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Strategic landscape-scale planning to improve mitigation hierarchy implementation: an empirical case study in Mediterranean France

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Key words: mitigation hierarchy; land-use planning; no net loss; strategic environmental assessment; conservation science

Abstract

Continued urban development is a major cause of the loss of biodiversity. In this context, the objective of a *No Net Loss* (NNL) of biodiversity has been adopted in many countries worldwide. Reaching such an objective requires the application of the mitigation hierarchy, an environmental policy that aims to minimise the impact of urban development. It consists of a hierarchy transposed in France by a sequence of avoidance, reduction and, as a last resort, offsetting of residual impacts on biodiversity that have not been avoided or reduced. Currently, a project-by-project approach with little avoidance, much investment in the reduction of impacts and piecemeal efforts to offset biodiversity losses, significantly limits the effectiveness of the application of the mitigation hierarchy. This difficulty is largely due to a lack of both anticipation and more strategic planning of the mitigation hierarchy by decision-makers at the landscape scale. The purpose of this study is to propose a method that “scales up” the implementation of the mitigation hierarchy from the project-level to a landscape-scale approach. Based on an empirical study, we propose an operational framework for implementation of the mitigation hierarchy at this landscape scale on the basis of spatial indices that are used to (1) set priorities for impact avoidance and (2) pre-identify sites as candidates for offset provision. This methodology provides a much-needed tool to anticipate for the avoidance step and integrate offsetting into the planning process in a more Strategic Environmental Assessment type approach. We show how the use of this method is relevant in a territory that is currently undergoing rapid population growth and urbanization (Montpellier Metropolitan Territory in the south of France). Finally, this paper illustrates the importance of conducting such research in close collaboration with practitioners and public decision-makers to facilitate interactions between developers and conservation stakeholders and improve implementation by land-use planners.

Highlights

1. From project level to landscape scale mitigation hierarchy implementation
2. Anticipation of avoidance and biodiversity offsets in land use planning
3. Elaboration of a systematic mitigation planning tool
4. Integrating the mitigation hierarchy into strategic environmental assessment

Manuscript

5. Introduction

Habitat loss, degradation, and fragmentation due to land take and, in particular, urban land expansion represent an immediate and tangible threat to biodiversity (Lawton and McCredie, 1995; McKinney, 2006, 2008; Sala et al., 2000). In this context, most countries in the world have attempted to implement a policy for biodiversity conservation that embraces the concept of « No Net Loss » (NNL) of biodiversity (Maron et al., 2016) to improve environmental strategies and actions for biodiversity conservation (Schulp et al., 2016). This notion has been proposed as a guiding principle for the application of a mitigation hierarchy with the aim to first “avoid” environmental impacts, then “reduce or minimise” impacts that are not avoided and, as a last resort, “offset” residual impacts (Bull et al., 2016; Hassan et al., 2015; Maron et al., 2016).

The mitigation hierarchy, in particular its biodiversity offset step, has received criticisms in terms of its environmental effectiveness (Bezombes et al., 2019; Bull et al., 2013; Curran et al. 2014; Gordon et al., 2015; Lindenmayer et al., 2017; Maron et al., 2012; Moreno-Mateos et al., 2015; May et al., 2017). The disproportionately low number of cases of avoidance relative to the number of measures to reduce the adverse impacts of development is of primary concern here (Bigard et al., 2017; Phalan et al., 2017). In addition, mitigation measures are proposed in the scope of the “environmental impact assessment” (EIA) made for individual site-specific development projects in a project-by-project approach (Mandelik et al., 2005; Morgan, 2012; Pope et al., 2013). Consequently, biodiversity offset sites are defined in a piecemeal way, mostly disconnected from the existing ecological network. In addition, the social pressure associated with a rather conflictual situation of land tenure in Mediterranean France complicates the identification of offset sites that are ecologically similar to impacted sites in terms of biodiversity composition and function. Finally, the EIA procedure is only implemented for projects that exceed a given size defined by French law. This allows for multiple development projects that are below this threshold size to proceed in the absence of an EIA procedure, and thus without mitigation measures.

Currently, such small projects represent a significant contribution to urban spread (approximately half of the total land take each year in France; Agreste, 2015; Virely, 2017). Consequently, the location and amount of these small projects are only regulated by large scale land-use planning.

To achieve NNL, there is thus an important need to implement policy on the basis of scientific methodology and tools that allow for the anticipation of future impacts of land take within all three steps of the mitigation hierarchy (BirdLife International, 2015; Copeland et al., 2007; Davis et al., 1990; Hayes, 2014; Kiesecker et al., 2010; Kujala et al., 2015; Phalan et al., 2017; Regnery et al., 2013; Tallis et al., 2015; Underwood, 2011). Scaling up the mitigation hierarchy from a project-by-project approach to the landscape level of land-use planning in a way that allows actors to anticipate the mitigation procedure and correctly identify sites for offsetting represents a possible step forward (Bigard et al., 2017). Several studies have demonstrated the potential conservation benefits of combining landscape-level conservation planning with offset location selection procedures (Habib et al., 2013; Kiesecker et al., 2010, 2009; Kreitler et al., 2015; Kujala et al., 2015; Moilanen, 2013; Underwood, 2011). However, a lack of concrete applications in which anticipation for avoidance and offsetting steps are combined into a proactive and strategic perspective makes it difficult to conclude based on the effectiveness of such an approach (Moilanen, 2013). It should also be realised that scientific guidelines for this decision-making process are rare, as are criteria that identify sites where avoidance is most critical and which represent appropriate candidate sites for offsetting (Kiesecker et al., 2010).

It is important to recognise two issues here. As Maron et al. (2016) highlight, NNL can be related either to overarching policy goals, or to responses to specific impacts. Indeed, the underlying principles are not different at the project and landscape levels; both are based on ecological equivalency, efficiency and additionality (BBOP, 2013). However, at the project level, the ecological equivalency between what is lost and what is gained has to be demonstrated on a species-by-species, habitat-by-habitat and ecological-function-by-ecological-function basis. In contrast, at the landscape scale, ecological equivalence is a question of anticipation that aims at optimising the efficiency of the mitigation hierarchy for individual projects in order to achieve a global NNL. Hence, this strategic approach, at ecologically and institutionally meaningful scales, does not supplant or contradict the implementation of the mitigation hierarchy at the project level, but is complementary (Arlidge et al., 2018).

Such a systematic approach brings the implementation of the mitigation hierarchy into the realm of Strategic Environmental Assessment (SEA), the planning counterpart of EIA. This is particularly interesting because, at the current time, SEA does not consistently use biodiversity as an input factor. Hence, the efficient integration of biodiversity into land-use policy through SEA is now necessary (Colsaet et al., 2018). The methods developed in the systematic conservation planning literature are of particular pertinence for the adoption of SEA integrating biodiversity (Margules and Pressey, 2000;

Pressey and Bottrill, 2008). Indeed, they can be adapted to select priority areas for impact avoidance and the search for similarity in the offsetting procedure. This systematic approach to impact avoidance and offsetting is particularly relevant and challenging in a peri-urban context (Bekessy et al., 2012; Crossman et al., 2007; Gordon et al., 2009; Prévost and Robert, 2016) where the matrix of areas surrounding high biodiversity sites currently undergoes high levels of direct or indirect impacts. These impacts destroy and fragment natural areas and thus reduce the ecological quality of remaining areas.

Finally, the research-implementation gap still remains a challenge in the context of policy and tools for biodiversity conservation (Arlettaz et al., 2010; Knight et al., 2008; Young et al., 2014). Scientific advances on this subject must also be made in a way that are useful for practitioners in a real socio-political context (Hulme, 2014; Knight et al., 2008), or by providing methodology that fits practitioners' needs and competences (e.g., Cabin, 2007; Margules and Pressey, 2000; Toomey et al., 2017). This is particularly true for the implementation of the mitigation hierarchy.

In this study, we develop a spatial analysis that explicitly integrates biodiversity policy in terms of mitigation hierarchy implementation, within the scope of urban planning, through Strategic Environmental Assessment. We construct a scientifically based, operational and repeatable methodology to guide decision-makers during the process of anticipating and setting priorities for impact avoidance and the search for appropriate candidate offset sites. To illustrate how the framework can be applied in a concrete socio-political context of implementing policy for biodiversity conservation, we expose and discuss the choices made in our methodological framework with local land-use planners (Montpellier Metropolitan Agency in the South of France) who were in the process of designing a strategic urban development plan for their territory. This case study thus provides an example of the conditions, benefits and limits of linking applied biodiversity conservation science to land-use planning issues.

6. Methods

2.1. The overall methodological approach

We propose a framework based on ecologically spatial indicators to facilitate the implementation of the mitigation hierarchy at the landscape scale. First, we adapt methods from the systematic conservation planning literature (Margules and Pressey, 2000; Pressey and Bottrill, 2008) to select priority areas for impact avoidance and to identify alternatives for zoning intended for urban development. This first stage of the mapping exercise seeks to indicate areas that provide a means to optimise the avoidance of adverse impacts, before moving to the next step in the mitigation hierarchy. Second, at a landscape scale, we develop spatial tools to identify potential biodiversity offset sites in the surrounding territory using

criteria based on proximity, similarity and feasibility. The losses due to a project's impacts and gains due to an offset measure still need to be described, measured, and balanced on a project-by-project basis. We deliberately do not deal with the reduction step of the mitigation hierarchy (French equivalent of the combination of minimisation and rehabilitation as defined by BBOP standards; BBOP, 2013) because this step can only be implemented at the project level when its localisation is decided. Figure 1 illustrates the global framework and details the steps in the method that will be described in the case study section.

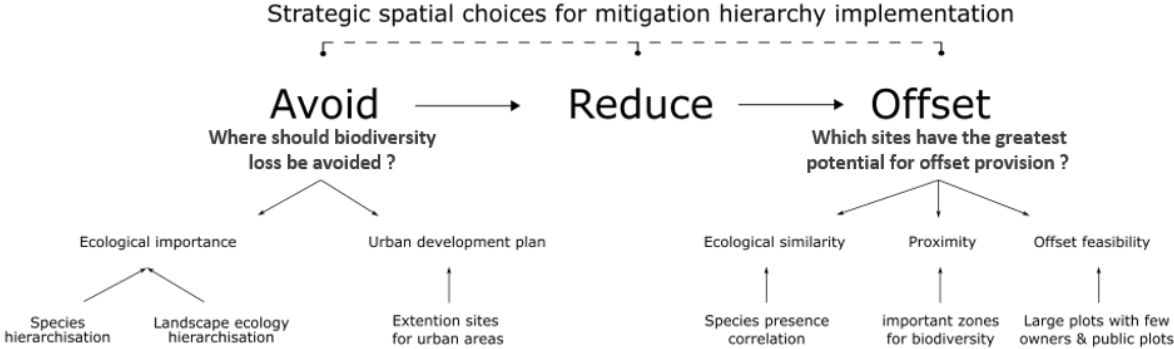


Figure 1. A “systematic mitigation planning” framework

This framework constitutes a decision support tool based on a series of choices for different criteria and a global mapping approach that decision-makers must integrate. As recognised elsewhere, a decision support tool should be based on a multi-criteria analysis to provide objective outputs and a search for coherence among different values, and not just promote optimisation (Roy and Vincke 1989). According to Cash et al. (2003), to become truly functional and practically effective, scientific work has to be (1) credible, i.e., authoritative and believable, (2) legitimate, by integrating the diverse values and perspectives of different stakeholders, and (3) salient, i.e., relevant and timely for decision-making. Thus, it should be adapted to practitioners needs to be implemented. The first of these three points was addressed by using scientifically tested tools and recommendations in the systematic conservation planning literature (Margules and Pressey, 2000; Pressey and Bottrill, 2008). The second point was treated and enhanced by an official partnership involving full-time immersion of the first author of this paper into the practitioners’ agency over a six-month period. This immersion allows us to assess the political, environmental and economic contexts in which the final tool could be included to promote its relevance. This link was maintained throughout the study. In addition, to ensure the reliability of the approach, we constructed the methodology in close contact with a range of stakeholders: conservation management staff, environmental consultants who provide services to developers, members of state agencies, data suppliers, NGOs and other scientists.

Within a GIS approach, which is relevant for spatial and multi-criteria analysis, we used several databases to build indicators that enable us to produce a hierarchy for conservation targets in the study area (Davis et al., 1990). The databases are primarily land-use, fauna and flora raw datasets and environmental variables (Appendix 1). For the study, we included a two-kilometre buffer zone around the Montpellier Metropolitan territory perimeter to limit edge effects within the perimeter of the study area. Thus, the overall study area was 760 km².

2.2. Case study

This study was carried out in the Montpellier Metropolitan territory that regroups 31 municipalities (~430 000 inhabitants in a territory of 440 km²) in the South of France. This territory has had (and continues to have) a rapid rate of population growth over the last 25 years (population growth of +1.03% between 2006 and 2011 in comparison to an average +0,45% in other metropolises in France; INSEE, 2016). This occurs in a typical Mediterranean landscape mosaic of semi-natural habitats and traditional agricultural activities that comprise the non-urbanised part of this territory (Blondel et al., 2010; Thompson, 2005). This imbrication of high biodiversity areas and the spread of suburban development, associated with a context of increasing land prices and small plot ownership, complicates the application of the mitigation hierarchy, in particular the avoidance of impacts on widespread high biodiversity areas and the acquisition of compensation sites.

As a public establishment for inter-municipality cooperation, the administrative organisation of Montpellier Metropolitan territory is in charge of land-use planning. In France, and particularly in Mediterranean coastal territories, spatial planning practices and the formulation of territorial strategies are heterogeneous (Prévost and Robert, 2016). In line with French urban and environmental regulations (Solidarity and Urban Renewal Act of 2000) and with the second Aïchi target (“*By 2020, at the latest, biodiversity values have been integrated into national and local development [...] strategies and planning processes*”), the territorial planning scheme (SCoT) has become the main tool for sustainable strategic inter-municipality urban planning over 15 to 20 years in France. The SCoT is a territorial plan, subject to strategic environmental assessment (SEA), which describes the development strategy and objectives for the territory. The administrative organisation of the Montpellier Metropolitan territory was revising its territorial plan at the time of our work, making it a particularly appropriate situation to apply our work.

2.3. Evaluation of biodiversity issues for avoidance

To anticipate the avoidance step, we constructed a map layer of relative ecological importance across the study area that combines species' distributions and landscape characteristics. We then juxtaposed this map with a map depicting current and future development projects (Fig. 2).

2.3.1. Species datasets, distribution and prioritisation

To set species' priorities, we first used a species distribution model by merging fauna and flora public databases comprised of GPS points provided by regional NGOs. We obtained point data for a total of 317 species (10 amphibians, 22 insects, 15 reptiles, 7 mammals, 100 plants and 163 birds, see Appendix 2) corresponding to approximately 50,000 observation points (CBNMP, 2009; DREAL, 2013). We used a generalised linear model (GLM) to build a distribution model for each species. Our objective was to produce a repeatable methodology that stakeholders could understand and that could be employed by agents in the land-use planning service. To achieve this goal, we developed the GLM procedure with an R script instead of using MaxEnt, which was poorly understood and considered "abstract" by our collaborators in the land-use planning service. GLM ensured clarity and allowed us to explain the reasons underlying the use of certain input parameters. For each species, we first generated a background of random absence points (reliable distribution data were available for these species), and we selected the best combination of environmental variables covering climate, land-use, watercourses and wetlands, land-use diversity, pedology and relief (Appendix 1). Following a binomial logistic regression, we plotted the receiver operating characteristic (ROC) curve and calculated the area under the curve (AUC) to evaluate each output. Finally, distribution maps were subjected to local expert opinion to validate the results of this procedure.

The freely available ZONATION conservation planning software, which is commonly used in similar work that aims to identify priority conservation areas that maximise the representivity of multiple biodiversity features, was then used to map the study area (Moilanen et al., 2005, 2012; Moilanen and Kujala, 2006). This software differs from other software for priority ranking such as MARXAN (Ball et al., 2009), such that targets do not need to be specified for each species. Like other tools, ZONATION is based on the concepts of irreplaceability and complementarity (Kukkala and Moilanen, 2013) and creates a hierarchical ranking of priorities and sites across the study area. Priorities were defined by weighting the species with their respective level of regional priority estimated by local experts in formal studies (CBNMP 2009; DREAL 2013; Appendix 2). This software was also chosen because particular functions were developed to foster ecological network formation. Thus, we chose the standard *core area zonation* (CAZ) algorithm, the *edge removal* and the *distribution smoothing* options (Moilanen et al., 2005; Moilanen, 2007; Moilanen and Wintle, 2006).

2.3.2. *Landscape ecology indicators*

To assess the suitability of the landscape for biodiversity and complete the above species-based approach, we used a series of indicators associated with principles in landscape ecology to assess the fragmentation of the landscape structure and the degree of connectivity between patches (Table 1). We used the map of current land-use occupation in the Montpellier Metropolitan territory, which is publicly available and compatible with the Corine land cover, but more accurate than the national equivalent (1:10 000 against 1:100 000 for CORINE Land Cover). We regrouped items of the fine-scale land-use layer into EUNIS Habitats according to the “Crosswalk between EUNIS habitats and Corine land cover” proposed by the European Environment Agency (Appendix 3). The EUNIS habitats layer was thus used as a proxy for natural habitats.

A first set of indicators deals with landscape configuration: diversity, patch shape complexity, core area, proximity and contrast. Assumptions concerning landscape potential for biodiversity were made for each indicator. For instance, a very diverse landscape is considered more favourable for biodiversity than a homogeneous landscape. A second list of indicators concerns landscape composition in terms of scarcity and responsibility of habitat types (Table 1). Finally, indicators that were developed to rank land-use types with assumptions such as natural areas (Mediterranean scrubland and woodland) are more favourable for biodiversity than agricultural land that is in turn more favourable than urban areas (Appendix 3). The scoring was based on a range of local studies in the grey literature, crossed with the results of a work session with a body of local ecological experts involved in the study. Wetlands and their functional areas also received a higher score because of their scarcity and systematic biological richness in the South of France. Composition, configuration and land-use indicators were combined without a weighting scheme to produce a synthetic indicator for a landscape ecology priorities map.

Indicators associated with landscape ecology were then combined with the species-based indicator with 0.5 weighting applied to the landscape ecology indicator because of the more basic assumptions and a less accurate raw data set that was used to quantify these indicators. The synthesis of the two maps into an “ecological importance” map is the first synthetic key element to help decision-makers (Fig. 2). Cells were ranked in five classes of priority, each containing 20% of the values. In other words, the 20% of the areas having the highest priority also have the highest irreplaceability. This class represents areas with the highest proportion of remarkable species and habitats.

Table 1. Indicators, indices, hypothesis and calculation process for setting priorities of landscape potential for biodiversity in the Montpellier Metropolitan territory (MMT) based on the following: 1, CRENAM et al. (2011); 2, McGarigal (2015) and McGarigal et al. (2002); 3, Crossman et al., (2007); 4, Leitão et al., (2012); 5, Vimal and Devictor (2015); 6, Kujala et al., (2015); 7, Letourneau and Thompson (2013) and 8, CEFE-CNRS expert communication.

Indicator	Index	Description	Assumptions	Data	Calculation	Ref.
Composition	Habitat Rarity	Patrimonial value of natural habitats due to its scarcity	Scarce habitats necessitate particular attention to maintain biodiversity	MMT EUNIS habitats (derived from MMT land-use)	Surface percentage of each land-use	1
Configuration	Diversity	Local diversity of land-use	High landscape diversity is favourable to biodiversity	MMT EUNIS habitats	Local Shannon Index	2
	Proximity	Distance between patches weighted by their size	Larger and closer patches enhance the ecological network	MMT EUNIS habitats	Proximity Index	2, 4
	Patch shape complexity	Complexity of patch shape	High shape complexity, creates more ecotone area and is more favourable for biodiversity	MMT EUNIS habitats	Fractal index: derived of the perimeter/area ratio	2, 3
	Core area	Area inside a patch when you remove the ecotone area (=core surface)	The higher the ratio (large core area), the more a patch is favourable for biodiversity	MMT EUNIS habitats	Core surface area: (plus negative buffer width of 20 m / total surface)	2
	Contrast	Structural differences between contiguous patches	The lower the contrast between two patches, the higher the connectivity and the more they are favourable for biodiversity	MMT EUNIS habitats	Edge contrast index	2
Characteristics	Natural habitats potential for biodiversity	Expert scoring of each natural habitat / biodiversity support potential	Natural areas (e.g., garrigue) have higher biodiversity than others (e.g., intensive agricultural land)	MMT EUNIS habitats	Scoring of each EUNIS habitats (Appendix 3)	1, 5, 6, 7
	Wetland potential for biodiversity	Wetlands and their functional area	Wetlands have high biodiversity within their perimeter and in their surroundings	Wetlands, Watercourses		1, 5, 6, 7
	Responsibility of a given territory for a habitat	MMT responsibility for natural habitats persistence	The higher the percentage of a habitat item in MMT versus in the Mediterranean region, the higher is the responsibility	Regional Land use, Biogeographical regions	Comparison of each EUNIS habitat percentage with its Mediterranean region percentage	8

2.3.3. Urban pressure

We used the urban development plan of the Montpellier Metropolitan territory as an indicator of pressure. This plan depicts urbanisation for the next 2 decades (until 2040) and identifies scheduled development projects that are present in the previous (2006) land-use planning scheme. This map of

future urban development was superposed on the layer for ecological importance to identify where future projects may impact high priority biodiversity areas and thus where the avoidance step should be adopted.

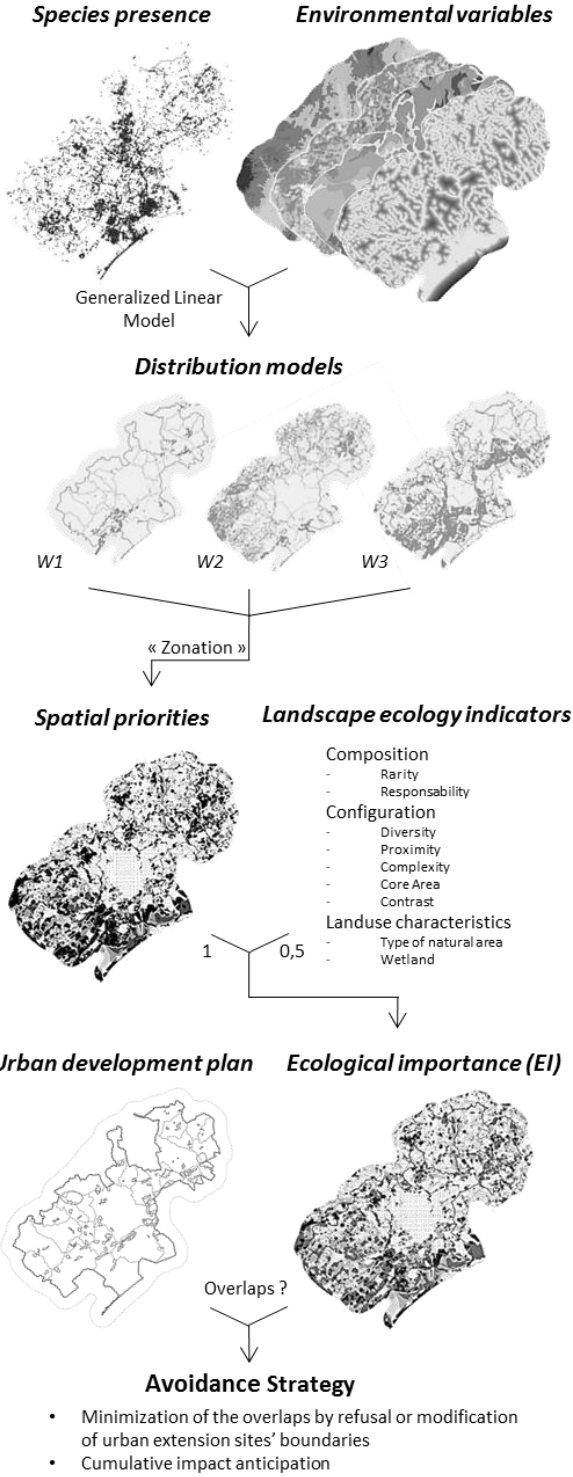


Figure 2: Data analysis and methodological process for the evaluation of biodiversity issues for avoidance

2.4. Biodiversity offset potential

At the local scale of project development, to identify candidate sites for the offset to be located, developers must define the amount of impact, the goal of offset measures and the metrics used to implement them. They must demonstrate ecological equivalency and show that their proposition is in line with NNL objectives. To follow national requirements, offsetting propositions in our study area must also be feasible, timely, performance-based, additional to existing policy targets and of sufficient duration (MEDDE, 2012; Quétier et al., 2014). Nevertheless, criteria for the identification of offset sites are not directly transposable at the planning level. Although the principles and objectives remain the same (ecological equivalency and NNL objectives), the principal question related to the offset step at the landscape scale is slightly different, in that the search is for the range of sites that have the greatest potential to be candidates for offset provision.

The objective is thus to guide decision-makers through a planning operation for offset provision once development projects are identified. To achieve this goal, we developed three spatial indicators (proximity, similarity and feasibility), which were fully compatible with the underlying principles for offsetting. These criteria must also be based on key information for decision-makers to anticipate the need of future offsetting measures at the planning level, while allowing flexibility to adjust decisions to the local context at the project level (Moilanen and Kotiaho, 2018). These indicators allow targeting sites with the greatest potential to become candidate sites for offset provision. Thus, they provide key indications to decision-makers to (i) favour sites that are close to the impacted site and thus in the same ecological zone (Proximity), (ii) optimise ecological similarity in terms of an “equivalence” between biodiversity loss induced by the project and “gains” from ecological restoration (Similarity) and (iii) assess future offset feasibility in terms of land tenure availability (Feasibility).

2.4.1. Proximity to high biodiversity areas

As a result of the implantation of a development project, ecological restoration and conservation actions are proposed to offset residual biodiversity loss and thus balance these residual losses with subsequent gains. These gains are conditioned by the success of ecological actions. The proximity to high biodiversity areas is essential in determining the success of ecological restoration because isolated areas will receive less colonisation from outside than sites closer to high biodiversity areas (Hodgson et al., 2011; Quétier et al., 2014). As a result, a pre-identification of sites close to areas known to have a high biodiversity at the landscape scale provides a means for developers to choose a site at the local scale of the project with an appropriate ecological potential for offsetting and to coordinate their actions around existing important areas for biodiversity. Thus, we developed an indicator of proximity to high biodiversity areas based on the distance to protected areas or other biodiversity offset sites in the study area. In this way, we mapped natural areas that are known to be important for biodiversity based on sites

under the RAMSAR convention, sites identified under the Natura 2000 habitat and birds directives and areas we identified with the highest ecological importance (the top 40% of biodiversity in the ecological importance map). A 1-km buffer around managed and protected zones was processed to highlight zones identified as preferential to increase the potential for ecological restoration actions to be successful, at least in terms of species recolonisation.

2.4.2. *Ecological similarity*

This indicator aims to help decision-makers identify areas that are ecologically similar to areas they open up to urbanisation development in terms of species composition. It allows them to examine whether potential sites for offset measures would be available in the same kind of ecological area and, thus, if future project development would be sustainable (because it would be possible to offset their impacts). To achieve this goal, we consulted local naturalist expertise and removed 45 ubiquitous species that occupy diverse habitats from the sample to avoid meaningless correlations. The distribution maps were juxtaposed on a regular grid square (500 m) to calculate the percentage of the surface occupied by each species (proportion of occupied grid cells). A grid-cell size of 500 m * 500 m was used because it represents a biologically relevant surface concerning the presence and movement of species, particularly sedentary species, and has been used elsewhere in territorial approaches to priorities for biodiversity conservation (e.g., Gauthier et al., 2013). Subsequently, the grid elements were classified according to their species composition with an agglomerative hierarchical clustering (AHC) procedure. This produced eight different classes of ecologically similar sites in terms of the species composition.

2.4.3. *Offset feasibility*

An offset feasibility map was produced to guide decision-makers in the identification of candidate sites that are unlikely to be blocked by problems associated with land tenure availability. There are two important points here concerning land acquisition that were integrated into this indicator: the cadastral parcel area and the number and type (private or public) of owners. To illustrate this issue, a large plot with one owner is theoretically easier to acquire and manage than several small plots all with different owners. Likewise, a publicly owned plot is easier to acquire (by a public organisation such as in our study case) than a privately owned plot. In addition to the publicly owned plot layer, we produce an indicator that takes into account the parcel surface area and the number of owners for each plot (the larger a plot is with few owners, the more interesting it is from a property purchase perspective). We used the “jenks” natural breaks classification method to identify five classes. This indicator thus provides information on property compactness and the feasibility of acquisition. In terms of data, property datasets were available only within the administrative boundaries of the Montpellier Metropolitan territory.

3. Results

3.1. Ecological importance

The ecological importance map (represented in Fig. 4) identifies areas that represent the highest priority for protection from development projects and thus where avoidance should be a priority at the landscape scale. Remarkable and very-high classes represent 40% of areas having the highest conservation priority based on their irreplaceability (on the ecological priority scale, remarkable represents the 80-100% class and very high the 60-80% class). Its classes cover 4% and 21% of the study area, respectively, and high biodiversity sites cover an additional 22% of the study area (Fig. 3). The remarkable class occurs in several small patches in the wetlands near the coastal lagoons, in numerous patches of Mediterranean scrubland in the south, the southwest and the north and northwest of the study area. Interestingly, 21% of the remarkable class surface and 42% of the “very high” one are outside any known ecological zoning of the territory. Finally, the remaining natural areas and agricultural land occur in the low priority classes that represent 27% of the study area, mostly around Montpellier and along the middle southeast-northwest axis, i.e., suburban and agricultural zones.

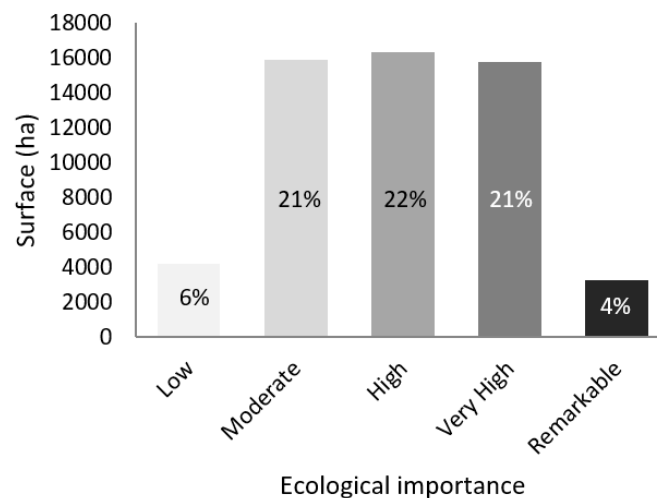


Figure 3. Extent and percentage of territory for each category of ecological importance. Each of the five classes covers 20% of the ecological values of the territory.

The spatial map of priority for avoidance (Fig. 4) results from a superposition of the urban development plan (that will become future development projects), on the map of ecological importance. Overlaps between these future development projects and areas of high ecological importance represent 60 ha with the remarkable class (2% of the total surface of the urbanization planned) and 661 ha with the very high priority sites (22% of the total surface of the urbanization planned). In addition, different strategic areas for development, still confidential (not mapped in Fig. 4), are currently under deliberation in the

Metropolitan agency and will also be taken into account in the avoidance process. Thus, these two layers represent the potential cumulative impact on which decision-makers can work to propose a less impactful and more sustainable territorial project in terms of ecological priorities.



Figure 4. Spatialization of priority for avoidance: ecological importance map overlaid with the urban development plan of the Montpellier Metropolitan agency

3.2. Potential offset areas

The proximity with high biodiversity areas, which are already protected or managed for ecological goals, enhances the probability of restoration “success”. Fig. 5a shows where these areas occur in and around the Montpellier Metropolitan territory and, thus, identifies candidate zones for biodiversity offsetting. Sites already managed or protected for their biodiversity represent 1,752 ha in the study area with approximately 915 ha within the Montpellier Metropolitan boundaries. Zones important for biodiversity within the 1 km buffer constitute 21,135 hectares with approximately half of this area within the Montpellier Metropolitan territory.

The “ecological similarity” indicator allows the identification of potential biodiversity offset areas in the same broad ecological area as the impacted zone. Associated with the “proximity” indicator, this

indicator should assure that candidate offset sites conform to the ecological equivalency condition. Overall, eight similar ecological classes were identified in the Montpellier Metropolitan territory (Fig. 5b). Each of these classes matches with a species assemblage that fits with particular land-use types. For instance, classes 1 and 3 are very similar and correspond to a fine-grained, hilly mosaic of agricultural areas (mainly vineyards and annual crops) and natural habitats (deciduous or coniferous woodland or Mediterranean shrub vegetation), class 2 concerns open Mediterranean forests and scrubland, and class 4, very distant from class 1, corresponds to an agricultural plain with small fields.

In a suburban context of very high pressure to develop land, Fig. 5c highlights areas that are the most feasible for offsets in terms of ease of acquisition and setting up of conservation management contracts in the site. These zones are primarily publicly owned, large plots, and with few owners. The most “feasible” zones are mainly in natural and semi-natural vegetation because agricultural plots are small and scattered across the study area.

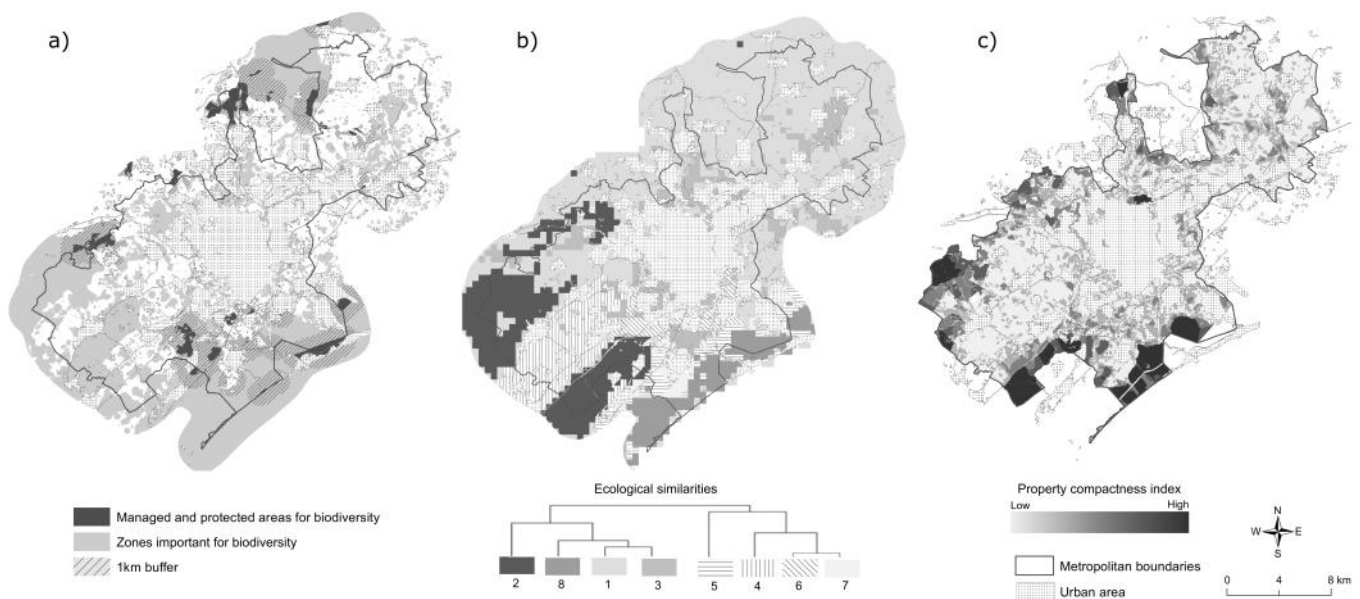


Figure 5. Criteria for offset site choice in terms of the following: a) proximity to high biodiversity areas, b) ecological similarity (the dendrogram provides information on ecological proximity among classes), c) feasibility of acquisition.

3.3. Application

A qualitative and important result of our work is that the methodological approach proposed herein was used in a strategic environmental assessment. Planners and practitioners of the Montpellier Metropolitan agency explicitly integrated this landscape scale approach to the mitigation hierarchy into their territorial

planning scheme, something that has not yet been observed in other urban planning documents in France (Autorité Environnementale, 2017, 2019). Our indicators were adapted by practitioners and planners to fit with diverse political issues.

4. Discussion

Our work is part of a growing contemporary movement towards the need to anticipate mitigation hierarchy implementation as part of policy for biodiversity conservation. Its contribution involves two themes that we will discuss. First, our study adds to a small body of recent work advocating the anticipation for avoidance and offsetting steps on a landscape scale. This upscaling does not remove the obligation to implement the mitigation hierarchy at the project level; it is complementary to the project level in that it could (1) improve avoidance of impacts on high biodiversity sites, (2) provide a better panorama of candidate sites for offsetting, and (3) begin to integrate (within the mitigation hierarchy) the existence of cumulative impacts of multiple projects in a given territory. Second, as proposed by Whitehead et al. (2017), our work has been done within the scope of a real social and political context and the concrete issues of urban planners and decision-makers. The scientific tools proposed herein introduce a robust and repeatable basis for decision-making for the inclusion and conservation of biodiversity in the early stages of the urban planning process.

4.1. From setting priorities to the search for similarity

In this paper, we illustrate how the concepts and tools developed in the Systematic Conservation Planning (SCP) literature can be used to develop a form of “Systematic Mitigation Planning” (SMP). In this application, avoidance has identical requirements and objectives for priority setting as in traditional SCP, while offsetting requires additional information on specific biodiversity features that permit a search for similarity among areas to satisfy the “like-for-like” or “in-kind” criteria between impacts and offsets (Kujala et al., 2015; Moilanen, 2013).

We show that the territorial (or “landscape”) scale is an appropriate spatial scale for impact anticipation. Indeed, it provides precise information on high biodiversity value sites through the whole territory that should then be identified for avoidance before projects are accepted. As discussed by Phalan et al. (2017), these types of territorial analyses are far too often neglected in practice during the early stages of environmental assessment of urban plans. Our results complete available information on existent ecological zoning: 21% of the surface of the remarkable priority class and 42% of the “very high” priority class are outside all previous ecological zoning. Local decision-makers can thus avoid impacts early in the planning mechanism by minimising overlaps between very high and remarkable classes of biodiversity and future urban development sites. In practice, such avoidance will lead to the refusal or

modification of proposed projects as part of a strategic urban extension plan that is in accordance with priorities for impact avoidance. Sites with low or moderate biodiversity priority could be proposed as more suitable for urban extension on ecological grounds. Within the requirement of an EIA at the project level, each future project development will be required to implement the mitigation hierarchy at the local scale. Hence, the complementarity between the two scales could be achieved, as proposed elsewhere (Aldridge et al., 2018). Obviously, economic and social dimensions must be taken into account to confirm the choices made at the territorial scale.

An additional advantage of this strategic approach is that it provides a basis to anticipate cumulative impacts of small but numerous urban development projects that are currently impossible to consider in a project level approach, but which clearly occur (Bigard et al., 2017). We believe that this step towards minimising cumulative impacts is essential for planning to work in an NNL perspective.

In our method, we propose three criteria to improve anticipation early in the land-use planning process for the identification of high potential candidate sites for the provision of offsets. The indicator of proximity to high biodiversity sites aims at maximising potential colonisation of future offset measures (especially those subject to restoration) and could enhance a spatial conservation strategy for the territory by grouping ecological restoration areas with existing protected areas and thus integrate such areas in a viable ecological network. The second indicator identifies ecological similarities across the territory and, thus, pinpoints sites with similar composition in terms of species presence to provide an “in-kind” (or “like for like”) form of offset planning. This approach should be used with caution; “in kind” may not always be the best solution for offset, and in case-specific contexts, “out-of-kind” alternatives may be more pertinent (Bull et al., 2015; McKenney and Kiesecker, 2010). The third indicator assesses the feasibility of acquisition at a large-scale, which is important because land tenure affects the way biodiversity offsets are implemented, especially for territories or regions (such as our study area) that are subject to ever-increasing pressures linked to high land values. Land acquisition is necessary to assure the long-term persistence of offset sites. Alternatively, contractual approach could provide a basis to manage biodiversity offsets, especially on private land (Le Coënt et al., 2017). However, in most cases, a combination of land acquisition and a contractual approach (rarely implemented on its own) may be the most efficient ways to ensure the long-term durability of an offset programme. Our study illustrates that the combination of the three criteria would help planners to anticipate the offset step of the mitigation hierarchy by elaborating different scenarios within the urban development plan. This proactive search for biodiversity offset candidates could thus alleviate the current drawbacks of biodiversity offset practices. Indeed, it proposes a concrete alternative to the current situation of piecemeal offset sites, which are disconnected from regional ecological networks that may reduce natural recolonisation during site restoration, and poor offset site selection in terms of functional ecology simply because of land tenure pressures at the local scale. We suggest that our framework could improve

the choice of where to locate offset measures and minimise the time-lag between the moment of loss and the moment when offset actions are achieved.

In terms of its limitations, the approach we have developed requires a uniform and comprehensive database that may not always be available (Moilanen, 2013). Where such data exist, the method is also dependent on the spatial quality and comprehensiveness for a given territory. The choice of working on a very diverse set of species (317 common species) could thus be an important ecological limitation in terms of methods and analyses. However, this choice is assumed because our objective was to propose a comprehensive approach to biodiversity that is not limited to a small number of charismatic species to raise the awareness of urban developers and planners. Another serious limitation is the basis, despite indicators for fragmentation and connectivity, of a static vision of biodiversity. The purpose of this work is to help decision-makers design a current urban plan so this limitation is not so problematic, but in other types of ecosystems involving rivers and aquatic habitats, it could be less realistic.

The SMP approach we propose involves close contact among scientists, stakeholders and planners that may also contribute to a shift in the attitude of decision-makers from a project-by-project approach based on local charismatic and listed species that block project development, to a strategic and comprehensive approach to protect overall biodiversity and landscape connectivity on a territorial scale. As Gordon et al. (2009) note, this strategic-type approach is essential for an effective conservation plan to be developed, as we now discuss.

4.2 Blending SMP with Strategic Environmental Assessment.

A systematic approach to the mitigation hierarchy at a territorial scale provides a decision support tool for planners and decision-makers to move from ad hoc choices for minimal avoidance and piecemeal mitigation in association with opportunities and political will, towards a proactive and systematic approach to anticipate avoidance and offsetting steps in land-use planning. It seeks coherence in its choices that must be adapted to a specific territory, instead of searching for optimum solutions (Roy and Vincke, 1989).

Strategic environmental assessment (SEA) has become a well-known, overarching concept in environmental management (Brown and Thérivel, 2000; Fundingsland Tetlow and Hanusch, 2012). SEA first appeared in the 1969 US National Environmental Policy Act concurrently with Environmental Impact Assessment (EIA) (Jones et al., 2005). In Europe, it was introduced in 1980 in a report for the European commission (Wood and Djeddour, 1989), and then in the SEA directive in 2001. Although SEA was developed in association with EIA practice and philosophy, there is an important conceptual distinction between SEA and EIA (Bina, 2007). While the latter assesses environmental impacts of

projects, SEA appraises environmental impacts of policies, plans and programmes, and it facilitates a proactive approach due to its consideration of decision-making in the early stages. In fact, the theory and practice of SEA provide a more strategic approach, with a potential political role through its possible influence on decision-making. Thus, it can be an opportune way to more directly assess environmental issues and integrate them into the decision-making process (Partidario, 2015). SEA is also renowned for its capacity to go beyond biodiversity conservation (environmental limits, cumulative impacts, ecosystem services, climate change...) to raise awareness of the environmental implications of decisions, producing a more transparent process (Fundingsland Tetlow and Hanusch, 2012).

Our test for the Montpellier Mediterranean territory shows empirically how the SMP methodology we propose can be closely linked to an SEA approach. An interesting point raised by our approach concerns how SMP can be used to integrate biodiversity into an urban territorial plan that implements the mitigation hierarchy logic that is assumed in SEA: avoidance first, then reduction, and as a last resort, offsetting. Second, SEA provides an ideal situation to use biodiversity conservation as a strategic goal in land-use planning, and SMP can assist and guide this initiative. By facilitating proactive use of the mitigation hierarchy, SMP introduces the triptych of avoidance, reduction and offsetting into the realm of SEA. A more explicit inclusion of the mitigation hierarchy within SEA could thus greatly improve the anticipation of the avoidance step and the rational choice of candidate sites for offset provision as part of strategic decision-making.

4.3. Science that contributes to practitioners needs

It is worth noting that although the mitigation hierarchy and the NNL objective are concerned with ecological and conservation outcomes, they were initiated in political circles and do not stem from a scientific discipline (Calvet et al., 2015). There is thus a strong link between our framework and a policy for the mitigation hierarchy both in France (MEDDE, 2012) and worldwide (Morandeu and Vilaysack, 2012). Nevertheless, there is a continued gap between practitioner needs, policy directions and current scientific knowledge (Anonymous, 2007; Arlettaz et al., 2010), and hence the critical need for methods that can be practically relayed to practitioners.

To respect the credibility, legitimacy and salience conditions of Cash et al. (2003), we constructed an operational method that promotes a context analysis with the insertion of a research scientist into a planning agency during the operational reevaluation of a territorial land-use plan in which biodiversity conservation is one of the objectives. In our case study, we were thus able to ensure a reciprocal understanding (1) by agents of the land-use planning agency of the indicators of biodiversity and the underlying principles of the decision tool and (2) by scientists for the operational requirements of land-use planners. This formally established collaboration between a research institute and a planning agency

(the Montpellier Metropolitan agency) enabled us to take into account diverse viewpoints and interests. The scientific information ensured the credibility of the work while simultaneously remaining prudent concerning the importance that can be given to scientific results. The relevance of the framework proposed herein was validated by decision-makers for the Montpellier Metropolitan territory during the work sessions, and it has been adopted in practice.

In addition to the conditions of credibility, legitimacy and salience, a follow-up stage is necessary after the end of technical GIS work such as ours (Arlettaz et al., 2010). Indeed, a sustained effort is required to raise the awareness of developers, planners and decision-makers to ensure the long-term use of the method. In fact, contrary to what one may imagine, one of the principal sources of confusion with decision-makers is the choice of modelling and the GIS analysis (Roy and Vincke, 1989). Maps represent a simple, static, spatial interpretation of the real territory, but it is often very delicate to display such maps in public. They are based on data that require subjective choices and interpretations in their treatment and on models that, by definition, simplify reality. To support decision-makers' choices, as socio-economic and political stakes come into play, work such as our study should be conducted in collaboration with planners, decision-makers and stakeholders, if a clear operational scope is to be obtained.

5. Conclusion

Our study is one of a small but growing body of studies that illustrate the importance of a strategic approach to avoidance and offsetting to more efficiently achieve NNL. Extending the mitigation hierarchy implementation into SEA could contribute to Aichi targets by 2020. In line with Phalan et al. (2017), such work could stimulate joint thinking by scientists and planners on how the avoidance step of the mitigation hierarchy may represent the first strategic step to biodiversity conservation, especially where there are limits for offsetability to achieve NNL.

Appendix 1. Database details

	Data name	Description	Supplier	Ownership	Date
General datasets	Land-use	SPOT THEMA nomenclature: 3 levels, 57 items at the more accurate level	SIRIS-FR	Public	2012
	Biogeographical regions (REGBIOFR)		INPN	Public	
	Regional land-use	43 items respecting CORINE Land Cover nomenclature and adapted functions of regional specificity	SIG-LR	Public	2006
Fauna and Flora dataset	Birds database (FAUNE-LR)	Bird observation	LPO	LPO	2010-2015
	Mammals and insects database	Mammal and insect observation	CEN	CEN	2010-2015
	Reptiles and amphibians (MALPOLON)	Reptile and amphibian observation	CNRS	CNRS	2000-2015
	Plants database (SILENE)	Plant observation	CBN	CBN	1990-2015
Fauna and Flora stakes	Fauna regional stakes	Classification of fauna species at stake	DREAL	Public	2013
	Flora regional stake (ZNIEFF)	Classification of floras species at stake determinant for French ZNIEFF	CBN	Public	2009
Environmental variables	Climate (BioClim)	19 variables derived from the monthly temperature and rainfall values	WordClim	Public	2000
	Relief	Topographic data generated from NASA's Shuttle Radar Topography Mission	SRTM*	Public	2015
	Pedology (BDSol-LR)	Product of the regional pedology referential (RPR)	INRA	SIG-LR	
	Wetlands	Wetlands and their functional areas	DREAL	Public	2014
	Watercourse (BD TOPO®/RGE)	Temporary and Permanent watercourses	IGN	Montpellier Metropolitan agency	
Biodiversity supply	Offset area	Regional biodiversity offset register	DREAL	Public	2016
	Other protected areas or zones known as being important for biodiversity	Natura 2000 sites, RAMSAR convention zones, national nature reserves, biotope protection decree, sensitive natural areas	data.gouv	Public	2016
Feasibility	Cadastral GPS layer	Number and types of owners	DRFP*	Montpellier Metropolitan agency	2016

* *Direction Régionale des Finances Publiques*

Appendix 2. Species taken into account with their level of stakes (REM- Remarkable, MODE- Moderate)

Amphibien
REM
<i>Pelobates cultripes, Pelophylax kl. grafi</i>
HIGH
<i>Pelophylax perezi</i>
MODE
<i>Triturus marmoratus</i>
LOW
<i>Alytes obstetricans, Bufo bufo, Bufo calamita, Hyla meridionalis, Lissotriton helveticus, Pelodytes punctatus</i>
Avifauna
REM
<i>Botaurus stellaris, Lanius meridionalis, Oenanthe hispanica, Remiz pendulinus</i>
HIGH
<i>Acrocephalus arundinaceus, Acrocephalus melanopogon, Aquila pennata, Ardea purpurea, Ardeola ralloides, Burhinus oedicnemus, Cecropis daurica, Charadrius alexandrinus, Chroicocephalus genei, Circaetus gallicus, Emberiza schoeniclus whiterbyi, Falco naumanni, Gelochelidon nilotica, Ixobrychus minutus, Lanius senator, Locustella luscinioides, Milvus milvus, Numenius arquata, Porphyrio porphyrio, Sterna sandvicensis, Sternula albifrons, Tetrax tetrax</i>
MODE
<i>Actitis hypoleucos, Anas querquedula, Anas strepera, Anthus campestris, Anthus pratensis, Anthus spinoletta, Apus melba, Apus pallidus, Athene noctua, Aythya ferina, Bubo bubo, Bubulcus ibis, Carduelis cannabina, Carduelis spinus, Casmerodius albus, Charadrius dubius, Chlidonias hybridus, Chlidonias niger, Chroicocephalus ridibundus, Ciconia ciconia, Circus aeruginosus, Circus cyaneus, Circus pygargus, Clamator glandarius, Coracias garrulus, Egretta garzetta, Elanus caeruleus, Falco peregrinus, Ficedula hypoleuca, Galerida cristata, Gallinago gallinago, Gyps fulvus, Himantopus himantopus, Jynx torquilla, Lanius collurio, Larus melanocephalus, Merops apiaster, Milvus migrans, Monticola solitarius, Muscicapa striata, Netta rufina, Nycticorax nycticorax, Oenanthe oenanthe, Otus scops, Panurus biarmicus, Parus ater, Phylloscopus sibilatrix, Phylloscopus trochilus, Plegadis falcinellus, Podiceps cristatus, Pyrrhula pyrrhula, Recurvirostra avosetta, Riparia riparia, Saxicola rubetra, Sterna hirundo, Sylvia cantillans, Sylvia hortensis, Sylvia undata, Tachybaptus ruficollis, Tringa totanus, Turdus torquatus, Tyto alba, Upupa epops, Vanellus vanellus</i>
LOW
<i>Accipiter gentilis, Accipiter nisus, Acrocephalus scirpaceus, Aegithalos caudatus, Alcedo atthis, Anas clypeata, Apus apus, Ardea cinerea, Asio otus, Buteo buteo, Caprimulgus europaeus, Carduelis carduelis, Carduelis chloris, Certhia brachydactyla, Cettia cetti, Cisticola juncidis, Coccothraustes Coccothraustes, Columba oenas, Corvus monedula, Coturnix coturnix, Cuculus canorus, Cygnus olor, Delichon urbicum, Dendrocopos major, Dendrocopos minor, Emberiza calandra, Emberiza cia, Emberiza cirrus, Emberiza citrinella, Erithacus rubecula, Falco subbuteo, Falco tinnunculus, Fringilla coelebs, Haematopus ostralegus, Hippolais polyglotta, Hirundo rustica, Larus michahellis, Loxia curvirostra, Lullula arborea, Luscinia megarhynchos, Motacilla alba, Motacilla cinerea, Motacilla flava, Oriolus oriolus, Parus caeruleus, Parus cristatus, Parus major, Passer domesticus, Passer montanus, Perdix perdix, Pernis apivorus, Petronia petronia, Phoenicurus ochruros, Phoenicurus phoenicurus, Phylloscopus bonelli, Phylloscopus collybita, Picus viridis, Podiceps nigricollis, Prunella modularis, Ptyonoprogne rupestris, Rallus aquaticus, Regulus ignicapillus, Regulus regulus, Scolopax rusticola, Serinus serinus, Sitta europaea, Strix aluco, Sylvia atricapilla, Sylvia borin, Sylvia communis, Sylvia melanocephala, Tadorna tadorna, Troglodytes troglodytes</i>
Insect

HIGH
<i>Coenagrion mercuriale, Oxygastra curtisii</i>
MODE
<i>Aeshna isocles, Calopteryx haemorrhoidalis, Gomphus simillimus, Ischnura pumilio, Lestes barbarus, Lestes sponsa, Libellula fulva, Libellula fulva O. F., Onychogomphus uncatus, Saga pedo, Zerynthia polyxena, Zerynthia rumina</i>
LOW
<i>Aeshna affinis, Ceriagrion tenellum, Erythromma viridulum, Platynemesis acutipennis, Sympetrum meridionale</i>
Mammal
HIGH
<i>Arvicola sapidus, Rhinolophus ferrumequinum</i>
MODE
<i>Oryctolagus cuniculus, Pipistrellus pygmaeus</i>
LOW
<i>Erinaceus europaeus, Genetta genetta, Sciurus vulgaris</i>
Plant
REM
<i>Delphinium staphisagria, Inula helenioides, Ononis mitissima, Spergularia tangerina</i>
HIGH
<i>Medicago secundiflora, Phalaris coerulescens, Polygonum robertii, Sideritis fruticulosa, Vitex agnus-castus</i>
MODE
<i>Athenia filiformis, Asparagus maritimus, Chenopodium chenopodioides, Crucianella maritima, Echium arenarium, Geropogon hybridus, Melilotus italicus, Mentha cervina, Pimpinella peregrina, Ranunculus ophioglossifolius, Teucrium polium subsp. clapae, Typha laxmannii</i>
LOW
<i>Aegilops biuncialis, Allium chamaemoly, Alopecurus bulbosus, Anagyris foetida, Anemone coronaria, Aristolochia paucinervis, Artemisia caerulescens subsp. Gallica, Astragalus stella, Bifora testiculata, Blackstonia acuminata, Blackstonia imperfoliata, Bufonia paniculata, Bupleurum semicompositum, Bupleurum subovatum, Callitriche stagnalis, Calystegia soldanella, Carex hispida, Centaurium maritimum, Ceratophyllum submersum, Cerinthe major, Cladium mariscus, Cotinus coggygria, Crypsis aculeata, Crypsis schoenoides, Cynanchum acutum, Daucus carota subsp. Maritimus, Echinophora spinosa, Eleocharis uniglumis, Eryngium maritimum, Euphorbia chamaesyce subsp. Chamaesyce, Euphorbia peplis, Gagea pratensis, Galium obliquum, Gratiola officinalis, Helianthemum ledifolium, Hippocrepis ciliata, Hypericum tomentosum, Inula britannica, Juncus striatus, Kickxia commutata, Lathyrus saxatilis, Leucojum aestivum subsp. Aestivum, Limonium bellidifolium, Limonium echioides, Limonium virgatum, Lotus delortii, Lupinus micranthus, Lythrum tribracteatum, Malcolmia littorea, Medicago doliata, Melilotus elegans, Myosotis ramosissima, Myosurus minimus, Nymphaea alba, Odontites viscosus, Ononis pubescens, Ononis viscosa subsp. Breviflora, Ophrys bombyliflora, Pancratium maritimum, Parietaria lusitanica, Polycarpon tetraphyllum, Polygonum bellardii, Potamogeton coloratus, Romulea columnae, Romulea ramiflora, Rorippa amphibia, Ruppia maritima, Suaeda splendens, Taeniatherum caput-medusae, Thalictrum flavum, Theligonum cynocrambe, Trifolium hirtum, Triglochin maritimum, Tripodion tetraphyllum, Tulipa clusiana, Tulipa raddii, Vallisneria spiralis, Velezia rigida, Veronica acinifolia</i>
Reptile
REM
<i>Mauremys leprosa, Timon lepidus</i>
HIGH

<i>Emys orbicularis</i>
MODE
<i>Chalcides striatus, Malpolon monspessulanus, Psammodromus algirus, Rhinechis scalaris</i>
LOW
<i>Anguis fragilis, Coronella girondica, Lacerta bilineata, Natrix maura, Natrix natrix, Podarcis liolepis, Podarcis muralis, Tarentola mauritanica</i>

Appendix 3. Scoring of each group of land-uses present in the study area and their EUNIS references

Correspondent EUNIS references (Davies et al., 2004)	Land-use	Rank of potential for biodiversity support
G1, G2 (except G2.8 and G2.9), G4	Woodlands (mixed or deciduous trees)	1
F5, F6, F7	Mediterranean shrubland	
F3, F4	Heathland and thickets	
E1, E2, E3	Grassland, natural grazing land, pasture and meadows	
B1	Beach and dunes	
C1	Wetlands	
G3	Coniferous forest	0.75
G2.8, G5	Logging zones and young plantations	
FA	Hedges	
G2.9	Orchard vergers including olive groves	0.5
FB	Grapevine crops	
I2	Family's gardens	0.25
I1	Annual crops	
H5.5	Burned areas	
From J1 to J6	Artificialised zones	0

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Bibliography

- Agreste, 2015. L'artificialisation des terres de 2006 à 2014: pour deux tiers sur des espaces agricoles. La statistique agricole N°326. Ministère de l'agriculture, de l'agroalimentaire et de la forêt.
- Anonymous, 2007. The great divide. *Nature* 450, 135–136. <https://doi.org/10.1038/450135b>
- Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T.S., Sierro, A., Watson, J.E.M., Braunisch, V., 2010. From Publications to Public Actions: When Conservation Biologists Bridge the Gap between Research and Implementation. *BioScience* 60, 835–842. <https://doi.org/10.1525/bio.2010.60.10.10>
- Arlidge, W.N.S., Bull, J.W., Addison, P.F.E., Burgass, M.J., Gianuca, D., Gorham, T.M., Jacob, C., Shumway, N., Sinclair, S.P., Watson, J.E.M., Wilcox, C., Milner-Gulland, E.J., A Global Mitigation Hierarchy for Nature Conservation, *BioScience*, Volume 68, Issue 5, May 2018, Pages 336–347, <https://doi.org/10.1093/biosci/biy029>
- Autorité Environnementale, 2017. L'Ae et les MRAe : une communauté d'Autorités environnementales - Synthèse annuelle 2016.
- Autorité Environnementale, 2019. L'Ae et les MRAe : une communauté d'Autorités environnementales - Synthèse annuelle 2018.
- Ball, I.R., Possingham, H.P., Watts, M., 2009. Marxan and relatives: software for spatial conservation prioritisation. *Spat. Conserv. Prioritisation Quant. Methods Comput. Tools Oxf. Univ. Press Oxf.* 185–195.
- BBOP, 2013. To no net loss and beyond, an overview of the Business and Biodiversity Offsets Programme (BBOP). Washington.
- Bekessy, S.A., White, M., Gordon, A., Moilanen, A., Mccarthy, M.A., Wintle, B.A., 2012. Transparent planning for biodiversity and development in the urban fringe. *Landsc. Urban Plan.* 108, 140–149.
- Bezombes, L., Kerbiriou, C., Spiegelberger, T., 2019. Do biodiversity offsets achieve No Net Loss? An evaluation of offsets in a French department. *Biological Conservation.* 231, 24–29.
- Bigard, C., Pioch, S., Thompson, J.D., 2017. The inclusion of biodiversity in environmental impact assessment: Policy-related progress limited by gaps and semantic confusion. *J. Environ. Manage.* 200, 35–45.
- Bina, O., 2007. A critical review of the dominant lines of argumentation on the need for strategic environmental assessment. *Environ. Impact Assess. Rev.* 27, 585–606.
- BirdLife International, 2015. Strengthening implementation of the mitigation hierarchy: managing biodiversity risk for conservation gains. *Camb. Conserv. Initiat. - Collab. Fund Proj. Rep. Compil. BirdLige Int. UNEP-WCMC RSPB FFI Univ. Camb.*

- Blondel, J., Aronson, J., Bodiou, J.-Y., Boeuf, G., 2010. The Mediterranean region: biological diversity in space and time. Oxford University Press, Oxford.
- Brown, A.L., Thérivel, R., 2000. Principles to guide the development of strategic environmental assessment methodology. *Impact Assess. Proj. Apprais.* 18, 183–189.
- Bull, J.W., Gordon, A., Watson, J.E.M., Maron, M., 2016. Seeking convergence on the key concepts in ‘no net loss’ policy. *J. Appl. Ecol.* 53, 1686–1693. <https://doi.org/10.1111/1365-2664.12726>
- Bull, J.W., Hardy, M.J., Moilanen, A., Gordon, A., 2015. Categories of flexibility in biodiversity offsetting, and their implications for conservation. *Biol. Conserv.* 192, 522–532.
- Cabin, R.J., 2007. Science-Driven Restoration: A Square Grid on a Round Earth? *Restor. Ecol.* 15, 1–7.
- Calvet, C., Ollivier, G., Napoléone, C., 2015. Tracking the origins and development of biodiversity offsetting in academic research and its implications for conservation: A review. *Biol. Conserv.* 192, 492–503. <https://doi.org/10.1016/j.biocon.2015.08.036>
- Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci.* 100, 8086–8091.
- CBNMP, 2009. Modernisation des ZNIEFF du Languedoc Roussillon (flore vasculaire et bryoflore). Conservatoire botanique national méditerranéen de Porquerolles, DIREN, Montpellier.
- Colsaet, A., Laurans, Y., Levrel, H., 2018. What drives land take and urban land expansion? A systematic review. *Land-use Policy* 79, 339–349.
- Copeland, H., Ward, J., Kiesecker, J.M., 2007. Threat, cost, and biological value: Prioritizing conservation within Wyoming ecoregions. *J. Conserv. Plan.* 3, 1–16.
- CRENAM, IPAMAC, Parcs naturels associés, 2011. Note méthodologique - Identification des réservoirs de biodiversité potentiels ; Projet “trame écologique du Massif Central.”
- Crossman, N.D., Bryan, B.A., Ostendorf, B., Collins, S., 2007. Systematic landscape restoration in the rural–urban fringe: meeting conservation planning and policy goals. *Biodivers. Conserv.* 16, 3781–3802.
- Curran, M., Hellweg, S., Beck, J., 2014. Is there any empirical support for biodiversity offset policy? *Ecological Applications* 24, 617–632.
- Davies, C.E., Moss, D., Hill, M.O., 2004. EUNIS habitat classification revised 2004. Rep. Eur. Environ. Agency-Eur. Top. Cent. Nat. Prot. *Biodivers.* 127–143.
- Davis, F.W., Stoms, D.M., Estes, J.E., Scepan, J., MICHAEL SCOTT, J., 1990. An information systems approach to the preservation of biological diversity. *Int. J. Geogr. Inf. Syst.* 4, 55–78.
- DREAL, 2013. Hiérarchisation des espèces présentes en Languedoc-Roussillon.
- Fundingsland Tetlow, M., Hanusch, M., 2012. Strategic environmental assessment: the state of the art. *Impact Assess. Proj. Apprais.* 30, 15–24.

- Gardner, T.A., Hase, A., Brownlie, S., Ekstrom, J.M., Pilgrim, J.D., Savy, C.E., Stephens, R.T., Treweek, J.O., Ussher, G.T., Ward, G., others, 2013. Biodiversity offsets and the challenge of achieving no net loss. *Conserv. Biol.* 27, 1254–1264.
- Gauthier, P., Foulon, Y., Jupille, O., Thompson, J.D., 2013. Quantifying habitat vulnerability to assess species priorities for conservation management. *Biol. Conserv.* 158, 321–325. <https://doi.org/10.1016/j.biocon.2012.08.012>
- Gordon, A., Bull, J.W., Wilcox, C., Maron, M., 2015. Perverse incentives risk undermining biodiversity offset policies. *J. Appl. Ecol.* 52, 532–537.
- Gordon, A., Simondson, D., White, M., Moilanen, A., Bekessy, S., 2009. Integrating conservation planning and landuse planning in urban landscapes. *Landsc. Urban Plan.* 91, 183–194.
- Habib, T.J., Farr, D.R., Schneider, R.R., Boutin, S., 2013. Economic and ecological outcomes of flexible biodiversity offset systems. *Conserv. Biol.* 27, 1313–1323.
- Hassan, F., Levrel, H., Scemama, P., Vaissière, A.-C., 2015. Le cadre de gouvernance américain des mesures compensatoires pour les zones humides, in: *Restaurer La Nature Pour Atténuer Les Impacts Du Développement*. Quae, pp. 45–58.
- Hayes, D.J., 2014. Addressing the environmental impacts of large infrastructure projects: making “mitigation” matter. *Environ. Law Report.* 44, 10016–10021.
- Hodgson, J.A., Moilanen, A., Wintle, B.A., Thomas, C.D., 2011. Habitat area, quality and connectivity: striking the balance for efficient conservation. *J. Appl. Ecol.* 48, 148–152. <https://doi.org/10.1111/j.1365-2664.2010.01919.x>
- Hulme, P.E., 2014. Bridging the knowing–doing gap: know-who, know-what, know-why, know-how and know-when. *J. Appl. Ecol.* 51, 1131–1136. <https://doi.org/10.1111/1365-2664.12321>
- INSEE, 2016. Montpellier Méditerranée Métropole : une métropole toujours attractive (INSEE Analyses Languedoc-Roussillon-Midi-Pyrénées No. 18).
- Jones, C., Baker, M., Carter, J., Jay, S., Short, M., Wood, C., 2005. *Strategic Environmental Assessment and Land-use Planning: An International Evaluation*. Earthscan, London.
- Kiesecker, J., Copeland, H., Pocewicz, A., McKenney, B., 2010. Development by design: blending landscape-level planning with the mitigation hierarchy. *Front. Ecol. Environ.* 8, 261–266.
- Kiesecker, J.M., Copeland, H., Pocewicz, A., Nibbelink, N., McKenney, B., Dahlke, J., Holloran, M., Stroud, D., 2009. A framework for implementing biodiversity offsets: selecting sites and determining scale. *BioScience* 59, 77–84.
- Knight, A.T., Cowling, R.M., Rouget, M., Balmford, A., Lombard, A.T., Campbell, B.M., 2008. Knowing but not doing: selecting priority conservation areas and the research–implementation gap. *Conserv. Biol.* 22, 610–617.
- Kreitler, J., Schloss, C.A., Soong, O., Hannah, L., Davis, F.W., 2015. Conservation planning for offsetting the impacts of development: A case study of biodiversity and renewable energy in the Mojave Desert. *PloS One* 10, e0140226.

- Kujala, H., Whitehead, A.L., Morris, W.K., Wintle, B.A., 2015. Towards strategic offsetting of biodiversity loss using spatial prioritization concepts and tools: a case study on mining impacts in Australia. *Biol. Conserv.* 192, 513–521.
- Kukkala, A.S., Moilanen, A., 2013. Core concepts of spatial prioritisation in systematic conservation planning. *Biol. Rev.* 88, 443–464.
- Lawton, J.H., McCredie, R., 1995. *Extinction rates*. Oxford University Press.
- Le Coënt, P., Calvet, C., Napoleone, C., Quétier, F., 2017. Challenges of achieving biodiversity offsetting through agri-environmental schemes: evidence from an empirical study in Southern France. WP2017-05, UMR LAMETA, University of Montpellier 50.
- Leitão, A.B., Miller, J., Ahern, J., McGarigal, K., 2012. *Measuring landscapes: A planner's handbook*. Island press.
- Letourneau, A., Thompson, J., 2013. Note méthodologique pour l'identification des espaces importants pour la conservation de la biodiversité et des continuités écologiques en Languedoc-Roussillon - Annexe au SRCE Languedoc-Roussillon.
- Lindenmayer, D.B., Crane, M., Evans, M.C., Maron, M., Gibbons, P., Bekessy, S., Blanchard, W., 2017. The anatomy of a failed offset. *Biological Conservation* 210, 286–292.
- Mandelik, Y., Dayan, T., Feitelson, E., 2005. Planning for biodiversity: the role of ecological impact assessment. *Conserv. Biol.* 19, 1254–1261.
- Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. *Nature* 405, 243–253.
- Maron, M., Brownlie, S., Bull, J.W., Evans, M.C., von Hase, A., Quétier, F., Watson, J.E.M., Gordon, A., 2018. The many meaning of no net loss in environmental policy. *Nature Sustainability* 1, 19–27.
- Maron, M., Hobbs, R.J., Moilanen, A., Matthews, J.W., Christie, K., Gardner, T.A., Keith, D.A., Lindenmayer, D.B., McAlpine, C.A., 2012. Faustian bargains? Restoration realities in the context of biodiversity offset policies. *Biological Conservation* 155, 141–148.
- Maron, M., Ives, C.D., Kujala, H., Bull, J.W., Maseyk, F.J., Bekessy, S., Gordon, A., Watson, J.E., Lentini, P.E., Gibbons, P., others, 2016. Taming a Wicked Problem: Resolving Controversies in Biodiversity Offsetting. *BioScience* 66, 489–498. <https://doi.org/10.1093/biosci/biw038>
- May, J., Hobbs, R.J., Valentine, L.E., 2017. Are offsets effective? An evaluation of recent environmental offsets in Western Australia. *Biological Conservation* 206, 249–257.
- McGarigal, K., 2015. FRAGSTAT Help [WWW Document]. URL <http://www.umass.edu/landeco/research/fragstats/documents/fragstats.help.4.2.pdf> (accessed 8.3.17).
- McGarigal, K., Cushman, S.A., Neel, M.C., Ene, E., 2002. FRAGSTATS: spatial pattern analysis program for categorical maps.
- McKenney, B.A., Kiesecker, J.M., 2010. Policy development for biodiversity offsets: a review of offset frameworks. *Environ. Manage.* 45, 165–176.

- McKinney, M.L., 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosyst.* 11, 161–176. <https://doi.org/10.1007/s11252-007-0045-4>
- McKinney, M.L., 2006. Urbanization as a major cause of biotic homogenization. *Biol. Conserv.* 127, 247–260.
- MEDDE, 2012. Doctrine relative à la séquence éviter, réduire et compenser les impacts sur le milieu naturel. Ministère de l'écologie, du développement durable, des transports et du logement, Paris, France.
- Moilanen, A., Kotiaho, J.S., 2018. Fifteen operationally important decisions in the planning of biodiversity offsets. *Biol. Conserv.* 227, 112–120.
- Moilanen, A., 2013. Planning impact avoidance and biodiversity offsetting using software for spatial conservation prioritisation. *Wildl. Res.* 40, 153–162.
- Moilanen, A., 2007. Landscape zonation, benefit functions and target-based planning: unifying reserve selection strategies. *Biol. Conserv.* 134, 571–579.
- Moilanen, A., Franco, A.M., Early, R.I., Fox, R., Wintle, B., Thomas, C.D., 2005. Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proc. R. Soc. Lond. B Biol. Sci.* 272, 1885–1891.
- Moilanen, A., Kujala, H., 2006. Zonation spatial conservation planning framework and software v. 1.0, User manual. Edita, Helsinki, Finland.
- Moilanen, A., Meller, L., Leppänen, J., Pouzols, F.M., Arponen, A., Kujala, H., 2012. Zonation spatial conservation planning framework and software v. 3.1, User manual. Biodivers. Conserv. Inform. Group Dep. Biosci. Univ. Hels. Hels.
- Moilanen, A., Wintle, B.A., 2006. Uncertainty analysis favours selection of spatially aggregated reserve networks. *Biol. Conserv.* 129, 427–434.
- Morandeau, D., Vilaysack, D., 2012. La compensation des atteintes à la biodiversité à l'étranger— Etude de parangonnage. *Etudes Doc.* 68.
- Moreno-Mateos, D., Maris, V., Béchet, A., Curran, M., 2015. The true loss caused by biodiversity offsets. *Biol. Conserv.* 192, 552–559.
- Morgan, R.K., 2012. Environmental impact assessment: the state of the art. *Impact Assess. Proj. Apprais.* 30, 5–14.
- Partidario, M.R., 2015. A strategic advocacy role in SEA for sustainability. *J. Environ. Assess. Policy Manag.* 17.
- Phalan, B., Hayes, G., Brooks, S., Marsh, D., Howard, P., Costelloe, B., Vira, B., Kowalska, A., Whitaker, S., 2017. Avoiding impacts on biodiversity through strengthening the first stage of the mitigation hierarchy. *Oryx* 1–9.
- Pope, J., Bond, A., Morrison-Saunders, A., Retief, F., 2013. Advancing the theory and practice of impact assessment: setting the research agenda. *Environ. Impact Assess. Rev.* 41, 1–9.

- Pressey, R.L., Bottrill, M.C., 2008. Opportunism, threats, and the evolution of systematic conservation planning. *Conserv. Biol.* 22, 1340–1345.
- Prévost, A., Robert, S., 2016. Local spatial planning practices in four French Mediterranean coastal territories under pressure. *Land-use Policy* 56, 68–80.
- Quétier, F., Regnery, B., Levrel, H., 2014. No net loss of biodiversity or paper offsets? A critical review of the French no net loss policy. *Environ. Sci. Policy* 38, 120–131.
- Regnery, B., Quétier, F., Cozannet, N., Gaucherand, S., Laroche, A., Burylo, M., Couvet, D., Kerbiriou, C., 2013. Mesures compensatoires pour la biodiversité : comment améliorer les dossiers environnementaux et la gouvernance ? *Sci. Eaux Territ. Hors-série numéro 12*, 1–8.
- Roy, B.P., Vincke, P., 1989. *L'aide multicritère à la décision*. Editions Ellipses.
- Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Hueneke, L.F., Jackson, R.B., Kinzig, A., others, 2000. Global biodiversity scenarios for the year 2100. *science* 287, 1770–1774.
- Schulp, C.J.E., Van Teeffelen, A.J.A., Tucker, G., Verburg, P.H., 2016. A quantitative assessment of policy options for no net loss of biodiversity and ecosystem services in the European Union. *Land-use Policy* 57, 151–163.
- Tallis, H., Kennedy, C.M., Ruckelshaus, M., Goldstein, J., Kiesecker, J.M., 2015. Mitigation for one & all: An integrated framework for mitigation of development impacts on biodiversity and ecosystem services. *Environ. Impact Assess. Rev.* 55, 21–34.
- Thompson, J.D., 2005. *Plant evolution in the Mediterranean*. Oxford University Press on Demand.
- Toomey, A.H., Knight, A.T., Barlow, J., 2017. Navigating the space between research and implementation in conservation. *Conserv. Lett.* 10, 619–625.
- Underwood, J.G., 2011. Combining Landscape-Level Conservation Planning and Biodiversity Offset Programs: A Case Study. *Environ. Manage.* 47, 121–129. <https://doi.org/10.1007/s00267-010-9589-9>
- Vimal, R., Devictor, V., 2015. Building relevant ecological indicators with basic data: Species and community specialization indices derived from atlas data. *Ecol. Indic.* 50, 1–7. <https://doi.org/10.1016/j.ecolind.2014.10.024>
- Vimal, R., Pluvinet, P., Sacca, C., Mazagol, P.-O., Etlicher, B., Thompson, J.D., 2012. Exploring spatial patterns of vulnerability for diverse biodiversity descriptors in regional conservation planning. *J. Environ. Manage.* 95, 9–16.
- Virely, B., 2017. *Artificialisation, de la mesure à l'action*. Ministère de la Transition Ecologique et Solidaire, Paris.
- Whitehead, A.L., Kujala, H., Wintle, B.A., 2017. Dealing with cumulative biodiversity impacts in strategic environmental assessment: A new frontier for conservation planning. *Conserv. Lett.* 1–10. <https://doi.org/10.1111/conl.12260>

- Wood, C., Djeddour, M., 1989. Environmental assessment of policies, plans and programmes. Interim report to the Commission of European Communities. EIA Centre, University of Manchester.
- Young, J.C., Waylen, K.A., Sarkki, S., Albon, S., Bainbridge, I., Balian, E., Davidson, J., Edwards, D., Fairley, R., Margerison, C., 2014. Improving the science-policy dialogue to meet the challenges of biodiversity conservation: having conversations rather than talking at one-another. *Biodivers. Conserv.* 23, 387–404.