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Key words

Biodiversity offsets, biodiversity indicators, standardized framework, ecological equivalence, offset policy, operationality, scientific basis, comprehensiveness

Abstract

In response to biodiversity erosion caused by human activities, biodiversity offsets are widely used to compensate for negative impacts with an objective of “No Net Loss” (NNL). One major challenge is to evaluate what biodiversity will be offset, and select the indicators based on which the losses of biodiversity due to impacts and the gains due to offsets are calculated. In most European countries and in France particularly, there is no recommended and available standardized method to evaluate biodiversity for offsets. This leads to heterogeneous practices that do not guarantee achieving NNL. In this paper we present the development of a practical framework for biodiversity evaluation adapted to the European offset policy with French specificities. We follow four steps during which filters are applied so that the framework is science-based, operational and comprehensive. First all stakeholders involved were rallied around the scientific vision of biodiversity in order to integrate its complexity into the framework (step 1). Then the European and French legislation requirements were identified (step 2) and a practical framework for biodiversity evaluation integrating the outcomes of step 1 and 2 was developed (step 3). Finally, a relevant set of indicators within this framework was selected. The resulting framework ensures that biodiversity is evaluated at a general level before focusing on the species and habitat at stake and that the landscape context in taken into account. We argue that the development of the framework is innovative and can be generalized to a wide range of situations. Finally, we identify perspectives for losses, gains and equivalence calculation based on the framework.

Summary

Figures and Tables

Figure 1: Schematic representation of the steps followed in the approach and the related filters applied. Dark grey boxes represent the filters and light grey boxes the different constituent parts of the methodological framework.

Figure 2: a) Schematic and b) cartographic representation of the practical framework of biodiversity evaluation. Biodiversity is evaluated at two levels (General and Specific, declined in species and habitats) and two spatial scales: Large Scale (grey boxes) and Site scale (white boxes). The perimeter of the Larger Scale is defined at each level.

Table 1: Specificities of French offset policy in the European context.

Table 2: Criteria used within the framework for biodiversity evaluation.

Table 3: Details on the study sites used to test the correlations between indicators.

Table 4: Framework structure (Levels, Scales, Criteria and Indicators).

Supplementary material

Appendix 1: List of all preselected indicators and details of the selection for the final set of indicators.

Appendix 2: Correlation matrix used in the indicator selection phase.

Appendix 3: Qualitative features used as an operationality filter for indicator selection.

1. Introduction

Biodiversity offsets are currently widely used to counteract impacts from development (Pilgrim *et al.* 2013). It consists in compensating biodiversity losses with equivalent gains provided by offset measures, in order to achieve “no net loss” (NNL) of biodiversity (ten Kate *et al.* 2004). Implementing biodiversity offsets implies that the initial state of biodiversity on both impacted and compensatory sites must be evaluated. Consequently, indicators have to be chosen as surrogates for biodiversity, based on which ecological equivalence between losses and gains can be calculated to demonstrate NNL (Quétier & Lavorel 2011).

Depending on the offset policy, indicators would target different biodiversity components according to local and national conservation issues (McKenney & Kiesecker 2010). In the USA, wetlands are mitigated under the Clean Water Act (1972), and indicators are usually related to wetland functions (State of Florida 2004; Levrel *et al.* 2015). In the state of Victoria in Australia, the Native Vegetation Act (2003) imposes compensation for endemic forest, thus indicators represent vegetation cover and structure (Parkes *et al.* 2003). In Europe, offset policies are complex and have been built up since the 1970’s based on early conservation principles (Quetier *et al.* 2014). Biodiversity offsets are currently required for several biodiversity components, for which conservation outcomes are stipulated in different legislations at both European and member states level. Offset measures must be implemented when significant residual impacts (those remaining after avoidance and reduction) occur on those biodiversity components.

Despite the recent enactment of new laws in European countries strengthening offset objectives and implementation (e.g., in France the Recapture of Biodiversity and Landscapes law in 2016), in some countries there are still no recommended and available standardized indicators or methods to size offsets (e.g., France, UK, Spain, Italy). Only a few methods are starting to emerge in these countries (DREFA 2013; Gayet *et al.* 2016). Therefore, there exists a gap between on one side offset policy requirements and scientific recommendations, and on the other side usual practices. This makes it problematic to achieve the NNL of specific target biodiversity components (Regnery *et al.* 2013).

In the context of biodiversity offsetting, the biodiversity components at stake (i.e. that must be offset) are usually selected based upon anthropogenic considerations to address patrimonial issues (Regnery *et al.* 2013) but can also address ecological issues such as ecosystem functionalities (Levrel *et al.* 2012). However, how these components at stake should be evaluated remains a key challenge. The main reason is that biodiversity is multidimensional and can be observed at several organizational, spatial and temporal scales (Noss 1990), which makes its evaluation complex. Moreover, biodiversity offsets are implemented in a context of development projects where the evaluation of biodiversity is subject to technical, financial and temporal constraints (Cuperus *et al.* 2001; Quigley & Harper 2006).

Standardized frameworks could improve the evaluation of biodiversity and the assessment of ecological equivalence between losses and gains, with quantitative indicators that better combine legislation requirements (McKenney & Kiesecker 2010) and biodiversity complexity (Gibbons & Lindenmayer 2007; Gardner et al. 2013). Based on this observation, we developed a standardized framework for a practical evaluation of biodiversity in the context of biodiversity offsets. The aim of this paper is to present the development this framework step by step. We proceed in four steps: (1) rallying all the stakeholders around the scientific vision of biodiversity; (2) identifying the characteristics of the offset policy and the legislation requirements; (3) developing a practical framework for biodiversity evaluation; and (4) prospecting for and selecting a relevant set of indicators within the framework, based on data collected on eight sites in France, that happen to be used in an offsets context. Following these four steps, different filters were applied (Fig. 1) to ensure that the framework is operational, science-based and comprehensive, which are necessary attributes for the framework to enable achieving NNL (Bezombes *et al.* 2017). The framework is adapted to the European context, including specificities of the French legislation but could be generalized to other contexts as we discuss it hereafter.+

2. Step 1: Rallying all the stakeholders around the scientific vision of biodiversity

The first step consisted in rallying all stakeholders involved in biodiversity offsets around the scientific vision of what biodiversity is and how it should be evaluated. It aims to broaden offsets beyond the strict box-ticking exercise of offset requirements. Although it can seem trivial, this step is crucial as in the context of development projects, biodiversity issues are often considered by companies only as legislative constraints. This first step should be a good opportunity to open up a dialogue between all stakeholders and spread knowledge about biodiversity toward the ones not usually directly involved in biodiversity matters.

Since biodiversity is multidimensional, it is important to conceptualize its intrinsic complexity as an explicit common basis for its evaluation, which should enlarge the required foci for offsets. This should increase the project efficiency by avoiding wasting time and money on doubtful evaluation of biodiversity and give a better advertising for developers by improving their image with the society.

In our case, all stakeholders involved in the framework development (scientists, practitioners, members of environmental authorities) agreed on the definition of biodiversity given by the Convention of Biological Diversity (CBD Secretariat 1992): biodiversity is the diversity between organisms and their interactions at different levels of organization, from genes to ecosystems. We completed this definition with the possibility to evaluate biodiversity through three primary dimensions: the composition, structure and function, as recommended by Noss (1990). These dimensions should be evaluated at both spatial and temporal scales of biodiversity. Indeed, spatial patterns drive the interactions between organisms at each level of organization (e.g., the flow of species from one favorable habitat to another through ecological corridors). There are also temporal successions of fauna and flora from the pioneer to the mature state of an ecosystem whose dynamic is influenced by the perturbation regime. We agreed that evaluating biodiversity according to the vision integrating all the above-mentioned elements should capture biodiversity in its complexity.

3. Step 2: Identifying the characteristics of the offset policy and the legislation requirements

The second step consists in identifying the characteristics of the offset policy and the legislation requirements that determine a set of biodiversity components at stake that have to be offset. This involves analyzing what is mandatory and what is not mandatory but considered as good practices (that contribute to improving biodiversity offsetting, and in turn the acceptance of project developments; BBOP 2012b).

3.1. *Mandatory*

In Europe, species protection is based on the EU Habitats Directive and the EU Birds Directive (EEC 1992, 2009). The protection of these species (with particularly declining population dynamics for most of them; Donald *et al.* 2007) prohibits the destruction or alteration of their habitats. When developers cannot avoid negative impacts on species or their habitat (considering the economic and social issues of development projects), derogation requests to legal protection can be attributed under articles 9 and 16 of the EU Habitats and Birds Directives. According to these articles, projects of development may be authorized under the condition that offset measures maintain or restore a favorable conservation status of the species populations concerned (Table 1). Thus, to effectively conserve these populations, offset measures have to target the same species that are impacted (like for like).

In addition to the European laws, in France, Environmental Impact Assessment (EIA) procedures are mandatory for projects defined in article R.122-2 of the Reform of the EIA Decree (2012). In these cases, the mitigation hierarchy must be applied and any significant residual impacts on woodlands, wetlands, protected species and protected natural habitats (at the European and national scales) have to be compensated by appropriate offset measures (Table 1) because they are considered as biodiversity components at stake (Quetier *et al.* 2014).

3.2. *Not mandatory but recommended*

In addition to these mandatory requirements, a French consultative process called “Grenelle de l’Environnement” has also encouraged developers since 2007 to evaluate the impacts of their projects on landscape level connectivity. Moreover, the EU 2020 Biodiversity Strategy requires that ecosystems and their services be maintained and enhanced by establishing green infrastructure (Commission to the European Parliament 2014). Also, other areas classified as natural areas of ecological, zoological and floristic value (ZNIEFF) are considered as patrimonial areas without mandatory protection, but the jurisprudence confirms that their presence must be taken into account in EIA.

In a general way, increasing recommendations from scientists stipulate that offset measures should focus on ecosystem functionalities. In practice, impacts on “ordinary biodiversity” (i.e., biodiversity components not considered to be at stake) are usually declared as nonsignificant, even though ordinary biodiversity supports ecosystem functionalities (Smith & Knapp 2003; Solan *et al.* 2004) and is declining (Julliard *et al.* 2004; Jiguet *et al.* 2010).

4. Step 3: Developing a practical framework for biodiversity evaluation

The objective of the third step is to develop a practical framework for biodiversity evaluation taking into account the complexity of biodiversity (step 1) but also adapted to a particular offset policy with legislation requirements (step 2, Fig. 1). Those brought together make the framework comprehensive. The elaboration of the framework was guided by the four following questions.

4.1. *What biodiversity components at stake does the framework target?*

To be operational, the framework should first focus on biodiversity components that must be offset by legislation. In the French offset policy, EIA procedures ensure that a diagnosis of the biodiversity found and possibly impacted is carried out in order to detect the components at stake that are required to be offset in both European and French offset policies (see Step 2). The problem is that currently, these components are evaluated quite heterogeneously in EIA since there is no standardize framework recommended by authorities (Bigard *et al.* 2017).Therefore, to fit all procedures (Table 1) in a more standardized and reproducible way, we suggest evaluating biodiversity at two distinct levels (general and specific; see Fig. 2a):

-the general level (GL) answer the question "what biodiversity is found on impacted and compensatory sites? "The biodiversity found is evaluated in a general way, without focusing on a particular species or natural habitat. The ordinary (supporting ecosystem functionalities) and patrimonial biodiversity (i.e. protected, rare, endangered or emblematic; Delzon *et al.* 2013) can be diagnosed in EIA with this level. This level should be used for every site evaluation.

-the specific level (SL), which is further subdivided into species level (spL) and habitat level (hL). It put the focus on species or habitats at stake detected at the GL, answering the question "what is the state of the species or habitats on the sites (species needs, population viability, threats, habitat structure and maturation etc.)? Within the European offset policy, the spL can be used to evaluate species protected under the EU Habitats and Birds Directives, and the hL for natural habitats such as wetlands (French specificities). This level should be used for sites where species or habitats at stake are identified.

4.2. *At what spatial scale is biodiversity evaluated?*

In Europe, only significant residual impacts on important ecological corridors tend to be compensated, but there is no obligation to integrate landscape context (general term used here to describe the surrounding environment that is several kilometers around the impacted or compensatory sites) in EIA. However, taking into account landscape context for linear infrastructures such as roads and railways is crucial because of their highly fragmenting effects over long distances (Cuperus *et al.* 2001; Jones *et al.* 2014; Mimet *et al.* 2016). The major difficulty in evaluating the value of the impacted or compensatory site in the landscape context is the lack of available data, which makes the assessment of losses and gains in the landscape context quite sensitive.

Therefore, we suggest evaluating not only biodiversity on the impacted or compensatory site area, but also at a broader scale. To do this in a standardized way, for each of the three levels (GL, sL and hL), we suggest that biodiversity is evaluated at two spatial scales, corresponding to different perimeters (see Fig. 2b):

-the Site Perimeter (SP), which is the perimeter delimited by the developer around the impacted and compensatory sites. Biodiversity is usually evaluated ate this scale in EIA. The direct influence of impacts (e.g., destruction of 1 ha of wetland) or offset measures (e.g., restoration of 2 ha of wetlands) can be observed at this scale, as well as species perturbation.

-the Expanded Perimeter (EP), which is an area surrounding the sites (Fig. 2b). This perimeter is defined according to various issues: the size and shape of impacted and compensatory sites (at the GL), the sites location in the catchment (at the hL), and dispersal capacity or vital area of the species at stake (at the spL). The EP does not properly correspond to a landscape context because depending on the project it would cover a very wide area that is too time-consuming to prospect. Evaluation at this scale is a proxy for landscape level phenomena such as connectivity between favorable habitats for a species, which can be fragmented by development projects or restored with offset measures.

4.3. *What dimensions of biodiversity are taken into account within the framework?*

As mentioned in step 1, we consider three main dimensions to evaluate biodiversity: composition, structure and function (Noss 1990). Depending on the objectives on conservation outcomes in offset policy, some dimensions seem more appropriate to evaluate the biodiversity components at stake than others. For example, in the *Fish Habitat* approach (Harper & Quigley 2005), the composition, structure and function of lacustrine habitats are evaluated, given that the offset policy aims to maintain lake fish productivity. In Europe, as there are several objectives for biodiversity in European and French legislation depending on the components considered (Table 1), we estimated that all three dimensions are necessary to evaluate biodiversity in a comprehensive way.

To facilitate the understanding of the framework without in-depth knowledge in ecology, we broke down the compositional, structural and functional dimensions of biodiversity into seven criteria more often used in EIA: Diversity, Patrimonial Status, Representativeness, Vegetation structure, Connectivity, Functionalities and Pressure (see Table 2 for definitions and references). Most of the criteria are related to ecological processes, except for the “Patrimonial Status” criterion, which refer to anthropogenic conservation choices.

According to Noss (1990), the term “function” involves ecological and evolutionary processes, including gene flow, disturbances and nutrient cycling. Therefore, we related it to the “Pressure” and “Functionalities” criteria. The “Functionalities” criterion refers to four main processes identified as the most relevant for offset policy objectives: (i) capacity of reproduction of species (ii) population specialization, (iii) soil quality, and (iv) maturity of the vegetal succession (Table 2).

4.4. *How does the framework integrate non mandatory good practices and recommendations?*

Some practices and recommendations may not be enacted in the legislation, but still contribute to effective biodiversity offsetting and acceptance of the project. They can be mentioned in guidelines recognized by the offset policy (e.g., Cuperus *et al.* 1999; BBOP 2012a, b; CGDD 2013), they can be encouraged by expert panels evaluating and advising legal authorities on the application of the mitigation hierarchy (e.g., National Committee for Nature Protection (CNPN) in France) and they can emerge from scientific research (Evans *et al.* 2015; Gelcich *et al.* 2016).

In France, the obligation of achieving NNL is currently legislated, but no method detailing how to measure it is imposed. Therefore biodiversity offsetting is based to a large extent on recommendations, notably:

-Offsetting impacts on connectivity are recommended at both the European and national levels (EU Strategy on Green Infrastructure and Grenelle de l'Environnement). Our framework integrates an evaluation of "Connectivity" (Table 2), from a structural approach.

-Scientific research recognizes that the evaluation of biodiversity in terms of species lists or habitats is not sufficient to evaluate losses and gains, and urges countries to assess impacts on species and habitats also in terms of their functionalities. Our framework integrates some of these functionalities within a dedicated criterion (Table 2).

5. Step 4: Prospecting and selecting a relevant set of indicators within the framework

The fourth step of the approach consists in first prospecting and then selecting a relevant set of indicators for biodiversity evaluation, as a basis for the calculation of biodiversity losses and gains. In the framework presented herein, indicators should aim to characterize the seven criteria chosen for the evaluation of biodiversity as best possible (Table 2). As a multitude of indicators is currently available, during this step we applied filters to reduce the high number of potential indicators (Heink & Kowarik 2010). Two main filters can be applied (Fig. 1) so that the indicators selected are both science-based and operational i.e., adapted to the temporal, technical and financial constraints that developers must contend with.

5.1. *Prospection phase*

During the prospection phase, an exhaustive list of indicators was created for assessing each criterion defined in step 3. We applied the scientific basis filter by investigating indicators validated in scientific publications to ensure that indicators have been tested and approved as valid surrogates of the target elements (e.g., Gibbons & Freudenberger 2006; Delzons *et al.* 2013). It is crucial that the indicators prospected respond to disturbances, anthropogenic stresses and changes over time in a predictable manner and that there is low variability in this response (Dale & Beyeler 2001).

In the context of offsets, the changes refer to development projects impacts and offset measures benefits on biodiversity. In European countries, development projects concern mainly urbanization, linear infrastructures, quarries, touristic activities (ski resorts, coastal development), industrial activities...; and offset measures that are accepted consist in ecosystem restoration, creation or maintenance (with preference when there is legal protection; Jacob *et al.* 2014). We searched only for indicators with quantitative indicators, excluding indirect notations relative to qualitative characteristics, in order to keep the evaluation direct and transparent.

The list of the preselected indicators after the prospection phase is detailed in Appendix 1. A total of 170 indicators were preselected (86 for GL, 57 for hL and 27 for sL). Indicators at specific levels were classified into the indicators adapted in every situation (i.e., for the evaluation of all habitats or species), and those adapted only for one type of natural habitat or species (e.g., the number of dead trees for forest habitats).

5.2. Selection phase

During the selection phase, a final set of most relevant indicators for biodiversity evaluation is selected out of the exhaustive list, by applying the scientific basis and operationality filters (Fig. 1). In a preliminary step, we identified the indicators usually found in current procedures (see Appendix 1) in order to give them priority in the selection of the final set of indicators, as, environmental authorities assessing procedures expect certain information.

5.2.1. Scientific basis filter: removal of redundant indicators

To obtain a final set of indicators without redundancy in the information they provide, we analyzed the correlations between indicators. In theory, they should be analyzed for all preselected indicators, but to illustrate this process we restrained our analysis only to indicators from the GL (see Appendix 1).
The data used were collected on eight sites in France: a mitigation banking experiment in the Belledonne mountains (French Alps) in the department of Isère; a compensatory site located on the upper Rhine River, in the department of Haut Rhin; four impacted sites along the Romanche River and two related compensatory sites downstream on the same river also in the department of Isère (see Table 3 for details). All data refer to the initial states of biodiversity before impacts or offset measures and various types of data were used: inventories, GIS, public data and field prospection.
This selection is intended to remove the indicators highly correlated to others from the exhaustive list (based on Spearman rank correlation; high correlation being considered as $R^2>0.6$, $P<0.05$) in order to obtain a minimum set of independent indicators. The selection proceeded in three stages: a) analyzing correlations between indicators not usually used in procedures; (b) analyzing correlations between indicators that are usually used in procedures (from mandatory requirements) and c) analyzing correlations between the indicators selected in a) and b). The three correlation matrices are presented in Appendix 3. Approximately half of the preselected indicators tested were removed (39 out 75; see Appendix 1) because they were highly correlated with other indicators.

5.2.2. Operationality filter: taking into account temporal, technical and financial constraints

We applied this filter to all three levels. Since the practical framework for biodiversity evaluation should remain operational in the context of biodiversity offsets, we passed all indicators (from General and Specific Levels) through an operationality filter. It aims to exclude indicators that would not be appropriate in a context driven by temporal (data collection could take several years), technical (software for which skills are not yet common among practitioners, e.g., “Graphab” for landscape connectivity evaluation; Foltête *et al.* 2012) and financial (expensive material) constraints.
We categorized operationality into three features related to the above-mentioned constraints (Appendix 3) based on the authors’ expertise of procedures: estimated time of data collection (temporal), type of skills needed to fill in the indicator (technical) and price of the data collection needed to fill in the indicator price (financial). Depending on the features’ modalities, three levels of operationality were assigned to indicators: low, medium or high. The overall level of operationality was evaluated as the mean levels of each feature. Indicators with an overall “low” operationality were removed first, but indicators with a medium or high level of operationality were also removed if they did

not pass the scientific basis filter (five out of 81 for GL, 13 out of 56 for hL and four out of 27 for spL; see Appendix 1).

5.2.3. Final result of selection

The final set of indicators organized by levels, scales and criteria is summarized in Table 4 (41 indicators in the GL, 43 in the HL and 23 in the sL). This constitutes a standardized framework for biodiversity evaluation adapted to the European context constructed following our methodological approach.

6. Discussion

Following a step by step approach, we constructed a standardized framework for biodiversity evaluation, adapted to the European and French offsets context and combining scientific basis, operationality and comprehensiveness. In this section we discuss the choices we made for the development of such framework and their implication in biodiversity offsetting. We then identify perspectives for equivalence assessment.

6.1. Innovative aspects in the framework development

6.1.1. Going beyond strict legal requirements

The framework enables a general diagnosis of the biodiversity found on the sites, before making a focus on components considered at stake that are required to be offset by the French legislation. Thus the "ordinary" biodiversity (Doremus 2001) is visible and so will be the possible benefit from offset measures, as increasingly recommended by the scientific sphere (Brownlie & Botha 2009; BenDor & Stewart 2011; Moreno-Mateos *et al.* 2015). Moreover, evaluating biodiversity in an Expanded Perimeter (EP) instead of restricting the evaluation to the Site Perimeter (SP) allows to contextualizes the assessment in regard to the surrounding landscape, and particularly ecological corridors that contribute to the success of offsets (Kiesecker *et al.* 2009; Bull *et al.* 2013). In a general way, the framework places great emphasis on the evaluation of the functionalities, with a dedicated criteria, to preserve both target components at stake (species and habitat) and the ecosystem's self-preservation capacity in uncertain future conditions (Naeem *et al.* 2012).

6.1.2. Non-aggregation of indicators values

For more transparency and coherence in the evaluation, we chose not to aggregate indicators into notes per criterion or even an overall "score of biodiversity" for an entire site (Maseyk et al. 2016). Even though an aggregation of indicators is easily interpretable for decision making, composite indices can lead to simplistic conclusions, some dimensions may be hidden by others and the necessary weighting of indicators is often arbitrary (Nardo *et al.* 2005).

With a non-aggregation, biodiversity components showing high or low values could be detected more easily and the consequences of actions on these components would be directly visible. For example, impacts should be avoided on site showing an important "Patrimonial Status" revealing the presence of numerous species or habitats at stake. Also, some actions can favor a species with a high patrimonial value but have a negative effect on other more ordinary biodiversity components. Therefore, these inevitable trade-offs have to be visible in order to inform properly decision-makers. The difficulty is to make such a large amount of information intelligible; therefore the visualization of indicators is all the more important for their understanding and interpretation by stakeholders.

6.1.3. Combining quantitative values and expert opinion

The standardization of the framework makes the evaluation of biodiversity operational and efficient (Laycock *et al.* 2013). It ensures that the essential components are evaluated in a quantitative way and better exploits efforts already made, for data collection notably. Within the standardized framework however, expert opinion is needed to fill in certain indicators in place of precise indicators not available considering the requirements described in step 4.

This concerns mainly the indicators within the species level (spL) such as "the area of favorable habitat" (on the site before and after impacts or offset measures). Instead of analyzing each habitat feature for all potential species at stake in a standardized way (over 900 species are protected under the EU Habitats Directive 92/43/EEC; EEC 1992), we enabled experts to decide on the favorability aspect of the habitat (i.e. what surface of the site does gather all vital elements for the target species?). The result is still a quantitative value (e.g. hectares). Nonetheless, experts should argument the attribution of the indicator values with documentation in order that the framework outputs remain transparent.

6.2. The adaptability of the framework to a wide range of situations

The framework we developed can be used for the evaluation of the biodiversity of a wide range of ecosystems and respond to the European and French offset policy requirements. It is designed to be applied on a case by case basis because in Europe and France it is the most common approach.

The strength of this framework is that it can also be adapted to other offset policies that claim different objectives and are constructed upon different conservation issues. Indeed, the changes would concern the set of indicators related to the biodiversity targeted by a given legislation or at stake in a given country that do not exist in the European context. We detail some adaptation hereafter according to:

-The *offset policy*. This framework focuses on species and habitats at stake in response to the importance given by EU and French offset policies in protecting species and habitat conservation. In the USA for example, wetland mitigation represents a major part in offset policy (Madsen *et al.* 2010) and therefore the framework would probably focus on a specific level for wetlands or a comprehensive set of indicators dedicated to wetlands evaluation within the habitat level. In the UK there is willingness from the government to preserve ordinary biodiversity (with less focus on biodiversity at stake; DREFA 2013), which could be evaluated only with an extended General level (GL).

-The *naturalness of ecosystems*. In European countries, biodiversity has evolved with human activities for centuries (Doxa *et al.* 2012) and only very few remaining ecosystems can be considered to have high naturalness (e.g., some Mediterranean primary forests, peatlands). In regions where wilderness areas never impacted by human activities still exist (e.g., tropical forests in Brazil), the framework should enable the evaluation of this naturalness, with a dedicated criterion for example. Moreover, such cases should be more favorable (less subject to debates) for comparison of the selected indicators to a reference state (i.e., high naturalness). Indicators would be relative rather than absolute indicators (e.g., values expressed as percentages of the benchmark; Parkes *et al.* 2003).

-The *type of ecosystems*. The framework is adapted to terrestrial biodiversity (including wetlands) and at the moment does not include indicators specific to aquatic or marine ecosystems. The indicators would necessarily be different since these ecosystems have different proprieties than the terrestrial ones. They notably have high temporal variability due to frequent hydrological disturbances (floods, low water) (Resh *et al.* 1988; Poff *et al.* 1997), very pronounced longitudinal structuring (Kondolf *et al.* 2003) and higher consumer biomass than primary producers (unlike terrestrial ecosystems).

-The *spatial scales*. In Europe, the high population density of countries (the urbanization rate is 75% according to the European Commission), and the low amount of remaining pristine habitat, influences land use which becomes very strategic. Land use is managed on smaller areas compared to countries like the USA, Australia, Brazil or Canada. In those areas, the Expanded Perimeter could be more related to an actual landscape scale since species dynamics can be observed over wide areas (Hanski 1998).

6.3. A basis for losses, gains and equivalence assessment

The indicators suggested in the framework are the basis for the assessment of the ecological equivalence between biodiversity losses and gains. For this purpose, each relevant indicator should be assessed four times: before impacts and offset measures (initial state of impacted and compensatory sites) and after impacts and offset measures (predicted state of the sites; Bezombes *et al.* 2017). Consequently, losses and gains can be calculated for each indicator as the predicted values minus the initial values. The ecological equivalence is logically reached when the values of losses equal the values of gains. To complete these steps, the two following aspects would still need to be worked on.

6.3.1. *Loss and gain predictions*

The ecological equivalence has to be assessed early in the project development process, in order that authorities evaluate whether the design of offset measures can achieve NNL. This timing implies that the values of indicators after impacts and offset measures are predictions that have to be made based on the impacted and compensatory sites' initial state. The use of modelling to evaluate "natural" ecosystem trajectories, i.e. without impacts or offset measures (Stringham et al. 2003), is an accurate way of calculating losses and gains but in practice experts involved do not have access to such technics (Sunderland et al. 2009). In any cases, the predictions are accompanied by a certain amount of uncertainties (Moilanen *et al.* 2009). Predicted values of indicators should therefore be modulated depending on the level of this uncertainty, which could be determined according to the target species or habitat (Tischew *et al.* 2010), the type and intensity of the impacts (temporary or permanent), the type of offset measures (Anderson 1995) etc.

6.3.2. *Equivalence assessment*

As we did not aggregate the indicators within the framework, the balance between losses and gains must be observed for each indicator individually. In an ideal situation, every indicator would be at least balanced or show a net gain, and consequently ecological equivalence would be reached for the whole project. In practice however, some indicators will be balanced (gain equals loss), while others will probably show a net gain or a net loss (Bull *et al.* 2014). To determine whether equivalence is reached overall, we suggest ranking indicators according to the biodiversity issues and the offset policy requirements (should we prioritize the conservation of natural areas, rare species, landscape fragmentation...; Brooks *et al.* 2006). Thus, equivalence (or net gain) should be reached at least for all "priority" indicators, i.e., the ones identified to represent the main biodiversity issues. The prioritization of indicator will certainly vary from a project to another, but some issues may be common to an entire territory.

Conclusion

Using the framework we present in this paper should ensure that the evaluation of biodiversity on impacted and compensatory sites is science-based, operational and comprehensive. This framework can provide an objective basis for discussion on biodiversity offset management and should be shared by the different stakeholders involved.

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