is to restore 100 ha of mudflats by an action on 300 ha. Although mudflats didn’t appear at the expected place, 60 ha appeared elsewhere, we assume that it is directly linked to the project and use the surface of mudflat as a metric to calculate gains with HEA. According to local observation of Aulert et al. (2009), surface of mudflats appeared is of 45 ha in 2008. We have to make assumptions to reconstitute intensity of restoration in time. Works ended in 2005, as a result we assume that apparition of mudflats started in 2006, letting one year for system stabilization after works. We then assume linear growth between 2006 and 2008 (45 ha) and between 2008 and 2012 (60 ha) and a stabilization of the system in 2012. Calculation of the ecological gains using HEA gave a result of 9.12 DSAYs for the rehabilitation of mudflats.

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| --- | --- | --- | --- |
| **Objective for valuation** | **Metrics**  | **Determination of baseline** | **DSAYs** |
| Compensate the loss of shorebird population  | Shorebird abundance: Density of shorebirds | Density of shorebirds in 1997 | 0,131 |
| Restore 100 ha of mudflats | Coverage of mudflats: surface of mudflats (ha.) | Coverage of 100 ha. | 9,12 |

Table 7 - Application of HEA to measure the environmental gains in the Seine estuary, using different proxys

Values in DSAYS make no sense in absolute terms, but we can consider them relatively to each project’s objectives. In the case of compensatory measures, we can value the temporal loss of services associated to port development (using the loss side of Equation 1). We measured a total loss of 2.16 DSAYs. According to Equation 2 and the quantity of DSAYs associated to the action of compensation, 16.4 ha of additional compensation would be necessary for the compensation of temporal losses. If we rely on the replacement cost principle, as 46.5 ha cost around 9.9 million EUR, we can value the temporal loss of services associated to shorebirds compensation to an additional 3.3 million EUR.



FIGURE 6 - Aerial view of Port 2000 and the environmental measures accompanying the project (Image: Google Earth - Cnes/Spot Image 2013)

## Libellule® Zone

In 2007, the towns of Saint-Just and Saint-Nazaire-de-Pézan undertook the renovation of their wastewater treatment plant (WWTP). Because of their location in the watershed of a protected Mediterranean lagoon exposed to eutrophication problems (the Or lagoon), partners proposed to create a lagoon system to apply tertiary treatment while securing the rejection of the WWTP. The company in charge offered to support the costs of establishing the lagoon system in exchange for the opportunity to implement the Libellule® zone in place of the original project which merely consisted of a pond planted with reeds. This new system, in addition to the initial objectives, included innovative projects - research program on micro-pollutants, joint production of a rich biodiversity or credit production for wetland and biodiversity offsets - with the view of using this pilot project to develop a market for implementation of Libellule® zone. It has been operational since 2009. Part of the water leaving the WWTP reaches a succession of wetland habitats - phytoplankton basin, reed marsh, meandering zone, anastomosing array and free zone - complemented by a humid meadow, an alluvial zone, a brush planted with trees and a sand filter (Figure 7).



FIGURE 7 - Map of the Libellule® zone (Image: Biotope)

As the goal of the project manager of the Libellule® zone is the creation of a market for this project, it can be valued in perspective of different objectives corresponding to different institutional contexts that would require implementation of similar projects. On the basis of the data available and the potential targeted markets we can select the elements to calibrate HEA for the calculation of gains of ecological services (Table 6).

If we consider the Libellule® zone in the context of the production of a lagoon system for WWTP, it can be valued in perspective of its objective of tertiary treatment. The project’s initiators decided to implement this constructed wetland because the WWTP was located in the watershed of a protected lagoon greatly exposed to eutrophication. Data availability and discussion with local experts led us to choose the level of dissolved oxygen as a proxy of the activity of vegetal species, among the major drivers of purification capacity of the Libellule® zone. Gains valued through HEA can thus be measured in perspective of the level of the proxy in the lagoon. We then calculated the gains using HEA and valued an amount of 1.26 DSAYS on a 25-year period length.

We also valued the project in perspective of alternative actions corresponding to different objectives such as offset production or security of the WWTP rejects as presented on Table 6. As a result we obtained 9.57 DSAYs and 6.44 DSAYs for the valuation of Libellule® zone in the perspective of offset production for habitat and biodiversity respectively and 6.92 DSAYs in perspective of security of the WWTP rejects.

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| --- | --- | --- | --- |
| **Objective for valuation** | **Metrics**  | **Determination of baseline** | **DSAYs** |
| Tertiary treatment | Dissolved oxygen : Presence of dissolved oxygen is an indication of the chemical activity of vegetal species in water. | Dissolved oxygen in the Or lagoon. | 1.26 |
| Offset production(Habitats) | Coverage of hydrophytes: Composite proxy considering surface and deep hydrophytes. | Coverage of 100% of available surface. | 9.57 |
| Security of the WWTP rejects | Surface of wetland: The total area occupied by wetland in the entire Libellule® zone. | Coverage of 100% of the entire Libellule® zone.  | 6.92 |
| Offset production (biodiversity) | Species richness (odonates) : Indicator of the number ofspecies of dragonflies inventoried on the site | Maximum of species inventoried on one area in Francea from 1970 to 2006. | 6.44 |

Table 8 - Application of HEA to measure the environmental gains on the Libellule® zone, using different proxys (a French society of odonatology, source: INVOD, ESRI)

As shown in Table 6, DSAYs valuation is very sensitive to the choice of assumptions for the calculation of gains (particularly for the metric and the reference state). Each of these assumptions can be disputed, thus there is not much sense in considering these results in absolute values. In this view we propose to discuss these values in perspective of the institutional objectives in which these projects take place. DSAYs could then be used as a unit for comparing alternative action within the same project.

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| --- | --- | --- | --- | --- |
|  | **Libellule® zone** | **Environmental measures of Port 2000** | **Kervigen marsh** | **Vurpillères stream** |
| Mudflats rehabilitation | Repositories |
| **Objective for valuation** | Depending on the targeted market | Creation of 100 ha of mudflat | Ecological neutrality of Port 2000 on the shorebirds in the estuary | Reduction of 50 kg nitrate per year through restoration of marshes | Ecological restoration of the site to its itinial state |
| **Metrics** | e.g. Dissolved oxygen | Surface of mudflats | Abundance of shorebirds in the estuary | Absorbed nitrate | Species richness  |
| **Initial level** | State of metric before works | Null | Number of shorebirds before impact | Absorbed nitrate without the marsh | Number of species before restoration |
| **Intensity of restoration** | Evolution of metrics during time | Surface of mudflats observed in 2008 and 2012, we assume linear growth between observations | Variation of number of birds from 2005 and return to the baseline in 2010. | Purification performance associated to the latest measures in 2008. | Number of observed species in 1993, 1998, 2002 and 2007, we assume linear growth between observations |
| **Hyptohsesis on the final level** | Management plan maintains level of service to its 2011 state. | Site is stabilised in 2012. | Return to the baseline in 2010. | Management plan maintains performance to its 2008 state. | In 2007, level of service is back to its initial level. |
| **Reference state** | Dissolved oxygen in the Or lagoon | Objective of mudflat creation (100 ha) | Number of birds in the estuary in 1997 | Nitrate reduction objective (50 tons per year) | Species richness in 2007 |
| **Reference date** | Beginning of works (2007) | Beginning of works (2005) | Beginning of impact (1997) | Beginning of project (2010) | Start of project (1997) |
| **DSAYs**  | 1.26 | 9.12 | 0.131 | 0.079 | 5.79 |

Table 9 - Synthesis of the application of HEA for valuation of actions of restoration of aquatic ecosystems

## Comparative results

As we mentioned, results of valuation using expanded HEA do not have much sense in absolute value and must be conducted in comparative terms. Table 8 shows the results of a cost-effectiveness analysis conducted on the basis of the ecological efficacy expressed in DSAYs and the cost per hectare of projects. The cost of the project was determined based on the cost of investment and annual costs associated to management and monitoring (when scheduled). Total costs for the project was calculated over the same time period as the one used for DSAYs calculation, i.e. on a 25 years period.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Objective** | **Cost of project****(EUR/ha)** | **DSAYs** | **Cost/Effectiveness Ratio (103)** |
| **Libellule® zone** | Market of lagoon systems | 1,338,000 | 1.26 | 1062 |
| Offset for biodiversity | 1,338,000 | 6.44 | 207 |
| **Environmental measures of Port 2000** | **Mudflats rehabilitation** | Production of mudflats | 77,000 | 7.589 | 10 |
| **Repositories** | Compensation of shorebirds | 213,000 | 0.21 | 1014 |
| **Kervigen marsh** | Mitigation of nitrate | 13,600 | 0.0495 | 275 |
| **Vurpillères stream** | Restoration | 10,600b | 10.38 | 1 |

Table 10 - Comparisons of costs and efficacies of projects (b Restoration was applied on 1100 meters of the river, piezometric level was improved on riverbanks on a strip of 10 to 20 meters large on each side of the river. We retain a width of 15 meter on each side to calculate the surface impacted by the restoration project)

# Discussion

HEA can provide a simple tool to clarify the objectives, the means to achieve them and a tool to assess the efficacy of actions to achieve these objectives. It enables us to assess the ecological efficacy of alternative restoration programs in biophysical units and to compare them with their costs.

## Results

Comparison of projects using expanded HEA then raised the question of the substitutability of DSAYs. At the level of investment in natural capital, we can compare restoration projects amongst themselves and restoration actions within these projects. Such a comparison should lead to determine the best investment in ecosystem services regardless of location, ecosystem type or institutional goal. In this way, priorizing investment at constant budget would imply to choose the project with the lowest cost-effectiveness ratio. In this way, the more interesting project is the restoration of Vurpillères stream (Table 8).

When we introduce more precise considerations, comparison needs to be conducted with caution. Indeed, as we can see on Table 8, the Libellule zone appears to be the worst project when we consider its efficacies in perspective of a restoration action focused on tertiary treatment of WWTP, whereas it becomes a more interesting project than bird repositories when we consider its efficacies in perspective of a restoration action focused on biodiversity offset. In the same way, projects are implemented on specific location, restricting investment to a specific area narrows the set of solution. In this way, the question of the best investment on the Seine estuary would lead to prefer mudflats rehabilitation over bird repositories restoration (Table 8). These issues are related to methodological assumptions that need to be discussed.

## Methodology

As mentioned earlier, the HEA methodology relies on key assumptions that need to be discussed in perspective of our proposal for expansion of its use.

First, the value of ecosystem services is supposed to be constant over time, which might be true for short periods but is more difficult to argue for longer periods as retained by HEA (Zafonte and Hampton, 2007). The question of constant value is also asked regarding the spatial dimension. We have considered this same assumption for our calculation.

Second, HEA applied a discount rate to the ecological services in order to integrate the human time preference for the present. There is an extended literature discussing the problems regarding discount rates and proposing modifications and alternatives (Henderson and Bateman, 1995 ; Weitzmann, 1998 ; Frederick et al., 2002; Young and Hatton McDonald, 2006). As a result, since the time reference is the year of impact, projects implemented earlier have a greater value. In the context of our extended approach, this can raise issues. For example in the case of the use of HEA to value production of biodiversity offset, a project implemented before impacts could accumulate enough ecological services to compensate impacts on larger area which seems to be the opposite of the objective of the legislation.

Third, the quantity of DSAYs we calculated using HEA is heavily dependent of the choice of metrics (Strange et al., 2002). This is part of the strength of HEA into the NRDA framework, it allows to focus discussion on the choice of the metrics. Adoption of HEA resulted from a will of simplification of the calculation of costs since previously, the complexity and opacity of calculations systems limited implementation of compensation measures.

Fourth, we note that calculation of DSAYs relies on assumptions about the maturity function or the observation of metrics. All assumptions on the value of the metrics explicitly stated in this paper were conducted according to data availability but only rely on authors’ arbitration. In its genuine use HEA relies on a more participatory process which helps reduce uncertainty accumulated through assumptions.

Fifth, HEA allows the application of a ratio, which can be applied to illustrate preference for some action over another (Levrel et al., 2012) or to weight on the location of compensation regarding the location of the impact. It can be a way to take, indirectly, the value of the ES lost and the ES gained. Thus, equation 1 can be transform in equation 2 so as to help operators determine the size of restoration. It is thus possible to apply the ratio of the value of damaged services to the value of restored services ($\frac{V\_{I}}{V\_{R}}$). Ratios can be applied, for example, to give preferences on the type of actions chosen to implement compensatory restoration (Levrel et al., 2012).

 $A\_{R}= \frac{V\_{I}}{V\_{R}}×\frac{A\_{I}I\_{t}(1+r)^{-T\_{I}}}{R\_{t}(1+r)^{-T\_{R}}}$

We have not applied any ratio in our calculations, but application of HEA in a decision procedure could consider application of ratio. For example, in the case of the meander, we stated that restoration outcome did not appear at the expected location. A ratio could be applied to underline the inadequacy of the outcomes to the institutional goal and to decrease the value of the ecological efficacy.

## What place for this new tool?

The objective of this paper is to discuss the perspective of expanding the use of the HEA to estimate the cost-effectiveness of investment in aquatic ecosystems in perspective of their institutional objectives.

In the end we obtained for each of our study sites a quantity of DSAYs calculated considering the institutional goal of every action. As we mentioned, this quantity of DSAYs has no meaning in absolute terms, it has to be considered in relative terms. In this view valuation with HEA can be used in 3 ways:

-(1) *ex ante* to size an action in order to produce the exact quantity of ecological services required;

- (2) *ex ante* to help the trade-off between several projects in order to choose the most cost-effective;

- (3) *ex post* to illustrate the efficacy of an action under a specific context.

Our proposition is strongly rooted toward the consideration of institutions as they constitute the frame of reference for valuation. Thus we can only discuss the results of valuation using HEA under the objective fixed by the relevant institutions. A restoration project that doesn’t meet its objective when implemented for a specific purpose can’t be considered as more valuable even if it has a more important monetary value. In this way, the valuation of restoration projects in biophysical terms shows some strengths as it doesn’t meet the usual critics addressed to monetary valuation and can thus be a good complement.

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1. Trustees are representatives of the public as a whole for defending the environmental interests of the population. It can be an environmental administration, a tribal party, a county, etc. [↑](#footnote-ref-1)
2. Today, the criteria of ranking are well-defined but it was not the case at the end of the 80s. Up to now, the restoration projects are retained if they have the potential to result in a quantifiable increase in one or more of the injured resources and if there is sufficient information about the project available to (a) evaluate the project and (b) enable implementation within the next 12 months. Next they are ranking according to 6 “qualitative” criteria: costs, level of ecological lifts in DSAYs, probability of success, potential collateral losses, number of targeted ecosystem services, effects on public health and safety. [↑](#footnote-ref-2)
3. Especially during the Exxon Valdez legal procedure which last 20 years and led to waste a lot of public time and efforts as well as a lot of money (1.3 milliards US$ 1991) without any action on the field. [↑](#footnote-ref-3)