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An update of the Visual_HEA software to improve the implementation of the Habitat Equivalency Analysis method

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ABSTRACT

The Visual_HEA software tool was created in 2006 to facilitate the assessment of losses and gains in ecosystem services related to compensatory mitigation under the United States National Resource Damage Assessment Act (NRDA). Habitat Equivalency Analysis (HEA) is an ecological equivalence assessment method under NRDA that can be performed using the Visual_HEA software and for which it was named. The newers version – 2.6 – was recently enhanced and tested over several years to be adapted to the European context and to facilitate adherence to the Environmental Liability Directive (2004/35/EC) to compensate for environmental damages. Herein, enhancements, limitations, and a turnkey method of calculating variable gain and loss rates over space and time using the 2.6 version of the software are discussed. Major functionality enhancements include a quarterly discount calculation, increased decimal precision, gain calculations that extend into perpetuity, and the elimination of many small software "bugs". A case study about the accidental pollution of the Mimizan River from a sodium hypochlorite spill at a paper mill illustrates the new functionalities of the software. The use of the HEA method to assess ecosystem services related to biodiversity offset has been widespread thanks to the development of this user-friendly software package. Furthermore, the HEA method implemented in Visual HEA_2.6 is recommended by the European Commission to enforce its Environmental Liability Directive and to size mitigations after accidental environmental damages.

1. Introduction

One of the most complex compromises for land-managers is to balance human activities with the necessity to protect biodiversity. The "No net loss" objective is the United States government's overall remediation policy goal for wetlands and many other types of ecosystems (Robertson, 2000). The fundamental concept is to strive to maintain a global ecosystem services balance by compensatory mitigation of the same quantity as a destroyed ecosystem for accidental or authorized environmental damages. In this paper, we discuss a software tool that can be useful to plan mitigation for accidental damages. Ideally, mitigation is intended to restore an ecosystem of equal value to the one which was lost; however, this is ecologically impossible (Moreno-Mateos et al., 2012). A best effort then is to attempt to reach a social compromise and acceptable standard of performance with the restoration project (Levrel et al., 2012).

In early 1990, Dunford et al. (2004), on behalf of the National Oceanic and Atmospheric Administration (NOAA), developed a biophysical method to assess the equivalency between losses and gains called Habitat Equivalency Analysis (HEA) (NOAA, 1995). In the US, the method consists of sizing habitat losses by scoring the level of ecosystemic services (ES) lost by non-authorized damages under Natural Resource Damage Assessment (NRDA) protocol started in 1990, including ES gained with a compensatory mitigation area. To help facilitate repetitive and fastidious calculations, the National Coral Reef Institute (NCRI) created the Visual_ HEA software in 2006 to help automate these calculations (Kohler and Dodge, 2006).

In Europe, the HEA approach was introduced into European policy with the adoption of Environmental Liability Directive (ELD) in

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2004 (2004/35/EC). The French government has also transposed this directive through the adoption of the Environmental Liability Law in 2008.[1] and the signing of its implementing decree in 2009[2] Based on the European program "Resource Equivalency Methods for Assessing Environmental Damage" (REMEDE, 2008), the French government in 2012 recommended HEA as a standard method for scoring loss and gain for accidental environmental damages (Bas and Gaubert, 2010; Gaubert and Hubert, 2013). Furthermore, the adaptation of this approach is growing. For example, Scemama and Levrel (2016) recently proposed an adaptation of the HEA method to assess deliberate and permanent impacts instead of accidental and temporary ones.

The purpose of this paper is to provide an overview of the application of the HEA method using Visual_HEA 2.6 – an enhanced, translated version of the software to comply with the recommendation of the French ministry regarding Environmental Liability. We also present an actual case study using the software. The new 2.6 version of Visual_HEA contains many bug fixes and adheres to the standard HEA calculation method with changes to facilitate future end-users of the service/service approach for ELD in Europe. The software is also relevant globally to other nations that have similar laws as Europe that aim to mitigate ecological human impacts. The software is available in Spanish, French and English.

2. Materials and methods

2.1. The HEA method

HEA is a method used by resource managers to compute the quantity of compensatory restoration of a habitat that is required to replace ecological loss of services of a resource due to accidental damages. The HEA method uses a discounting algorithm to value a natural resource asset which is equal to all future services of that asset after degradation due to injury. The resultant value is then combined with the computed value of any compensatory action to arrive at a total area that must be restored to compensate for damages. The formula to calculate the level of ecological services gained and lost is a percent increase from a baseline level for each year of assessed losses and potential gains are added for the duration of each loss over the compensatory action period. A discount rate (see section 2.3 for complete definition) is applied each year to actualize the losses or gains as a percentage rate and per time unit, assuming that services provided sooner are more highly valued than those provided later (for the complete HEA formula, please refer to Kohler and Dodge, 2006).

The HEA method provides a quantitative and temporal measure of the loss and gain of ecological services of a habitat for a set period of time. In the HEA method, services are assessed by evaluating a proxy region – a commonly used method in HEA when one area is more difficult to research than another. Damages to the proxy region are expressed in Discounted of Services per unit of Area and per Year(s) in Visual_HEA, with the acronym "DSAYs". One of the main principles of the HEA method is to separate remediation by three levels: 1) primary (recovery action onsite), 2) complementary (offset of net losses, after primary remediation), and 3) compensatory (compensation for interim losses). For conciseness, we direct the reader to studies by Unsworth and Bishop (1994), Mazzotta et al. (1994), Milon and Dodge (2001), and Dunford et al. (2004) for complete review and information about the HEA procedure.

[1] https://www.legifrance.gouv.fr/eli/loi/2008/8/1/DEVX0700028L/jo/texte.
[2] https://www.legifrance.gouv.fr/eli/decret/2009/4/23/DEVK0823109D/jo/texte.

2.2. Visual_HEA

The Visual_HEA computer program was created by NCRI in 2006 to provide a consistent and robust way for resource managers to perform the standard HEA calculation method, leveraging technology to perform the tedious and repetitive calculations required. The program was written with the robust programming language Visual Basic and targets the Windows operating system platform. Visual_HEA provides a rich graphical user interface which accepts user-defined parameters that are required to perform HEA analysis. These input parameters are based on assumptions of loss and gain in relation to pre- and post-injury of a resource combined with any compensatory action performed to mitigate the injured resource. Input parameters are graphically depicted in the user interface and calculations are automatic based on user inputs. Values resulting from the analysis are presented graphically with the option to output the analysis results to an ASCII text file or Portable Document Format (PDF) file. Since its introduction in 2006, Visual_HEA has been downloaded more than 7000 times and is used globally to value ecosystem loss due to injury using the standard HEA calculation method. Kohler and Dodge (2006) provide a more in depth discussion on the mechanics of the program, required parameter inputs, and algorithm calculations. Additional information about the software and a download link can be obtained by visiting the NCRI Visual_HEA website at the following location http://www.nova.edu/ocean/visual_hea/.

2.3. Input parameters

Following is a brief review of the input parameters required by Visual_HEA to perform the HEA calculation method.

2.3.1. Baseline levels of services

These parameters, expressed as percentages, designate the level of services that were provided by the injured site before the injury occurred and the compensatory site after restoration. These levels of services are often deemed as perceived values due to the difficulty in assessing the value of the damage site.

2.3.2. Discount rate

This parameter is expressed as a percentage rate per time unit. The discount rate functions under the presumption that future restored services are more highly valued initially and then discounted as time lapses over the duration of the analysis period. Conversely, the values of past services increase over the analysis period, subject to the discount rate. Future and past ecological service calculations function independently and can be computed for different temporal durations.

2.3.3. Year of claim

This parameter indicates the year the claim is made, which can be actual or arbitrary to provide a starting point for analysis.

2.3.4. Service loss parameters from the injury

This suite of parameters is composed of the actual size of the injured area and level and duration of habitat loss from the point in time of injury until recovery, if applicable.

2.3.5. Service gain parameters from the compensatory action (restoration)

These parameters consist of the level and duration of services gained due to compensatory action for the period analysed.

Parameterized with these data, the Visual_HEA software applies the standard HEA method and displays the results of analysis within a detailed viewer.

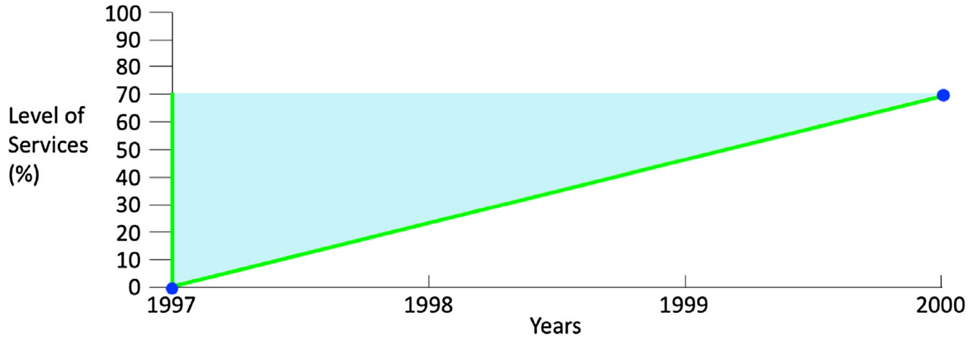

Fig. 1. Increase in the level of services of the damaged area over time after the accident. Cumulative losses of services appear in blue.

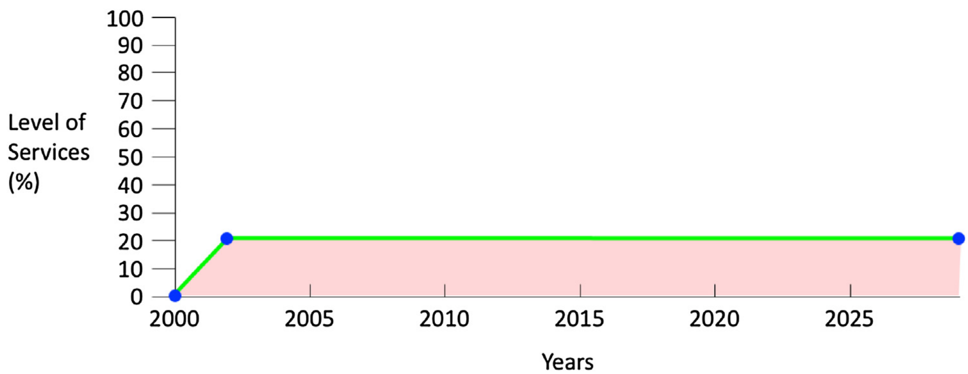

Fig. 2. The level of services obtained from the compensatory measure for the damaged area over time. Gains of services appear in pink.

3. Results

3.1. Improvements to Visual_HEA

The French version, Visual_HEA 2.6, retains the same overall parameter inputs, interface structure, and processing algorithms as version 2.5, with added enhancements that allow the software to adhere to established French Governmental guidelines in Europe (REMEDE, 2008) and in France (Gaubert and Hubert, 2013). Bug fixes in the French version were also applied to the English language version of the software and both designated as version 2.6 (French and English versions, respectively). Herein is a summation of changes to version 2.6 exclusive of the French language translation.

3.2. Major software enhancements and bug fixes

3.2.1. Quarterly discount rate errors

European standards often dictate the use of quarters instead of years when performing HEA, whereas yearly discounting is a common practice in the United States (Gaubert and Hubert, 2013). Version 2.5 of the software contained a software bug which incorrectly calculated service loss when using a quarterly discount rate. Instead of calculating the proportional quarterly discount from the yearly rate parameter, the software calculated the full year discount rate for each quarterly period. This resulted in raw and discounted service losses that were four times the actual value. Related to this error, the algorithm failed to distribute percentage services lost over the entire analysis period when designating a quarterly period, resulting in incorrect percentage services lost values. Additionally, the percentage of services gained calculation failed to evaluate all four quarters of the last year, instead only considering the first quarter of the final year. The algorithm was fixed to properly calculate all quarters of all years for services gained. The default quarterly discount rate for the French version was also set to default to a rate of 4% in accordance with European standards for the HEA method.

3.2.2. Decimal precision

When importing a saved .hea file (the proprietary file format for saved Visual_HEA data), the value-injured and value-restored values were rounded to one decimal place, resulting in a potential loss of precision. Nodes in both the gains and losses section also exhibited this loss of precision when importing a saved file. To preserve accuracy, discount rate precision was increased to three decimal places and node precision was increased to two decimal places.

3.2.3. Gain perpetuity

It is common in European HEA to end compensation at a specified time interval, while in the United States 'gain perpetuity' is commonly the *de facto* standard to indicate that compensation is not removed at a specific point in time. To accommodate European standards, the program was modified to allow a specified end point, which results in a drop to zero value on the last node while still preserving the gain perpetuity option.

3.2.4. Analysis results output to portable file document (.pdf) format

Visual_HEA 2.5 allowed analysis output to PostScript (PS) format which is format in high use in electronic and desktop publishing applications. The majority of users of Visual_HEA, however, convert this PS file to a PDF file format which is an industry standard for data presentation. For brevity therefore the PS file output was discontinued and the PDF file format was introduced in its place. This enhancement eliminated one processing step for most users and allows a standard method to present analysis results.

Table 1
Summary of the data used for the application of HEA to the Mimizan River case study (Rousseau, 2007).

Type of data	Data for the Mimizan river example
Proxy	Glass eel biomass
Year of reference for discounting	1997
Damaged surface area	7.5 ha
Annual discount rate	4%
Level of services supplied before the damage	70%
Level of services supplied after the damage	0%
Regeneration pace of the river (primary restoration)	23.33% per year, within 3 years (from 1997 to 1999), linear function
Lifetime of the compensatory measure	20 years (from 2000 to 2019)
Gains of service obtained from the compensatory measure	20% additional, within 2 years (from 1997 to 1999), linear function

Table 2
HEA losses and gains for the Mimizan River case study.

Service loss at injury area

Year	% Service Lost			Raw	Discount	Discounted
	Beginning	End	Mean	SAYs Lost	factor	SAYs Lost
1997	70.00%	46.67%	58.33%	4.375	1.000	4.375
1998	46.67%	23.33%	35.00%	2.625	0.962	2.524
1999	23.33%	.00%	11.67%	0.875	0.925	0.809
2000	.00%	.00%	0.00%	0.000	0.889	0.000
Total discounted SAYs lost:						**7.708**

Service gain at the compensatory area

Year	% Service Gained			Raw	Discount	Discounted
	Beginning	End	Mean	SAYs Gained	factor	SAYs Gained
2000	.00%	10.00%	5.00%	0.375	0.889	0.333
2001	10.00%	20.00%	15.00%	1.125	0.855	0.962
2002	20.00%	20.00%	20.00%	1.500	0.822	1.233
2003	20.00%	20.00%	20.00%	1.500	0.790	1.185
2004	20.00%	20.00%	20.00%	1.500	0.760	1.140
2005	20.00%	20.00%	20.00%	1.500	0.731	1.096
2006	20.00%	20.00%	20.00%	1.500	0.703	1.054
2007	20.00%	20.00%	20.00%	1.500	0.676	1.013
2008	20.00%	20.00%	20.00%	1.500	0.650	0.974
2009	20.00%	20.00%	20.00%	1.500	0.625	0.937
2010	20.00%	20.00%	20.00%	1.500	0.601	0.901
2011	20.00%	20.00%	20.00%	1.500	0.577	0.866
2012	20.00%	20.00%	20.00%	1.500	0.555	0.833
2013	20.00%	20.00%	20.00%	1.500	0.534	0.801
2014	20.00%	20.00%	20.00%	1.500	0.513	0.770
2015	20.00%	20.00%	20.00%	1.500	0.494	0.740
2016	20.00%	20.00%	20.00%	1.500	0.475	0.712
2017	20.00%	20.00%	20.00%	1.500	0.456	0.685
2018	20.00%	20.00%	20.00%	1.500	0.439	0.658
2019	20.00%	20.00%	20.00%	1.500	0.422	0.633

Total discounted SAYs gained: 17.527.
Discounted SAYs gained per unit area 2.337.
Replacement habitat size (hectare): 1.000 * 7.708/2.337 3.298.

3.3. *Minor software bug fixes*

3.3.1. *Quarterly nodes*

A software bug in version 2.5 prevented the user from reliably placing and editing nodes at quarterly intervals. As quarterly calculations are common practice in European HEA, this option was refactored to eliminate errors in placement.

3.3.2. *Moving nodes*

When moving nodes by dragging and dropping with a mouse, intermediate positions were not removed from the display. Though this software bug did not cause calculation errors, the interface was update to prevent this error.

3.3.3. *Clear data button*

The clear data button was displaying intermittent functionality, sometimes preserving erroneous data previously entered by the user via the interface. Users also often encountered a 'missing or non-numeric value for gains start year' error during this process. Both of these software bugs have been addressed.

3.4. *Case study: mimizan coastal river*

To test this new version of Visual_HEA and to guide future users, we present herein a case study using the software.

Damages to the Mimizan River were first described by Rousseau (2007). On April 5, 1997 in Mimizan, Landes, France, a pipe ruptured at a paper mill and spilled sodium hypochlorite into the Mimizan River. Subsequently, freshwater and marine life was destroyed over a distance of 4 km – i.e., 25 t[3] of fishes and the entire benthic vege-

[3] French database ARIA (*Analyse, Recherche et Information sur les Accidents* for analysis, research and information on accidents) available at http://www.aria.developpement-durable.gouv.fr/rechercher-un-accident/.

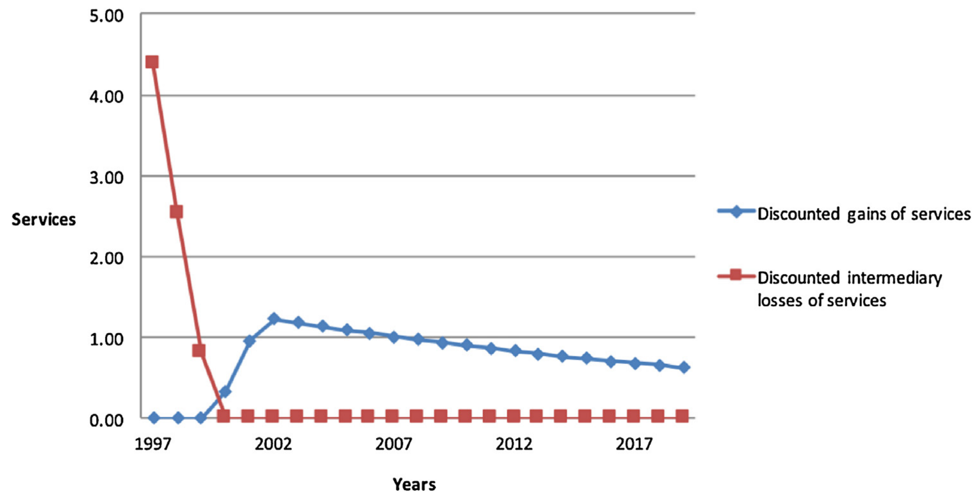

Fig. 3. Intermediary losses and gains of services over time.

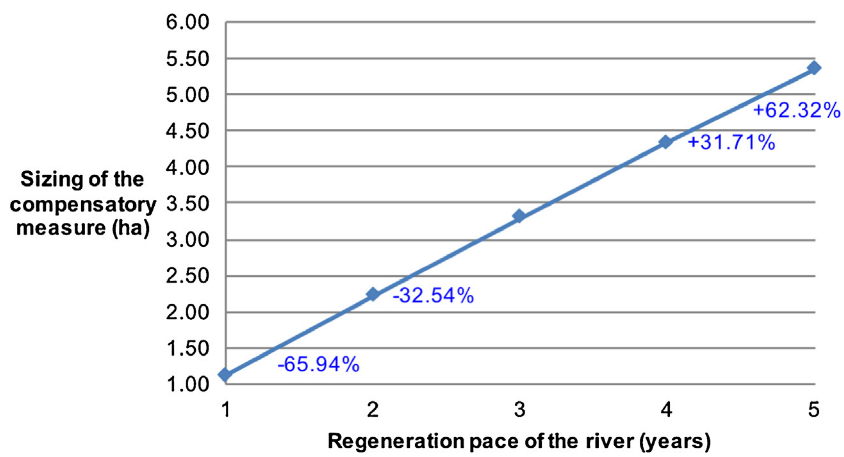

Fig. 4. Size of the compensatory area by regeneration pace of the river.

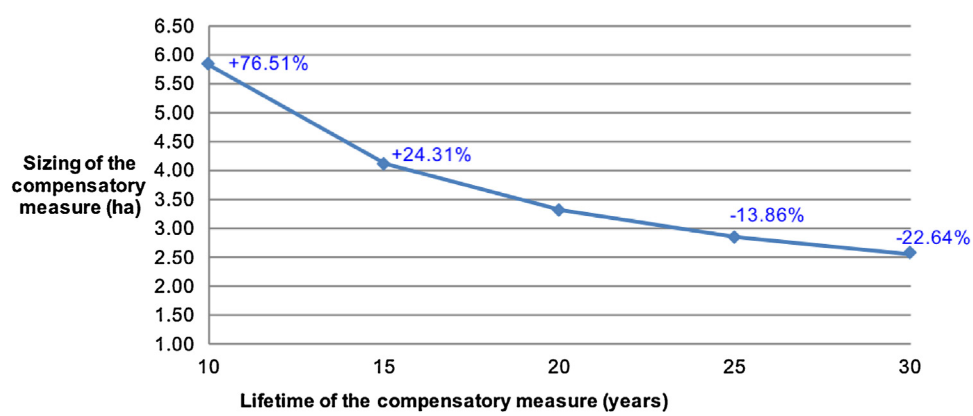

Fig. 5. Size of the compensatory area versus the lifetime of the compensatory action.

tation. The surface damages measured 7.5 ha (3 km) in area of direct impacts and effects were seen 4 km downstream from the plant.

The ecosystem service chosen by Rousseau (2007) for the Mimizan River was "the purification and maintenance of water quality" as most uses of the river are based on bathing, fishing, and other flora and fauna services. The proxy used to measure this service was the "glass eel biomass", given that the glass eel is a fragile species that needs good quality water to survive and is a strong economic asset. Data on this proxy are available in Rousseau (2007).

The Mimizan River was considered to initially provide 70% of "purification and maintenance of water quality" services, based on experts opinions. Indeed, this is a river with good water quality but with a disturbed water regime; river banks are eroded and a there was pre-existent pollution. After the impact, and based on accident reports from the fisheries association the Office National de l'Eau et des Millieux Aquatiques and the French water agency, the level of services was considered to be 0% – i.e., all the freshwater and marine fish species were destroyed. The primary restoration (i.e.,

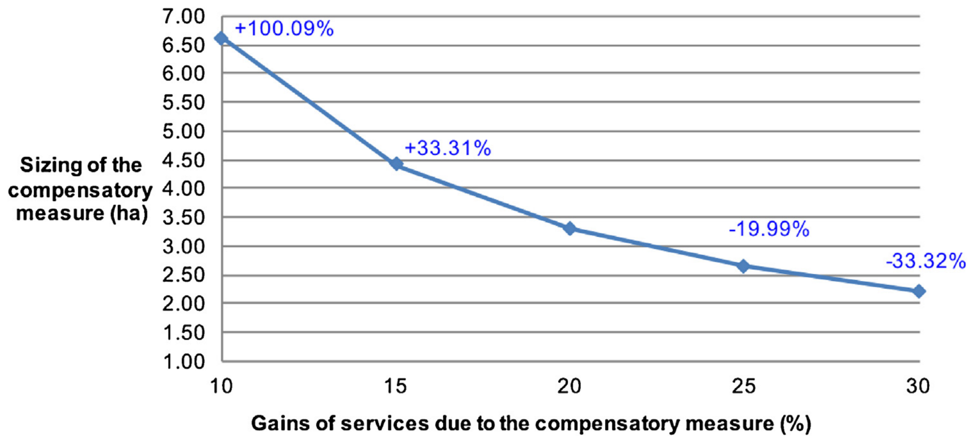

Fig. 6. Size of the compensatory area versus the percentage gain of services.

the collections of dead fishes and cleaning of the river) was carried out over a period of 3 years, equal to a regeneration pace of 23.33% per year.

The compensation project for damages to the Mimizan River was an *in situ* restoration of the river bank and an improvement of the river morphology. The aim was that the river would produce a level of 90% of services pre-damage. Give a lack of information on river ecological restoration, Two hypotheses are proposed herein using the HEA method and the Visual_HEA 2.6 software:

– The project needs 2 years to be successful to obtain a level of 90% services. We modeled this restoration spanning the years 2000–2001.
– The project needs 20 years to be successful to obtain a level of 90% services. We modeled this restoration spanning the years 2000–2019 (Table 1).

3.4.1. Results

Fig. 1 illustrates the natural increase in the level of services supplied over time by the Mimizan River after the damage and Fig. 2 demonstrates the increase in the level of services supplied by ecological restoration performed *in situ*. Following three years of primary restoration, the total level of services increased by 20% between 2000 and 2001 and was stable at 90% until 2019. Detailed results from the Visual_HEA v2.6 analysis of the Mimizan River case study are summarized per year in Table 2.

Cumulative losses that occurred to the Mimizan River were estimated at 7.708 DSAYs, spanning the year of the damage to recovery (i.e., 1997–2000). These DSAYs losses equal 7.708 ha of coastal river that no longer provided “purification and maintenance of the water quality” services as a result of the toxic leak. After 20 years, the gains obtained from the compensatory measure were estimated at 17.527 DSAYs – i.e., 2.337 DSAYs per restored hectare. Hence, at the end of the project lifetime, each restored hectare supplied a gain of service of 233.7% in relation to the initial level of services provided by the river before the damage. To compensate for the intermediary losses of services (Fig. 1), therefore, 3.298 ha (1.3 km) of river must be restored. Fig. 3 illustrates the discounted losses and discounted gains of services per year over the lifetime of the damage and restoration. Note that after 2002 – i.e., one year after 20% of additional gains of services was reached – gains of services decreased over time because of discounting.

3.4.2. Sensitivity analysis

A sensitivity analysis was performed by altering the regeneration pace between one and five years to understand the influence of protracted recovery on the sizing of the compensatory action.

When decreasing the regeneration pace of the river from one to five years in one-year increments, the surface area to be restored increased from 1.12 ha to 5.36 Ha, i.e. a change of −65.94% to 62.32% (Fig. 4). Hence, decreasing the regeneration pace by one year (i.e., from two years to three) increased the required restoration area by one hectare.

When increasing the lifetime of the compensatory measure from 10 to 30 years, the surface area to be restored decreased from 5.82 ha to 2.55 ha, i.e. a change of −22.64% to 76.51% (Fig. 5). It follows that the longer the lifetime of the measure, the smaller the surface area that needs to be restored. This effect was greater between 10 and 15 years (i.e., the surface area to be restored decreased by 2.52 ha) than between 20 and 30 years (i.e., the surface area to be restored decreased by 0.85 ha) due to the discounting rate.

When changing the gain of services due to the compensatory action from 10 to 30% (i.e., in relation to the initial level of services provided by the river before the damage), the surface area to be restored decreased from 6.60 ha to 2.20 ha – i.e., a change of −33.32% to 100.09% (Fig. 6). Similar to increasing the lifetime of the compensatory action, the greater the percentage gains of services, the smaller the surface area that would need to be restored. This effect was more considerable between 10 and 20% whereas the surface area to be restored decreased by nearly 4 ha than between 20 and 30% when the surface area to be restored decreased by 1.10 ha.

4. Discussion

4.1. Limitations of Visual_HEA

We acknowledge that the primary limitation of using the HEA method as a compensatory mitigation tool (and therefore Visual_HEA 2.6 as well) lies in a paucity of knowledge and data available on regenerative functions and rates to parameterize HEA analyses. Still, Visual_HEA 2.6 can be a useful tool when ecosystem functions, values, and rates are known; however, the software is still subject to some inherent limitations. For instance, Visual HEA 2.6 natively calculates losses and gains using yearly or quarterly time units only and is unable to perform calculations that require trimestral periods. While trimestral calculation is not a common procedure in either the United States or European nations, this feature may be desirable to expand the software’s user base and provide additional analysis options for present and future users. Additionally, if the injury affected the study ecosystem unevenly, the software is unable to provide analysis of variable service loss rates within the same HEA session. This fixed rate also applies to gains for compensatory actions. To simulate this functionality, the user must perform separate HEA calculations at different rates for each area that was affected and combine the results to form composite values. While this is not ideal, the resulting values are not affected by this extra processing step.

4.2. Future enhancements of Visual_HEA

4.2.1. Technology

The programming language used to produce Visual_HEA (i.e., Visual Basic version 6.0) is past its prime. While this does not affect calculations or the presentation of HEA results, it is desirable to update the base code to a more modern and extensible programming language. The latest version of Visual Basic (VB 2017) is a robust and tried technology and a natural successor to Visual Basic 6.0. Additional upgrades to the software may include a version natively designed to run on the Macintosh or Linux platform as this would increase accessibility of the software. It would also be prudent to examine the possibility of a web-based and platform-independent version of Visual_HEA that is accessible via any modern web browser.

4.2.2. Functionality

The addition of trimestral time-unit calculations may be useful in future versions to increase the resolution of DSAY values. Though the need for this type of calculation has not yet been suggested by the user-base, a pre-emptive inclusion of this feature would provide additional calculation options and preclude the need for repetitive calculations. Both of these value-added features may increase the use of the software and solidify Visual_HEA's position as the global *de facto* standard for performing automated HEA calculations.

4.2.3. Other methods and software to assess losses and gains related to biodiversity offsets

Multiple methods have been developed to assess losses and gains related to biodiversity offsets (Tools for Ecological Assessment, 2004; Bull et al., 2013; Pioch et al., 2015). Despite the use of common parameters to size ecological mitigation projects between methods (e.g., distinctiveness, condition, surface occupied by the species and habitat impacted, risk associated with the restoration technique, time discount rate, etc.), very few software tools have emerged to help automate the process. Among these, a BioBanking Credit Calculator software program, available online, can be used to calculate the quantity and type of credits required at a development site, or created at a biobank site, in New South Wales. One of the interesting features incorporated into the BioBanking Credit Calculator is a database that contains detailed information of 1600 vegetation types and the characteristics of listed threatened species (Mamouney et al., 2009). In the framework of the ELD, the Spanish Ministry of Agriculture, Alimentation and Environment has developed a software tool named MORA (Modelo de Oferta de Responsabilidad Ambiental). This tool provides operators carrying out dangerous activities and administration with a method to calculate the recovery cost of a natural resource following an accidental environmental damage. MORA combines the approach of HEA, known in the ELD as Resource Equivalency Analysis (Zafonte and Hampton, 2007), to assess compensatory measures and offers a catalogue of recovery techniques for different risk scenarios. MORA, therefore, should help operators establish their mandatory financial security as required by Spanish law. MORA, with its innovative features, is available online at http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/temas/responsabilidad-mediambiental/modelo-de-oferta-de-responsabilidad-ambiental/ These innovative software tools, we suggest, should be discuss by the European and French governments to enhance the HEA approach and to help efficiently mitigate damages to natural resources.

5. Conclusion

The use of the HEA method to value ecosystem services has been widespread, though there is an acknowledged scarcity of tools such as Visual_HEA to help automate the process. The Visual_HEA 2.6 software tool discussed here has been adapted to European ELD, retains the same overall parameter inputs, interface structure, and processing algorithms as the American version 2.5. Enhancements were added and software bugs were also identified and definitively addressed. The use of a real case study illustrates these new features and gives insights into potential improvements in the future.

Beyond Visual_HEA, some initiatives, such as the REMEDE project in the EU, are aiming to develop a standard toolkit for determining the scale of remedial measures necessary to adequately offset environmental damage in accordance with the requirements of different environmental European Directives (e.g., the Environmental Liability Directive and the Environmental Impact Assessment, Habitats and Wild Birds Directives). It follows within the scope of the EU No Net Loss concept that the development of standardized methodological tools, such as Visual_HEA 2.6, will continue in the future.

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