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## Development of a standardized framework for the evaluation of biodiversity in the context of biodiversity offsets

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### ► To cite this version:

Lucie Bezombes, Stéphanie Gaucherand, Thomas Spiegelberger, Véronique Gouraud, Christian Kerbirou. Development of a standardized framework for the evaluation of biodiversity in the context of biodiversity offsets. *Ecological Indicators*, 2018, 93, pp.1244-1252. 10.1016/j.ecolind.2018.06.027 . hal-02295898

**HAL Id: hal-02295898**

**<https://hal.sorbonne-universite.fr/hal-02295898>**

Submitted on 27 Sep 2019

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1 **Development of a standardized framework for the evaluation of biodiversity in the context of**  
2 **biodiversity offsets.**

3

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18 **Acknowledgments**

19 We are thankful to Marie-Eve Reinert for her useful comments on an earlier draft of this article. We are  
20 grateful to the researchers from IRSTEA who participated in the working group on the framework  
21 development. We also thank Agnes Barillier and Frederick Jacob for relevant comments and advice on  
22 the choice of indicators, and all the organizations that collected the data on the study sites. This  
23 research was financed by the French government "CIFRE" grant for PhD students and Electricité de  
24 France (EDF).

25

26 **Key words**

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

29 **Abstract**

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

48

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80 **Figures and Tables**

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82 applied. Dark grey boxes represent the filters and light grey boxes the different constituent parts of the  
83 methodological framework.

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

88

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

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

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

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

93

94 **Supplementary material**

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

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

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

99 Biodiversity offsets are currently widely used to counteract impacts from development (Pilgrim *et al.*  
100 2013). It consists in compensating biodiversity losses with equivalent gains provided by offset  
101 measures, in order to achieve “no net loss” (NNL) of biodiversity (ten Kate *et al.* 2004). Implementing  
102 biodiversity offsets implies that the initial state of biodiversity on both impacted and compensatory  
103 sites must be evaluated. Consequently, indicators have to be chosen as surrogates for biodiversity,  
104 based on which ecological equivalence between losses and gains can be calculated to demonstrate  
105 NNL (Quétier & Lavorel 2011).

106 Depending on the offset policy, indicators would target different biodiversity components according to  
107 local and national conservation issues (McKenney & Kiesecker 2010). In the USA, wetlands are  
108 mitigated under the Clean Water Act (1972), and indicators are usually related to wetland functions  
109 (State of Florida 2004; Levrel *et al.* 2015). In the state of Victoria in Australia, the Native Vegetation  
110 Act (2003) imposes compensation for endemic forest, thus indicators represent vegetation cover and  
111 structure (Parkes *et al.* 2003). In Europe, offset policies are complex and have been built up since the  
112 1970’s based on early conservation principles (Quétier *et al.* 2014). Biodiversity offsets are currently  
113 required for several biodiversity components, for which conservation outcomes are stipulated in  
114 different legislations at both European and member states level. Offset measures must be  
115 implemented when significant residual impacts (those remaining after avoidance and reduction) occur  
116 on those biodiversity components.

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

124 In the context of biodiversity offsetting, the biodiversity components at stake (i.e. that must be offset)  
125 are usually selected based upon anthropogenic considerations to address patrimonial issues (Regnery  
126 *et al.* 2013) but can also address ecological issues such as ecosystem functionalities (Levrel *et al.*  
127 2012). However, how these components at stake should be evaluated remains a key challenge. The  
128 main reason is that biodiversity is multidimensional and can be observed at several organizational,  
129 spatial and temporal scales (Noss 1990), which makes its evaluation complex. Moreover, biodiversity  
130 offsets are implemented in a context of development projects where the evaluation of biodiversity is  
131 subject to technical, financial and temporal constraints (Cuperus *et al.* 2001; Quigley & Harper 2006).

132 Standardized frameworks could improve the evaluation of biodiversity and the assessment of  
133 ecological equivalence between losses and gains, with quantitative indicators that better combine  
134 legislation requirements (McKenney & Kiesecker 2010) and biodiversity complexity (Gibbons &  
135 Lindenmayer 2007; Gardner *et al.* 2013). Based on this observation, we developed a standardized  
136 framework for a practical evaluation of biodiversity in the context of biodiversity offsets. The aim of this  
137 paper is to present the development this framework step by step. We proceed in four steps: (1) rallying

138 all the stakeholders around the scientific vision of biodiversity; (2) identifying the characteristics of the  
139 offset policy and the legislation requirements; (3) developing a practical framework for biodiversity  
140 evaluation; and (4) prospecting for and selecting a relevant set of indicators within the framework,  
141 based on data collected on eight sites in France, that happen to be used in an offsets context.  
142 Following these four steps, different filters were applied (Fig. 1) to ensure that the framework is  
143 operational, science-based and comprehensive, which are necessary attributes for the framework to  
144 enable achieving NNL (Bezombes *et al.* 2017). The framework is adapted to the European context,  
145 including specificities of the French legislation but could be generalized to other contexts as we  
146 discuss it hereafter.+

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

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

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

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

## 171 **3. Step 2: Identifying the characteristics of the offset policy and the legislation** 172 **requirements**

173 The second step consists in identifying the characteristics of the offset policy and the legislation  
174 requirements that determine a set of biodiversity components at stake that have to be offset. This  
175 involves analyzing what is mandatory and what is not mandatory but considered as good practices

176 (that contribute to improving biodiversity offsetting, and in turn the acceptance of project  
177 developments; BBOP 2012b).

### 178 **3.1. Mandatory**

179 In Europe, species protection is based on the EU Habitats Directive and the EU Birds Directive (EEC  
180 1992, 2009). The protection of these species (with particularly declining population dynamics for most  
181 of them; Donald *et al.* 2007) prohibits the destruction or alteration of their habitats. When developers  
182 cannot avoid negative impacts on species or their habitat (considering the economic and social issues  
183 of development projects), derogation requests to legal protection can be attributed under articles 9 and  
184 16 of the EU Habitats and Birds Directives. According to these articles, projects of development may  
185 be authorized under the condition that offset measures maintain or restore a favorable conservation  
186 status of the species populations concerned (Table 1). Thus, to effectively conserve these populations,  
187 offset measures have to target the same species that are impacted (like for like).

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

### 194 **3.2. Not mandatory but recommended**

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

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

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

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



213 **4.1. What biodiversity components at stake does the framework target?**

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

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

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

234

235 **4.2. At what spatial scale is biodiversity evaluated?**

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

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

248 -the Site Perimeter (SP), which is the perimeter delimited by the developer around the impacted and  
249 compensatory sites. Biodiversity is usually evaluated ate this scale in EIA. The direct influence of

250 impacts (e.g., destruction of 1 ha of wetland) or offset measures (e.g., restoration of 2 ha of wetlands)  
251 can be observed at this scale, as well as species perturbation.

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

#### 259 **4.3. What dimensions of biodiversity are taken into account within the framework?**

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

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

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

#### 279 **4.4. How does the framework integrate non mandatory good practices and recommendations?**

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

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

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

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

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

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

### 305 **5.1. Prospection phase**

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

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

319 The list of the preselected indicators after the prospection phase is detailed in Appendix 1. A total of  
320 170 indicators were preselected (86 for GL, 57 for hL and 27 for sL). Indicators at specific levels were  
321 classified into the indicators adapted in every situation (i.e., for the evaluation of all habitats or  
322 species), and those adapted only for one type of natural habitat or species (e.g., the number of dead  
323 trees for forest habitats).

324 **5.2. Selection phase**

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

330 **5.2.1. Scientific basis filter: removal of redundant indicators**

331 To obtain a final set of indicators without redundancy in the information they provide, we analyzed the  
332 correlations between indicators. In theory, they should be analyzed for all preselected indicators, but to  
333 illustrate this process we restrained our analysis only to indicators from the GL (see Appendix 1).

334 The data used were collected on eight sites in France: a mitigation banking experiment in the  
335 Belledonne mountains (French Alps) in the department of Isère; a compensatory site located on the  
336 upper Rhine River, in the department of Haut Rhin; four impacted sites along the Romanche River and  
337 two related compensatory sites downstream on the same river also in the department of Isère (see  
338 Table 3 for details). All data refer to the initial states of biodiversity before impacts or offset measures  
339 and various types of data were used: inventories, GIS, public data and field prospection.

340 This selection is intended to remove the indicators highly correlated to others from the exhaustive list  
341 (based on Spearman rank correlation; high correlation being considered as  $R^2 > 0.6$ ,  $P < 0.05$ ) in order to  
342 obtain a minimum set of independent indicators. The selection proceeded in three stages: a) analyzing  
343 correlations between indicators not usually used in procedures; (b) analyzing correlations between  
344 indicators that are usually used in procedures (from mandatory requirements) and c) analyzing  
345 correlations between the indicators selected in a) and b). The three correlation matrices are presented  
346 in Appendix 3. Approximately half of the preselected indicators tested were removed (39 out 75; see  
347 Appendix 1) because they were highly correlated with other indicators.

348 **5.2.2. Operationality filter: taking into account temporal, technical and financial constraints**

349 We applied this filter to all three levels. Since the practical framework for biodiversity evaluation should  
350 remain operational in the context of biodiversity offsets, we passed all indicators (from General and  
351 Specific Levels) through an operationality filter. It aims to exclude indicators that would not be  
352 appropriate in a context driven by temporal (data collection could take several years), technical  
353 (software for which skills are not yet common among practitioners, e.g., “Graphab” for landscape  
354 connectivity evaluation; Foltête *et al.* 2012) and financial (expensive material) constraints.

355 We categorized operationality into three features related to the above-mentioned constraints  
356 (Appendix 3) based on the authors’ expertise of procedures: estimated time of data collection  
357 (temporal), type of skills needed to fill in the indicator (technical) and price of the data collection  
358 needed to fill in the indicator price (financial). Depending on the features’ modalities, three levels of  
359 operationality were assigned to indicators: low, medium or high. The overall level of operationality was  
360 evaluated as the mean levels of each feature. Indicators with an overall “low” operationality were  
361 removed first, but indicators with a medium or high level of operationality were also removed if they did

362 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;  
363 see Appendix 1).

### 364 5.2.3. *Final result of selection*

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

## 369 6. Discussion

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

### 375 6.1. Innovative aspects in the framework development

376

#### 377 6.1.1. *Going beyond strict legal requirements*

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

389

#### 390 6.1.2. *Non-aggregation of indicators values*

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

396 With a non-aggregation, biodiversity components showing high or low values could be detected more  
397 easily and the consequences of actions on these components would be directly visible. For example,  
398 impacts should be avoided on site showing an important "Patrimonial Status" revealing the presence  
399 of numerous species or habitats at stake. Also, some actions can favor a species with a high

400 patrimonial value but have a negative effect on other more ordinary biodiversity components.  
401 Therefore, these inevitable trade-offs have to be visible in order to inform properly decision-makers.  
402 The difficulty is to make such a large amount of information intelligible; therefore the visualization of  
403 indicators is all the more important for their understanding and interpretation by stakeholders.

#### 404 6.1.3. *Combining quantitative values and expert opinion*

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

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

418

### 419 **6.2. The adaptability of the framework to a wide range of situations**

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

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

428 -The *offset policy*. This framework focuses on species and habitats at stake in response to the  
429 importance given by EU and French offset policies in protecting species and habitat conservation. In  
430 the USA for example, wetland mitigation represents a major part in offset policy (Madsen *et al.* 2010)  
431 and therefore the framework would probably focus on a specific level for wetlands or a comprehensive  
432 set of indicators dedicated to wetlands evaluation within the habitat level. In the UK there is willingness  
433 from the government to preserve ordinary biodiversity (with less focus on biodiversity at stake; DREFA  
434 2013), which could be evaluated only with an extended General level (GL).

435 -The *naturalness of ecosystems*. In European countries, biodiversity has evolved with human activities  
436 for centuries (Doxa *et al.* 2012) and only very few remaining ecosystems can be considered to have  
437 high naturalness (e.g., some Mediterranean primary forests, peatlands). In regions where wilderness  
438 areas never impacted by human activities still exist (e.g., tropical forests in Brazil), the framework

439 should enable the evaluation of this naturalness, with a dedicated criterion for example. Moreover,  
440 such cases should be more favorable (less subject to debates) for comparison of the selected  
441 indicators to a reference state (i.e., high naturalness). Indicators would be relative rather than absolute  
442 indicators (e.g., values expressed as percentages of the benchmark; Parkes *et al.* 2003).

443 -The *type of ecosystems*. The framework is adapted to terrestrial biodiversity (including wetlands) and  
444 at the moment does not include indicators specific to aquatic or marine ecosystems. The indicators  
445 would necessarily be different since these ecosystems have different properties than the terrestrial  
446 ones. They notably have high temporal variability due to frequent hydrological disturbances (floods,  
447 low water) (Resh *et al.* 1988; Poff *et al.* 1997), very pronounced longitudinal structuring (Kondolf *et al.*  
448 2003) and higher consumer biomass than primary producers (unlike terrestrial ecosystems).

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

455

### 456 **6.3. A basis for losses, gains and equivalence assessment**

457 The indicators suggested in the framework are the basis for the assessment of the ecological  
458 equivalence between biodiversity losses and gains. For this purpose, each relevant indicator should  
459 be assessed four times: before impacts and offset measures (initial state of impacted and  
460 compensatory sites) and after impacts and offset measures (predicted state of the sites; Bezombes *et al.*  
461 2017). Consequently, losses and gains can be calculated for each indicator as the predicted values  
462 minus the initial values. The ecological equivalence is logically reached when the values of losses  
463 equal the values of gains. To complete these steps, the two following aspects would still need to be  
464 worked on.

465

#### 466 6.3.1. *Loss and gain predictions*

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

476 or habitat (Tischew *et al.* 2010), the type and intensity of the impacts (temporary or permanent), the  
477 type of offset measures (Anderson 1995) etc.

478

### 479 6.3.2. *Equivalence assessment*

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

491

### 492 **Conclusion**

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



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