



Review

Biodiversity Offset Program Design and Implementation

Marie Grimm *  and Johann Köppel

Environmental Assessment and Planning Research Group, Technical University of Berlin, 10623 Berlin, Germany; johann.koeppel@tu-berlin.de

* Correspondence: marie.grimm@tu-berlin.de; Tel.: +49-(0)-30-314-27388

Received: 10 October 2019; Accepted: 2 December 2019; Published: 4 December 2019



Abstract: Biodiversity offsets are applied in many countries to compensate for impacts on the environment, but research on regulatory frameworks and implementation enabling effective offsets is lacking. This paper reviews research on biodiversity offsets, providing a framework for the analysis of program design (no net loss goal, uncertainty and ratios, equivalence and accounting, site selection, landscape-scale mitigation planning, timing) and implementation (compliance, adherence to the mitigation hierarchy, leakage and trade-offs, oversight, transparency and monitoring). Some more challenging aspects concern the proper metrics and accounting allowing for program evaluation, as well as the consideration of trade-offs when regulations focus only on the biodiversity aspect of ecosystems. Results can be used to assess offsets anywhere and support the creation of programs that balance development and conservation.

Keywords: biodiversity offsets; no net loss; offset design; offset implementation; compensation; mitigation

1. Introduction

Noticing an increasing pressure on ecosystems due to development, governments have implemented various policy approaches to protect ecosystems and halt, or at least slow down, the decline of biodiversity. One approach has been the implementation of impact mitigation regulations [1], aiming at internalizing external the environmental cost of development. Where command and control approaches (strict regulatory prohibition) failed to avoid air pollution [2], allowing compensation for unavoidable impacts introduced flexibility, and then spread to other environmental policies: after all avoidance and minimization measures are exhausted, compensation offers a compromise between socio-economic objectives and nature conservation. The United States and Germany introduced policies to assess the environmental impacts of actions and required mitigation as early as the 1970s [3]. Their model, including the mitigation hierarchy—avoid, minimize, and compensate for residual, unavoidable impacts—is applied in many countries today. We acknowledge that there are differences in terminology and in the definition of the mitigation hierarchy. We use the term compensation to describe on-site measures ensuring the functionality of the impact site, as well as off-site measures to compensate for adverse impacts. Compensation measures can include conservation, management, restoration/rehabilitation, enhancement, and creation/establishment of habitat (other terms may also be used to describe these actions). What we do not consider here is restoration/rehabilitation after the project is decommissioned, as it takes place after the fact, whereas the other steps are taken before the impact occurs.

One central biodiversity policy goal is the conservation and/or restoration of nature, which can include the preservation of existing, as well as the rehabilitation or enhancement of degraded, resources. These approaches have also been applied in offset programs to compensate for impacts. The Business and

Biodiversity Offsets Programme (BBOP 2012) defines biodiversity offsets as ‘measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development after appropriate prevention and mitigation measures have been taken. The goal of biodiversity offsets is to achieve no net loss (NNL) and, preferably, a net gain, of biodiversity with respect to species composition, habitat structure, ecosystem function and people’s use and the cultural values associated with biodiversity [4]. To bring more clarity into the terminology, Brownlie et al. (2013) define the term ‘compensation’ as a scenario in which a tradeoff occurs, whereas an ‘offset’ assures at least no net loss of biodiversity and ecosystem services (ES) [5]. However, in the context of this paper, the terms ‘compensation’ and ‘offset’ will be used interchangeably for ease of reading.

Many scholars have discussed biodiversity offsets [6–10]. Effective offsets must counterbalance the impacts of a project, bring measurable long-term benefits, and produce desired results [11]. The effectiveness of offset programs strongly depends on the policy framework and implementation thereof [12–14]. Legislation provides a basic conceptualization as it sets a frame for implementation and applies existing paradigms, i.e., the polluter pays principle. Although some have come up with evaluation frameworks [15] and partial evaluations of offset programs [16,17], a “a need for “proof of concept” and successful implementation remains” [18] (p. 393). Many authors have pointed out that the success of offsets is unclear [6,11,19,20]. Different opinions on offsetting are reflected in the literature: Spash (2015) argues that the economic concepts applied in offsetting legitimize habitat destruction instead of preventing it [21]. Some criticize offsets from a social perspective (e.g., social equity, considering the redistribution of nature), others from natural sciences (e.g., considering baselines) or integrated perspectives (e.g., considering time-lag) [9]. Hrabanski (2015) lists a number of major points of criticism: whereas some voice more ‘radical criticism’ opposing the idea of natural capital, and a commodification of nature, doubting the effectiveness of offsets, others apply ‘reformist criticism’ aimed at a lack of monitoring and difficulties in assessment, irreplaceability of environmental resources and metrics, weakening of legislation, spatial distribution issues, and a weakening of the avoidance requirement [2]. Approaches to the latter provide a framework to analyze offset programs as an effective instrument in combining development with conservation. This also contributes to research concerning socio-economic conditions and regulatory frameworks enabling effective offsets [6].

Lapeyre et al. (2015) point out the importance of differentiating between different types of offsets in furthering the state of research; ‘one should rather precisely analyse each policy instrument or scheme on the ground, and disentangle its institutional and economic characteristics as well as its relations to market mechanisms and their main features’ [3]. In this paper, we focus on offsets that are implemented in mandated frameworks, e.g., non-voluntary offsets that are legally required through legislation to compensate for impacts on biodiversity. Within such a framework the developer can implement compensation measures or, if allowed, use a third-party. Some offsets may be placed within a regulation-driven market context (e.g., conservation banking, as explained below). One of the strictest legal frameworks for biodiversity protection is the 1973 U.S. Endangered Species Act (ESA). Compensation under ESA can be implemented using various mechanisms where either the permittee implements compensation projects, or a third party takes on this responsibility. Besides permittee-responsible mitigation (PRM: The developer implements project-specific compensation measures on- or off-site) or in-lieu fees (ILF: A third-party form of compensation in which a third party collects a fee from developers and implements measures to take care of multiple compensation requirements) the developer may buy credits from a conservation bank (‘a site, or suite of sites [...], that is conserved and managed in perpetuity, and provides ecological functions and services expressed as credits for specified species or resources, that are later transferred or sold to others for use as compensation for impacts occurring elsewhere to the same species.’ [22] (p. 2). We use also use term ‘biodiversity bank’ as an umbrella term for conservation banks, species banks and habitat banks in this paper). The bank sponsor is then responsible for the maintenance and success of the compensation project. Benefits of biodiversity banks include better conservation outcomes, advanced mitigation and

higher efficiency due to economies of scale [23–27]. The ESA aims to conserve and protect listed species and their habitat. Although more than 170 conservation banks exist today [28], there is little literature on their implementation or effectiveness [29]. This paper provides a framework for the assessment of biodiversity offset programs such as the conservation banking program to draw implications for their effectiveness. The framework outlined here can also support the creation of new offset programs.

Methodology and Aim

This paper is based on peer reviewed literature, grey literature and legislation (the sources of the grey literature were reviewed critically before including them, we mainly use studies and guidance documents from federal agencies or non-government entities such as BBOP). The literature was accumulated between November 2017 and November 2018 using ScienceDirect, Thomson Reuters 'Web of Science' and Google (Scholar) to search for papers published in English from after 2000. Search terms included 'offset', 'compensation', 'mitigation', 'biodiversity bank', 'habitat bank' and 'conservation bank' on their own and in combination with 'design', 'implementation', 'effectiveness', 'success', and 'compliance'. Papers that didn't provide information on offset program design and implementation were excluded based on the full paper content (not just the abstracts). A snowball approach was used to identify additional relevant papers. We identified recurring aspects discussed in the papers and clustered the content in an iterative-inductive approach, which resulted in Table 1.

The overall research question is 'which aspects must be considered in offset program design and implementation to create an effective biodiversity offset program?'. Concerning the improvement in existing and future offset programs, there appear to be two major groups of authors; (a) those that discuss design issues and improvements thereof, and (b) those that deal with the actual implementation and effectiveness of offsets. The state of research and open questions in each of these groups are discussed in the following subchapters to answer our research question. We contribute to a better understanding of what comprises effective offsets, providing a framework to analyze program design and the implementation of biodiversity offset programs.

2. Results: A Framework for Effective Offsets

This chapter discusses aspects of effective offset program design and implementation. Table 1 at the end of this chapter provides a summary of the factors discussed in in this paper (partially overlaps with a categorization established by [8]). Clearly, some of these aspects cannot be categorized clearly and are strongly interconnected (see Figure 1 in discussion).

2.1. Offset Design

A number of authors have discussed the technical design of offsets with the aim to improve conservation outcomes and reach NNL or a net gain [18,30,31]. The effectiveness of offset programs is strongly dependent on the policy framework, offset design, the implementation thereof and compliance [12].

2.1.1. No Net Loss and Additionality

NNL or a net gain should be the goal of offset policies in order to halt the loss of biodiversity [4,18,32]. Overall, the policy goal and the resources protected must be clearly defined [31,33]. It must be clear whether NNL refers to acres of habitat, the number of individual animals or their conservation status ('NNL of what?' [34]): NNL can have different meanings depending on what the goal refers to [32]. Therefore, the legislators must define the frame of reference, e.g., the status before the impact or business-as-usual scenario in which biodiversity declines ('no net loss compared with what?' [34]). Without such a clear goal, offset programs' success in reaching their goals cannot be evaluated. To reach NNL, offsets should provide additional conservation outcomes, measured not only by area, but also ecological quality (the determination of what constitutes ecological quality depends on the aim of the NNL goal and should be reflected in the metrics and methods applied) [35–37]. For, if additionality is

not provided, NNL cannot be attained [9]. Additionality describes the idea that the offset should bring additional conservation outcomes that would not have occurred without the offset. Additionality is measured in relation to a baseline that could, for example, be based on a business-as-usual or a counterfactual scenario. Baselines are crucial to allow the measuring of biodiversity benefits and prove additionality on a project scale, as well as program success on a policy scale [38]. The baseline is 'a state or trajectory (e.g., of a system) used as a comparator. The term is used in many contexts: shifting baseline is often used to refer to the way in which our concept of what is 'normal' or 'pre-impact' changes over time (e.g., Papworth et al., 2009; Pauly, 1995); baseline data often refers to data that reflect the starting-point or reference state of a system before some expected perturbation (or restoration) (e.g., Downs et al., 2011); a baseline site can refer to a 'control' or 'reference' site in an experimental design or natural experiment (e.g., Brinck and Frost, 2009; Golding et al., 1997); a baseline trajectory is a counterfactual trajectory that describes how a system is expected to behave in the absence of some perturbation or action (e.g., Costa et al., 2000)' [38] (p. 505). The baseline used to quantify the value of the compensation measures must reflect the frame of reference of the NNL policy goal. In addition, all losses must be accounted for properly, for 'what is not measures, is not compensated' [39]. Protection or 'averted loss offsets' may pose an obstacle to reaching an NNL goal [18,38–42] as they 'only' conserve existing habitats. Bull et al. (2015) refer to this question as the 'how' of offsetting [43]. This offset type may be appropriate where the rate of loss of biodiversity is high, and large, intact areas can be protected from development [18,44]. In this case, additionality would be provided compared to a counterfactual scenario (what the state of the site would be if it weren't protected). Gibbons et al. (2016) apply a calculator to find out when NNL is feasible, and find that averted loss offsets are only feasible for 'biodiversity that is declining under the counterfactual at an annual rate $\geq 6\%$ ' (with discount rate 3%, and offset ratios $\leq 10:1$, [45] (p.256)). Buschke (2017) points out that NNL with averted loss offsets is most feasible when '(a) the initial loss of biodiversity is small, (b) the background decline in biodiversity is rapid and (c) conservation interventions are effective' [46], and that the shape of the biodiversity trajectory affects the outcome as well, and therefore should be included in the offset planning. Moilanen and Laitila (2016) provide some other criteria: (a) if otherwise no compensation would take place, (b) if biodiversity, time lag, leakage and uncertainties were accounted for, (c) when trading up, (d) if 'the price paid includes a permanent regional reduction in utilization of natural resources' [40] (p.109).

Relevant questions are: What is the policy goal (NNL of what and compared to what scenario)? Are additional conservation outcomes required and accounted for? What is the frame of reference? Is additionality provided compared to a baseline or a counterfactual scenario? Does the chosen baseline/counterfactual reflect the frame of reference of the NNL goal?

2.1.2. Uncertainty and Ratios

Risk and uncertainties, such as climate change effects or uncertainty due to limited knowledge, can affect NNL as well as the offsetting program [35,47–49]. Uncertainty is inherent in biodiversity conservation and can increase with climate change [50]. It can relate to the lack or interpretation of data, concepts and proxies [51]. Potential conflicts between land uses, unexpected costs, and other unexpected factors can also affect the offsetting. In addition to strict regulatory requirements, for example, concerning advance mitigation or financial safeguards, mitigation ratios can provide a tool for this [18,31,52–54]. They can account for governance, social and technical challenges, and lead to better conservation outcomes [37,55,56]. They can vary depending on time-lag, type of ecosystem, and uncertainty and offset activity (e.g., protection, restoration, creation). A number of authors discuss the importance of ratios or multipliers in achieving at least NNL [18,31,52]. However, currently applied ratios are not sufficient to counteract risk of failure, time lags and uncertainties [52]. Tallis et al. (2016) call for a replicable and transparent offset-ratio method to combine relevant variables to establish ratios [54]. Overall, offsets do not constitute a remedy for failed offset projects (e.g., in cases of wildfire).

Relevant questions are: Does the regulatory framework acknowledge and consider uncertainties? What kind of uncertainties are acknowledged and accounted for? How is uncertainty dealt with? Which criteria influence mitigation ratios? Are they set transparently?

2.1.3. Equivalence and Accounting

Equivalence of impact and offset can refer to the proper amount of compensation, but herein will mostly refer to the type and function. The flexibility here lies in ‘in-kind’ vs. ‘out-of-kind’ compensation [43,44,54,57,58]. Some authors discuss ‘trading up’ to aim offsets at high priority species or habitats [31,35,43,59]. The idea is to aim offsetting efforts at high priority species or habitats instead of the species or habitats impaired at the impact site if they are of less importance. Still, based on the overall policy goal, the definition of equivalence can focus on ecosystem services (ES), utility, species or habitats or functional equivalence [23]. What is being accounted for at biodiversity banks is referred to as ‘credit metrics’ and affects the aim of conservation efforts and functioning of the regulatory market [9,60]. Options are vast; indicators can be practice or performance based and focus on area, functionality, species or habitat [60–64]. Moreno-Mateos et al. (2015) discuss ecological, non-instrumental (intrinsic, cultural) and instrumental (ES) values of biodiversity that should be accounted for to avoid ecological as well as ethical losses [39]. Transparent and effective accounting that goes beyond acreage is needed [35]. Accounting metrics (e.g., the quality or extent of a habitat, number of individual species) and methods (the accounting method in which the metrics are embedded establishes how the biodiversity value is measured e.g., how different metrics and potentially other indicators are combined to calculate the biodiversity value) should be identical at both impact and compensation sites and reflect the policy goal.

Relevant questions are: Are offsets in-kind? What metrics are used? Are the same metrics used at impact and compensation site? Do the metrics reflect the policy goal?

2.1.4. Site Selection and Spatial Relation to the Impact Site

Another aspect is the spatial relation to the impact site (on-site vs. off-site compensation) [43,44,59,65–68]. On-site mitigation can maintain some of the functionality of the impact site, but can also be affected by the surrounding development area (e.g., edge effects) as the compensation site will be rather small compared to larger areas, where third-parties consolidate multiple compensation requirements. However, on-site mitigation does not lead a redistribution of natural resources to more rural areas. In addition, off-site compensation can be sited to support landscape-scale conservation goals, but site selection can also be affected by land prices and availability. Third party compensation is always provided off-site, and the location should make ecological sense (e.g., consider species distribution, habitat connectivity, ecological functionality). Landscape-scale conservation goals can influence site selection. A biodiversity bank is assigned a service area, outlining the geographic region in which credits can be sold to developers [22]. There are various approaches to the definition of the service areas; for example, Tallis et al. (2016) suggest the serviceshed of ecosystem services as the proper range [56,69] (‘the spatial extent of a serviceshed is determined by the area that supports biophysical service production, and allows beneficiaries both physical and institutional access to the service (Tallis and Polasky, 2009)’ [69] (p.25)). The size of the area is closely tied to the question of the distribution of nature, and associated social, economic and environmental impacts [54,70–72]. These aspects should be considered when determining offset sites and service areas as they can have implications for reaching policy goals, access to nature for recreational purposes and the feasibility of a biodiversity bank.

Relevant questions are: Is compensation required on- or off-site and why? What are criteria for offset site selection (e.g., species distribution, habitat connectivity, ecological functionality, etc.)? What are the criteria for determining the service area (or requirements concerning the spatial relation of impact and offset site)? Are ecological, social and economic aspects considered?

2.1.5. Landscape-Scale Mitigation Planning

Sochi et al. (2016) point out that most offset policies focus on one or a small number of biodiversity features, and provide a mitigation framework in which the ‘full suite of conservation priorities in a region’ are supported, and discuss a number of design safeguards to provide effective offsetting programs [35] (p.320). Various authors have acknowledged and discussed a trend away from project-by-project compensation planning towards landscape-scale mitigation planning (‘an approach to conservation planning that applies the mitigation hierarchy for impacts to resources and their values, services, and functions at the relevant scale, however narrow or broad, necessary to sustain, or otherwise achieve established goals for those resources and their values, services, and functions.’ [22], see [73] for a more detailed discussion of the approach), highlighting the potential benefits associated with such an approach [1,18,35,42,43,54,57,74–78]. Associated benefits include assessment of cumulative effects, cost savings, quicker permitting processes, better conservation outcomes through larger, well-connected areas, and contribution towards strategic conservation goals [ibid.]. Overall, landscape-scale mitigation planning suggests using large-scale conservation plans to inform the application of the mitigation hierarchy. However, no empirical studies regarding the effectiveness of the approach have been undertaken [79].

Relevant questions are: Are landscape-scale conservation objectives (e.g., species recovery plans, habitat conservation plans, landscape plans, biotope networks, Natura 2000 networks, conservation strategies) considered in impact and mitigation planning? How? Is there a comprehensive conservation planning system that can inform mitigation or do plans need to be established first?

2.1.6. Advance Mitigation

One major issue with impact mitigation is time-lag: if an impact occurs before the compensation measures are completed and functional resources are lost [37]. This can be avoided by providing advance mitigation, which is argued to bring ecological benefits, such as improved mitigation quality and alignment with strategic conservation goals, as well as benefits for the permittee [26,41,43,55,57,80–83]. The permittee can benefit from quicker permitting processes and cost savings due to economies of scale, lower transaction costs and lower direct mitigation cost (e.g., land prices and inflation) [81]. However, unless third parties are involved, funding for compensation is usually only generated when the impact is permitted. Time discounting offset ratios can help in this case, as higher ratios are required when compensating immediate loss with future biodiversity gains [84,85].

Relevant questions are: Is the offset site functional before the impact occurs? If not, are time discounting and ratios applied?

2.1.7. Perpetuity

The long-term stewardship and functionality of compensation sites is a major success factor in reaching policy goals [8,9,86]. Conservation easements and other tools exist to protect sites in the long run. Depending on the overall policy goal and the definition of additionality [32] long-term protection either provides ‘enough’ benefits to offset an environmental impact (see discussion on averted loss offsets above), or must be combined with management to provide additional conservation outcomes [86]. Overall, long-term management and monitoring are questions of the banking operation, compliance and enforcement. The latter strongly depends on the implementation’s framework and institutional capacities, as discussed below.

Relevant questions for analysis are: Are offset sites secured and managed in perpetuity? How? By whom?

2.2. Implementation and Compliance

Although many authors discuss the aspects discussed above, there are very few studies that empirically test compliance in real-life permitting processes. Design related factors strongly influence

the permitting process and compliance with legislation [13] and the organizational capacity of overseeing institutions can affect their implementation [16]. A potential risk is the misuse of offsets to reach business-as-usual conservation goals [87–90], or ineffective offsets that allow otherwise unpermissible impacts [18,21,49,91,92]. This section also focuses on factors that are strongly influenced by the permitting process and actual compliance with regulatory frameworks.

2.2.1. Avoidance and Adherence to the Mitigation Hierarchy

Avoidance and adherence to the mitigation hierarchy—avoid, minimize, compensate—play a major role in effective mitigation policies [18,31,93–97]. Even proponents of biodiversity offsets state that some impacts cannot be offset [9], questioning the ‘offsetability’ or ‘irreplaceability’ of certain species, habitats or ecosystems [18,39,43,56,98–101]. Tallis et al. (2016) call for ecosystem services thresholds to identify no-go areas for development [54]. Landscape-scale approaches can also help to identify such areas.

Relevant questions are: Is compensation only allowed after all options of avoidance and minimization have been exhausted? Are impact permits denied due to the irreplaceability of resources or due to a lack of avoidance? Is there a threshold determining which impacts are ‘offsettable’?

2.2.2. Leakage and Trade-Offs

Another challenge is avoiding leakage and trade-offs when permitting impacts [5,18,40,102]. Leakage refers to a displacement of impacts to an area outside the offset program boundaries: ‘Leakage means the phenomenon of environmentally damaging activity relocating elsewhere after being stopped locally by avoided loss offsetting. Indirect leakage means that locally avoided losses displace to other administrative areas or spread around diffusely via market effects.’ [35] (p. 106). Direct and indirect leakage can be influenced by the organization doing the resource extraction, mitigation ratios, the type of resource extracted, and in-kind vs. out-of-kind leakage [40]. Trade-offs can occur when the management of an offset site for one environmental resource can be detrimental to another. This is an especially crucial aspect when regulations only protect one aspect of the ecosystem or only one ecosystem service (e.g., biodiversity), but development can impair other ecosystem functions as well (e.g., carbon sequestration or water retention). Trade-offs are difficult to measure, especially when multiple agencies are involved and no strategic oversight exists [40]. However, these issues can be managed with careful monitoring, tracking and oversight. Another option could be a more comprehensive regulation, such as the German impact mitigation regulation that covers the functionality of the ecosystem as well as landscape scenery.

Relevant questions are: Are additional offset programs or other regulation in places beyond the program boundaries that can reduce or avoid leakage? Are additional regulations in place that protect ecosystem components that are not covered by the offset program to avoid trade-offs when managing only for biodiversity? Is there strategic oversight across agencies and ecosystem components to avoid these phenomena?

2.2.3. Oversight, Transparency and Monitoring

Few papers discuss regulatory compliance [95,103,104] and monitoring [18,53,96]. But authors such as Sahley et al. (2017) document how large-scale monitoring can inform mitigation and restoration priorities in Peru [105]. Overall, strict oversight and transparency in the permitting process is a major factor in determining program success [106–108]. One or multiple agencies must provide standards, fairness and accountability [78]. It is crucial to collect comparable data on impacts and compensation sites across agencies to allow program assessment and improvement. To allow for proper monitoring, the availability of baseline data that reflects the frame of reference of the NNL policy goal may be an issue if the frame of reference is not the state at the time of project development. In addition, the collection of comparable data for monitoring requires standardized methods for monitoring that reflect the policy goal as well as the institutional capacity for its enforcement.

Relevant questions are: What are the monitoring requirements for compensation sites? Are there comparable data on impacts and offsets? Is that data analyzed to assess the overall program success?

Table 1. Summary of Aspects of Program Design and Implementation.

Offset Program Design	Implementation and Compliance
No Net Loss and Additionality [4,9,31–38]	Avoidance and Adherence to the Mitigation Hierarchy [18,31,39,93–101]
Uncertainty and Ratios [18,31,35,37,47–49,53–56]	Leakage and Trade-Offs [5,18,40,102]
Equivalence and Accounting [23,31,35,43,44,57,58,60–64]	Oversight, Transparency and Monitoring [53,78,99,100,103–108]
Site Selection and Spatial Relation to the Impact Site [43,44,54,65–68,70–72]	
Landscape-Scale Mitigation Planning [35,42,43,73–79]	
Advance Mitigation [26,37,41,43,57,80–83]	
Perpetuity [8,9,86]	

3. Discussion and Conclusion

The framework above provides a two-step approach to offset assessment; (1.) the proper design of the regulatory framework, and (2.) the actual implementation and compliance. The regulatory framework is only a starting point and the implementation in practice—from the permitting process for impacts and offsets to proper oversight—is the real question concerning effective offsets (discussed below). Overall, the aspects discussed are strongly connected and cannot be categorized clearly (Figure 1). To begin with, almost all aspects affect the overall NNL policy goal: by avoiding temporal loss, advanced mitigation contributes to this goal while also reducing uncertainties (which, in turn, threaten the goal). In addition, the metrics and credits chosen to measure impacts and offsets also measure and determine whether equivalence and additionality (proven by a proper baseline) are obtained. Both additionality and equivalence, strongly affect whether an NNL goal is reached. Mitigation ratios can contribute to additionality by requiring higher amounts of compensation. On a more strategic note, landscape-scale mitigation planning can be used to avoid leakage and trade-offs and it can inform the application of the mitigation hierarchy, as well as compensation site selection. Perpetual management affects the long-term success of the program. Oversight, transparency and monitoring should function as an umbrella, ensuring compliance, tracking and an evaluation of overall program success.

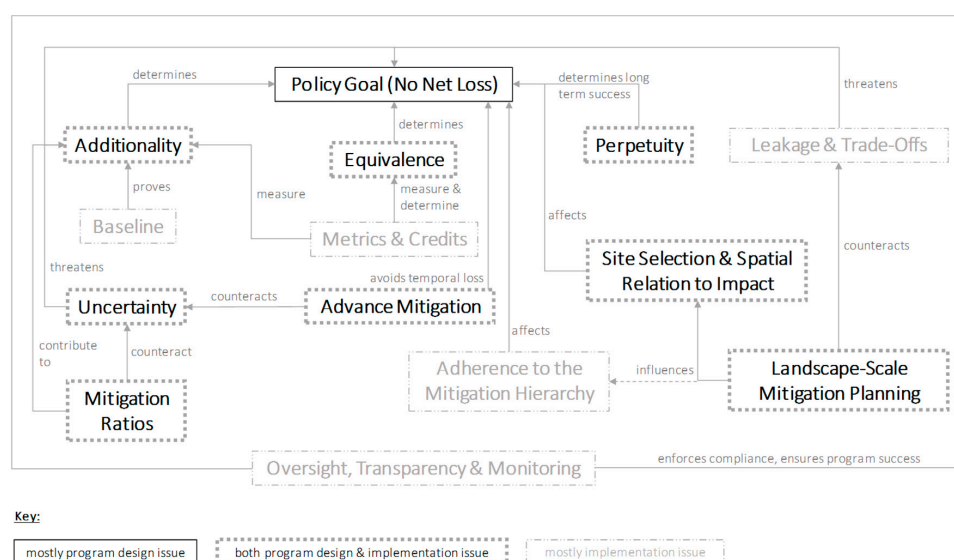


Figure 1. Visual conceptualization of offset design and implementation.

Overall, the framework presented here is based on the literature published in English, which may exclude relevant insight published in other languages. It is possible that some stakeholders disagree and this must be reflected in the context of the specific regulatory and institutional conditions of each offset program. We advised the master's thesis of Eva Ulfeld who conducted five semi-structured interviews with different stakeholders in California (bank sponsors, developers, agencies, consultants) to test the validity of this framework [109]. She found that all stakeholders listed most of the aspects named above when asked what must be considered for effective offset program design and implementation. She also found that one aspect was missing: cooperation between agencies and other stakeholders, which is discussed below. It is crucial to point out that many of the compiled aspects above can be discussed in more detail in the context of specific offsetting programs. In this section, we also discuss some general issues with regard to some of these aspects. One major point of international discourse is whether the goal of NNL or a net gain is even attainable and how it could be reached. The current state of research is that we don't know: many offset frameworks do not clearly define what exactly NNL refers to and most programs are lacking overall success evaluations. In order to even attempt the latter, we need a clear definition of NNL (of what, and compared to which, scenario?) as well as standardized metrics and methods that reflect the overall program goal. The framework we present here can be used as a tool for analysis of existing offset programs to see what shortfalls the program might have, and to draw implications for its effectiveness and identify possible improvements. The NNL goal also affects what baseline is relevant, what criteria must determine the site selection process and what is considered appropriate ecological quality at the offset site. It can even affect landscape-scale conservation planning, as the overarching plans and mitigation should benefit each other. The program goal trickles down through all relevant aspects. Thus, we must generally ask whether this goal is reflected throughout the program design and implementation.

As mentioned above, the implementation in practice determines whether offset program goals are attained or not. The organizational capacity of all stakeholders involved, as well as the overall institutional framework, with clear responsibilities, play a crucial role in this [34,109]. For example, the standardization of fair and equitable metrics, methods, ratios and site selection criteria is not an easy task (standardization across offset programs and even across administrative borders could be an approach to reduce leakage by establishing at least similar requirements for developers); depending on the NNL (e.g., improved conservation status for individual species) different assessment methods may be needed for each species. This requires data, research and resources, in addition to stakeholder involvement, to increase acceptability of the established standards. Cooperation between different stakeholders is also an important step in landscape-scale mitigation approaches, as different land use sectors, as well as potentially conflicting environmental objectives, must be united [72]. Cooperation can be challenging when different levels of governance with different regulations, jurisdictions and agencies are involved (e.g., centralized vs. federal policy structure); tiering gives different responsibilities to different levels, and therefore implementation and administrative oversight may vary across regions or agencies. Also, different agencies may implement different regulations and therefore follow different objectives, but also need to cooperate in order to avoid trade-offs. Trade-offs may be difficult to notice when agency jurisdictions only cover certain components of ecosystems and no strategic oversight exists. Overall, agencies must have sufficient capacity for monitoring, enforcement and evaluation. The specific context, however, is offset program specific, and must be discussed in the analysis of any offset program. This does not only cover the offsetting side of the regulations, but also the impact permit side; consistent methods must be applied to assess the impacts and strict enforcement, for example, considering whether avoidance and what is even 'offsettable', are also needed. Landscape-scale conservation objectives can help determine 'no-go-areas' based on irreplaceable environmental resources.

Biodiversity offsets can provide a compromise between conservation and development, if designed and implemented prudently. This framework provides aspects that need to be considered to provide effective offset programs, including biodiversity banks. Some critical scholars fear flawed offset design and implementation facilitating development, calling for a halt of their application.

However, an empirical evaluation of programs, such as conservation banking, is needed before dismissing or supporting any policy instrument.

Author Contributions: Conceptualization, methodology, writing—original draft preparation, visualization M.G.; writing—review and editing, M.G. and J.K.; supervision, J.K.

Funding: This research received no external funding.

Acknowledgments: We acknowledge support by the German Research Foundation and the Open Access Publication Fund of TU Berlin for the publication of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kennedy, C.M.; Miteva, D.A.; Baumgarten, L.; Hawthorne, P.L.; Sochi, K.; Polasky, S.; Oakleaf, J.R.; Uhlhorn, E.M.; Kiesecker, J. Bigger is better: Improved nature conservation and economic returns from landscape-level mitigation. *Sci. Adv.* **2016**, *2*, e1501021. [[CrossRef](#)] [[PubMed](#)]
2. Hrabanski, M. The biodiversity offsets as market-based instruments in global governance: Origins, success and controversies. *Ecosyst. Serv.* **2015**, *15*, 143–151. [[CrossRef](#)]
3. Lapeyre, R.; Froger, G.; Hrabanski, M. Biodiversity offsets as market-based instruments for ecosystem services? From discourses to practices. *Ecosyst. Serv.* **2015**, *15*, 125–133. [[CrossRef](#)]
4. BBOP. Standard on Biodiversity Offsets. 2012. Available online: http://www.forest-trends.org/documents/files/doc_3078.pdf (accessed on 22 August 2017).
5. Brownlie, S.; King, N.; Treweek, J. Biodiversity tradeoffs and offsets in impact assessment and decision making: Can we stop the loss? *Impact Assess. Proj. Apprais.* **2013**, *31*, 24–33. [[CrossRef](#)]
6. Gelcich, S.; Vargas, C.; Carreras, M.J.; Castilla, J.C.; Donlan, C.J. Achieving biodiversity benefits with offsets: Research gaps, challenges, and needs. *Ambio* **2016**, *46*, 184–189. [[CrossRef](#)]
7. Coralie, C.; Guillaume, O.; Claude, N. Tracking the origins and development of biodiversity offsetting in academic research and its implications for conservation: A review. *Biol. Conserv.* **2015**, *192*, 492–503. [[CrossRef](#)]
8. Gonçalves, B.; Marques, A.; Soares, A.M.V.D.M.; Pereira, H.M. Biodiversity offsets. From current challenges to harmonized metrics. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 61–67. [[CrossRef](#)]
9. Lave, R.; Robertson, M. Biodiversity Offsetting. In *The Routledge Handbook of the Political Economy of Science*; Tyfield, D., Ed.; Taylor and Francis: Abingdon, UK, 2017; pp. 224–236. ISBN 978-1-138-92298-3.
10. Bonneuil, C. Tell me where you come from, I will tell you who you are: A genealogy of biodiversity offsetting mechanisms in historical context. *Biol. Conserv.* **2015**, *192*, 485–491. [[CrossRef](#)]
11. May, J.; Hobbs, R.J.; Valentine, L.E. Are offsets effective? An evaluation of recent environmental offsets in Western Australia. *Biol. Conserv.* **2017**, *206*, 249–257. [[CrossRef](#)]
12. Thébaud, O.; Boschetti, F.; Jennings, S.; Smith, A.D.M.; Pascoe, S. Of sets of offsets: Cumulative impacts and strategies for compensatory restoration. *Ecol. Model.* **2015**, *312*, 114–124. [[CrossRef](#)]
13. Taherzadeh, O.; Howley, P. No net loss of what, for whom? Stakeholder perspectives to Biodiversity Offsetting in England. *Environ. Dev. Sustain.* **2018**, *20*, 1807–1830. [[CrossRef](#)]
14. Ambrose, R.F.; Callaway, J.C.; Lee, S.F. An Evaluation of Compensatory Mitigation Projects Permitted Under Clean Water Act Section 401 by the California State Water Resources Control Board, 1991–2002. Available online: http://www.waterboards.ca.gov/water_issues/programs/cwa401/docs/mitigation_finalreport_full081307.pdf (accessed on 24 August 2017).
15. Peterson, I.; Maron, M.; Moillanen, A.; Bekessy, S.; Gordon, A. A quantitative framework for evaluating the impact of biodiversity offset policies. *Biol. Conserv.* **2018**, *224*, 162–169. [[CrossRef](#)]
16. Guillet, F.; Semal, L. Policy flaws of biodiversity offsetting as a conservation strategy. *Biol. Conserv.* **2018**, *221*, 86–90. [[CrossRef](#)]
17. Sonter, L.J.; Barnes, M.; Matthews, J.W.; Maron, M. Quantifying habitat losses and gains made by U.S. Species Conservation Banks to improve compensation policies and avoid perverse outcomes. *Conserv. Lett.* **2019**, *105*, e12629. [[CrossRef](#)]

18. Brownlie, S.; Treweek, J. Biodiversity Offsets for 'No Net Loss' through Impact Assessment. In *Handbook on Biodiversity and Ecosystem Services in Impact Assessment*; Geneletti, D., Ed.; Edward Elgar Publishing: Cheltenham, UK; Northampton, MA, USA, 2016; pp. 364–394. ISBN 978-1-78347-898-9.
19. Madsen, B.; Carroll, N.; Moore Brands, K. *State of Biodiversity Markets—Offset and Compensation Programs Worldwide*; 2010. Available online: <http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf> (accessed on 24 August 2017).
20. Pawliczek, J.; Sullivan, S. Conservation and concealment in SpeciesBanking.com, USA: An analysis of neoliberal performance in the species offsetting industry. *Environ. Conserv.* **2011**, *38*, 435–444. [[CrossRef](#)]
21. Spash, C.L. Bulldozing biodiversity: The economics of offsets and trading-in Nature. *Biol. Conserv.* **2015**, *192*, 541–551. [[CrossRef](#)]
22. US FWS. *Interim Guidance for Implementing the Endangered Species Act Compensatory Mitigation Policy*. 2017. Available online: https://www.fws.gov/endangered/improving_esa/pdf/Interim_Guidance_for_Implementing_the_Endangered%20Species%20Act%20Jan%202017.pdf (accessed on 24 August 2017).
23. EFTEC. *The Use of Market-Based Instruments for Biodiversity Protection—Habitat Banking Case Studies*. 2010. Available online: http://www.forest-trends.org/publication_details.php?publicationID=2410 (accessed on 24 August 2017).
24. Calvet, C.; Napoléone, C.; Salles, J.-M. The Biodiversity Offsetting Dilemma: Between Economic Rationales and Ecological Dynamics. *Sustainability* **2015**, *7*, 7357–7378. [[CrossRef](#)]
25. Camacho, A.E.; Taylor, E.M.; Kelly, M.L. Lessons from Areawide, Multiagency Habitat Conservation Plans in California. *Environ. Law Rep.* **2016**, *46*, 10222–10248.
26. Carroll, N.; Bayon, R.; Fox, J. The Future of Biodiversity Offset Banking. In *Conservation and Biodiversity Banking: A Guide to Setting up and Running Biodiversity Credit Trading Systems*; Carroll, N., Fox, J., Bayon, R., Eds.; Earthscan: London, UK, 2009; pp. 223–226. ISBN 978-1-84407-814-1.
27. Sciara, G.C.; Bjorkman, J.; Stryjewski, E.; Thorne, J.H. Mitigating environmental impacts in advance: Evidence of cost and time savings for transportation projects. *Transp. Res. Part D Transp. Environ.* **2017**, *50*, 316–326. [[CrossRef](#)]
28. US DOI. *Departmental Manual 600 DM 6: Implementing Mitigation at the Landscape-Scale*. 2015. Available online: <https://www.doi.gov/sites/doi.gov/files/uploads/TRS%20and%20Chapter%20FINAL.pdf> (accessed on 4 October 2017).
29. RIBITS. Regulatory in Lieu Fee and Bank Information Tracking System. Available online: <https://ribits.usace.army.mil/> (accessed on 6 August 2019).
30. Apostolopoulou, E.; Adams, W.M. Biodiversity offsetting and conservation: Reframing nature to save it. *Oryx* **2017**, *51*, 23–31. [[CrossRef](#)]
31. Bull, J.W.; Gordon, A.; Watson, J.E.M.; Maron, M.; Carvalho, S. Seeking convergence on the key concepts in 'no net loss' policy. *J. Appl. Ecol.* **2016**, *53*, 1686–1693. [[CrossRef](#)]
32. Maron, M.; Brownlie, S.; Bull, J.W.; Evans, M.C.; von Hase, A.; Quétier, F.; Watson, J.E.M.; Gordon, A. The many meanings of no net loss in environmental policy. *Nat. Sustain.* **2018**, *1*, 19–27. [[CrossRef](#)]
33. Bezombes, L.; Gaucherand, S.; Spiegelberger, T.; Gouraud, V.; Kerbiriou, C. A set of organized indicators to conciliate scientific knowledge, offset policies requirements and operational constraints in the context of biodiversity offsets. *Ecol. Indic.* **2018**, *93*, 1244–1252. [[CrossRef](#)]
34. Maron, M.; Ives, C.D.; Kujala, H.; Bull, J.W.; Maseyk, F.J.F.; Bekessy, S.; Gordon, A.; Watson, J.E.M.; Lentini, P.E.; Gibbons, P.; et al. Taming a Wicked Problem: Resolving Controversies in Biodiversity Offsetting. *BioScience* **2016**, *66*, 489–498. [[CrossRef](#)]
35. Sochi, K.; Kiesecker, J.; McKenzie, A. Optimizing regulatory requirements to aid in the implementation of compensatory mitigation. *J. Appl. Ecol.* **2016**, *53*, 317–322. [[CrossRef](#)]
36. Quétier, F.; Lavorel, S. Assessing ecological equivalence in biodiversity offset schemes: Key issues and solutions. *Biol. Conserv.* **2011**, *144*, 2991–2999. [[CrossRef](#)]
37. Overton, J.M.; Stephens, R.T.T.; Ferrier, S. Net present biodiversity value and the design of biodiversity offsets. *Ambio* **2013**, *42*, 100–110. [[CrossRef](#)]
38. Maron, M.; Bull, J.W.; Evans, M.C.; Gordon, A. Locking in loss: Baselines of decline in Australian biodiversity offset policies. *Biol. Conserv.* **2015**, *192*, 504–512. [[CrossRef](#)]
39. Moreno-Mateos, D.; Maris, V.; Béchet, A.; Curran, M. The true loss caused by biodiversity offsets. *Biol. Conserv.* **2015**, *192*, 552–559. [[CrossRef](#)]

40. Moilanen, A.; Laitila, J. FORUM: Indirect leakage leads to a failure of avoided loss biodiversity offsetting. *J. Appl. Ecol.* **2016**, *53*, 106–111. [[CrossRef](#)]
41. Bekessy, S.A.; Wintle, B.A.; Lindenmayer, D.B.; McCarthy, M.A.; Colyvan, M.; Burgman, M.A.; Possingham, H.P. The biodiversity bank cannot be a lending bank. *Conserv. Lett.* **2010**, *3*, 151–158. [[CrossRef](#)]
42. Sonter, L.J.; Barrett, D.J.; Soares-Filho, B.S. Offsetting the impacts of mining to achieve no net loss of native vegetation. *Conserv. Biol.* **2014**, *28*, 1068–1076. [[CrossRef](#)] [[PubMed](#)]
43. Bull, J.W.; Hardy, M.J.; Moilanen, A.; Gordon, A. Categories of flexibility in biodiversity offsetting, and their implications for conservation. *Biol. Conserv.* **2015**, *192*, 522–532. [[CrossRef](#)]
44. Habib, T.J.; Farr, D.R.; Schneider, R.R.; Boutin, S. Economic and ecological outcomes of flexible biodiversity offset systems. *Conserv. Biol.* **2013**, *27*, 1313–1323. [[CrossRef](#)] [[PubMed](#)]
45. Gibbons, P.; Evans, M.C.; Maron, M.; Gordon, A.; Le Roux, D.; von Hase, A.; Lindenmayer, D.B.; Possingham, H.P. A Loss-Gain Calculator for Biodiversity Offsets and the Circumstances in Which No Net Loss Is Feasible. *Conserv. Lett.* **2016**, *9*, 252–259. [[CrossRef](#)]
46. Buschke, F.T. Biodiversity trajectories and the time needed to achieve no net loss through averted-loss biodiversity offsets. *Ecol. Model.* **2017**, *352*, 54–57. [[CrossRef](#)]
47. Bernazzani, P.; Bradley, B.A.; Opperman, J.J. Integrating climate change into habitat conservation plans under the U.S. endangered species act. *Environ. Manag.* **2012**, *49*, 1103–1114. [[CrossRef](#)]
48. Bull, J.W.; Suttle, K.B.; Singh, N.J.; Milner-Gulland, E.J. Conservation when nothing stands still: Moving targets and biodiversity offsets. *Front. Ecol. Environ.* **2013**, *11*, 203–210. [[CrossRef](#)]
49. Levrel, H.; Scemama, P.; Vaissière, A.C. Should we be wary of mitigation banking? Evidence regarding the risks associated with this wetland offset arrangement in Florida. *Ecol. Econ.* **2017**, *135*, 136–149. [[CrossRef](#)]
50. Kujala, H.; Burgman, M.A.; Moilanen, A. Treatment of uncertainty in conservation under climate change. *Conserv. Lett.* **2013**, *6*, 73–85. [[CrossRef](#)]
51. Haila, Y.; Henle, K. Uncertainty in biodiversity science, policy and management: A conceptual overview. *Nat. Conserv.* **2014**, *8*, 27–43. [[CrossRef](#)]
52. Curran, M.; Hellweg, S.; Beck, J. Is there any empirical support for biodiversity offset policy? *Ecol. Appl.* **2014**, *24*, 617–632. [[CrossRef](#)] [[PubMed](#)]
53. Pickett, E.J.; Stockwell, M.P.; Bower, D.S.; Garnham, J.I.; Pollard, C.J.; Clulow, J.; Mahony, M.J. Achieving no net loss in habitat offset of a threatened frog required high offset ratio and intensive monitoring. *Biol. Conserv.* **2013**, *157*, 156–162. [[CrossRef](#)]
54. Tallis, H.; Kennedy, C.M.; Ruckelshaus, M.; Goldstein, J.; Kiesecker, J.M. Mitigation for the People: An Ecosystem Services Framework. In *Handbook on Biodiversity and Ecosystem Services in Impact Assessment*; Geneletti, D., Ed.; Edward Elgar Publishing: Cheltenham, UK; Northampton, MA, USA, 2016; pp. 397–427. ISBN 978-1-78347-898-9.
55. Maron, M.; Hobbs, R.J.; Moilanen, A.; Matthews, J.W.; Christie, K.; Gardner, T.A.; Keith, D.A.; Lindenmayer, D.B.; McAlpine, C.A. Faustian bargains? Restoration realities in the context of biodiversity offset policies. *Biol. Conserv.* **2012**, *155*, 141–148. [[CrossRef](#)]
56. McKenney, B.A.; Kiesecker, J.M. Policy development for biodiversity offsets: A review of offset frameworks. *Environ. Manag.* **2010**, *45*, 165–176. [[CrossRef](#)] [[PubMed](#)]
57. Gardner, T.A.; Hase, v.A.; Brownlie, S.; Ekstrom, J.M.M.; Pilgrim, J.D.; Savy, C.E.; Stephens, R.T.T.; Treweek, J.; Ussher, G.T.; Ward, G.; et al. Biodiversity offsets and the challenge of achieving no net loss. *Conserv. Biol.* **2013**, *27*, 1254–1264. [[CrossRef](#)] [[PubMed](#)]
58. Wissel, S.; Wätzold, F. A conceptual analysis of the application of tradable permits to biodiversity conservation. *Conserv. Biol.* **2010**, *24*, 404–411. [[CrossRef](#)]
59. Kiesecker, J.M.; Copeland, H.; Pocewicz, A.; McKenney, B. Development by design: Blending landscape-level planning with the mitigation hierarchy. *Front. Ecol. Environ.* **2010**, *8*, 261–266. [[CrossRef](#)]
60. Pindilli, E.; Casey, F. *Biodiversity and Habitat Markets—Policy, Economic, and Ecological Implications of Market-Based Conservation*; U.S. Department of the Interior, U.S. Geological Survey: Reston, VA, USA, 2015; ISBN 978-1-4113-3977-4.
61. Bezombes, L.; Gaucherand, S.; Kerbiriou, C.; Reinert, M.E.; Spiegelberger, T. Ecological Equivalence Assessment Methods: What Trade-Offs between Operationality, Scientific Basis and Comprehensiveness? *Environ. Manag.* **2017**, *60*, 216–230. [[CrossRef](#)]

62. Maseyk, F.J.F.; Barea, L.P.; Stephens, R.T.T.; Possingham, H.P.; Dutson, G.; Maron, M. A disaggregated biodiversity offset accounting model to improve estimation of ecological equivalency and no net loss. *Biol. Conserv.* **2016**, *204*, 322–332. [[CrossRef](#)]
63. Jacob, C.; Vaissiere, A.C.; Bas, A.; Calvet, C. Investigating the inclusion of ecosystem services in biodiversity offsetting. *Ecosyst. Serv.* **2016**, *21*, 92–102. [[CrossRef](#)]
64. Carreras Gamarra, M.J.; Lassoie, J.P.; Milder, J. Accounting for no net loss: A critical assessment of biodiversity offsetting metrics and methods. *J. Environ. Manag.* **2018**, *220*, 36–43. [[CrossRef](#)] [[PubMed](#)]
65. Doyle, M. Flexible Service Areas Could Allow Regulators to Reward Success. *Natl. Wetl. Newsl.* **2013**, *35*, 16.
66. Amato, P. Lessons learned on setting service areas. *Natl. Wetl. Newsl.* **2013**, *35*, 10–11.
67. Holland, H.; DeYoung, G. A Building-block approach to service areas. *Natl. Wetl. Newsl.* **2013**, *35*, 12–13.
68. Martin, S.; Brumbaugh, R. Defining service areas for wetland mitigation: An overview. *Natl. Wetl. Newsl.* **2013**, *35*, 9.
69. Tallis, H.; Kennedy, C.M.; Ruckelshaus, M.; Goldstein, J.; Kiesecker, J.M. Mitigation for one & all: An integrated framework for mitigation of development impacts on biodiversity and ecosystem services. *Environ. Impact Assess. Rev.* **2015**, *55*, 21–34. [[CrossRef](#)]
70. Drechsler, M.; Wätzold, F. Applying tradable permits to biodiversity conservation: Effects of space-dependent conservation benefits and cost heterogeneity on habitat allocation. *Ecol. Econ.* **2009**, *68*, 1083–1092. [[CrossRef](#)]
71. BenDor, T.; Stewart, A. Land use planning and social equity in North Carolina’s compensatory wetland and stream mitigation programs. *Environ. Manag.* **2011**, *47*, 239–253. [[CrossRef](#)]
72. BenDor, T.; Brozović, N.; Pallathucheril, V.G. The Social Impacts of Wetland Mitigation Policies in the United States. *J. Plan. Lit.* **2008**, *22*, 341–357. [[CrossRef](#)]
73. Grimm, M.; Köppel, J.; Geißler, G. A Shift Towards Landscape-Scale Approaches in Compensation—Suitable Mechanisms and Open Questions. *Impact Assess. Proj. Apprais.* **2019**, *47*, 1–12. [[CrossRef](#)]
74. Clement, J.P.; Belin, A.; Bean, M.J.; Boling, T.A.; Lyons, J.R. A Strategy for Improving the Mitigation Policies. A Report to the Secretary of the Interior from the Energy and Climate Change Task Force. 2014. Available online: https://www.doi.gov/sites/doi.gov/files/migrated/news/upload/Mitigation-Report-to-the-Secretary_FINAL_04_08_14.pdf (accessed on 1 September 2017).
75. Kiesecker, J.M.; Copeland, H.; Pocewicz, A.; Nibbelink, N.; McKenney, B.; Dahlke, J.; Holloran, M.; Stroud, D. A framework for implementing biodiversity offsets: Selecting sites and determining scale. *BioScience* **2009**, *59*, 77–84. [[CrossRef](#)]
76. Hayes, D.J. Addressing the environmental impacts of large infrastructure projects: Making “mitigation” matter. *Environ. Law Rep.* **2014**, *44*, 10016–10021.
77. Kreitler, J.; Schloss, C.A.; Soong, O.; Hannah, L.; Davis, F.W. Conservation planning for offsetting the impacts of development: A case study of biodiversity and renewable energy in the mojave desert. *PLoS ONE* **2015**, *10*, e0140226. [[CrossRef](#)] [[PubMed](#)]
78. Saenz, S.; Walschburger, T.; González, J.; León, J.; McKenney, B.; Kiesecker, J. A framework for implementing and valuing biodiversity offsets in Colombia: A landscape scale perspective. *Sustainability* **2013**, *5*, 4961–4987. [[CrossRef](#)]
79. Underwood, J.G. Combining landscape-level conservation planning and biodiversity offset programs: A case study. *Environ. Manag.* **2011**, *47*, 121–129. [[CrossRef](#)]
80. Robertson, M.M. Emerging ecosystem service markets: Trends in a decade of entrepreneurial wetland banking. *Front. Ecol. Environ.* **2006**, *4*, 297–302. [[CrossRef](#)]
81. Sciara, G.C.; Stryjewski, E. Saving money when safeguarding species and habitats: Conventional vs. advance land acquisition for transportation mitigation. *Res. Transp. Econ.* **2015**, *52*, 100–110. [[CrossRef](#)]
82. Drechsler, M.; Hartig, F. Conserving biodiversity with tradable permits under changing conservation costs and habitat restoration time lags. *Ecol. Econ.* **2011**, *70*, 533–541. [[CrossRef](#)]
83. Sciara, G.C.; Bjorkman, J.; Lederman, J.; Thorne, J.H.; Schlotterbeck, M.; Wachs, M. Task 2 Report: Setting the Stage for Statewide Advance Mitigation in California. Available online: <https://escholarship.org/uc/item/7bn594hx> (accessed on 9 January 2018).
84. Laitila, J.; Moilanen, A.; Pouzols, F.M. A method for calculating minimum biodiversity offset multipliers accounting for time discounting, additionality and permanence. *Methods Ecol. Evol.* **2014**, *5*, 1247–1254. [[CrossRef](#)]

85. Moilanen, A.; van Teeffelen, A.J.A.; Ben-Haim, Y.; Ferrier, S. How Much Compensation is Enough? A Framework for Incorporating Uncertainty and Time Discounting When Calculating Offset Ratios for Impacted Habitat. *Restor. Ecol.* **2009**, *17*, 470–478. [[CrossRef](#)]
86. Teresa, S. Perpetual Stewardship Considerations for Compensatory Mitigation and Mitigation Banks. *Stetson Law Rev.* **2009**, *38*, 337–356.
87. Githiru, M.; King, M.W.; Bauche, P.; Simon, C.; Boles, J.; Rindt, C.; Victurine, R. Should biodiversity offsets help finance underfunded Protected Areas? *Biol. Conserv.* **2015**, *191*, 819–826. [[CrossRef](#)]
88. Maron, M.; Gordon, A.; Mackey, B.G.; Possingham, H.P.; Watson, J.E.M. Conservation: Stop misuse of biodiversity offsets. *Nature* **2015**, *523*, 401–403. [[CrossRef](#)] [[PubMed](#)]
89. Maron, M.; Gordon, A.; Mackey, B.G.; Possingham, H.P.; Watson, J.E.M. Interactions Between Biodiversity Offsets and Protected Area Commitments: Avoiding Perverse Outcomes. *Conserv. Lett.* **2016**, *9*, 384–389. [[CrossRef](#)]
90. Gordon, A.; Bull, J.W.; Wilcox, C.; Maron, M.; Banks-Leite, C. FORUM—Perverse incentives risk undermining biodiversity offset policies. *J. Appl. Ecol.* **2015**, *52*, 532–537. [[CrossRef](#)]
91. Hayes, N.; Morrison-Saunders, A. Effectiveness of environmental offsets in environmental impact assessment: Practitioner perspectives from Western Australia. *Impact Assess. Proj. Apprais.* **2007**, *25*, 209–218. [[CrossRef](#)]
92. Santos, R.U.I.; Schröter-Schlaack, C.; Antunes, P.; Ring, I.; Clemente, P. Reviewing the role of habitat banking and tradable development rights in the conservation policy mix. *Environ. Conserv.* **2015**, *42*, 294–305. [[CrossRef](#)]
93. Clare, S.; Krogman, N.; Foote, L.; Lemphers, N. Where is the avoidance in the implementation of wetland law and policy? *Wetl. Ecol. Manag.* **2011**, *19*, 165–182. [[CrossRef](#)]
94. Jacob, C.; Pioch, S.; Thorin, S. The effectiveness of the mitigation hierarchy in environmental impact studies on marine ecosystems: A case study in France. *Environ. Impact Assess. Rev.* **2016**, *60*, 83–98. [[CrossRef](#)]
95. Niner, H.J.; Milligan, B.; Jones, P.J.S.; Styan, C.A. A global snapshot of marine biodiversity offsetting policy. *Mar. Policy* **2017**, *81*, 368–374. [[CrossRef](#)]
96. Jenner, N.; Howard, P. *Biodiversity Offsets: Lessons Learned from Policy and Practice*; Synthesis Report; Fauna & Flora International: Cambridge, UK, 2015.
97. Phalan, B.T.T.; Hayes, G.; Brooks, S.; Marsh, D.; Howard, P.; Costelloe, B.; Vira, B.; Kowalska, A.; Whitaker, S. Avoiding impacts on biodiversity through strengthening the first stage of the mitigation hierarchy. *Oryx* **2018**, *52*, 316–324. [[CrossRef](#)]
98. Pilgrim, J.D.; Brownlie, S.; Ekstrom, J.M.M.; Gardner, T.A.; von Hase, A.; ten Kate, K.; Savy, C.E.; Stephens, R.T.T.; Temple, H.J.; Treweek, J.; et al. A process for assessing the offsetability of biodiversity impacts. *Conserv. Lett.* **2013**, *3*, 12002. [[CrossRef](#)]
99. Pilgrim, J.D.; Brownlie, S.; Ekstrom, J.M.M.; Gardner, T.A.; von Hase, A.; ten Kate, K.; Savy, C.E.; Theo Stephens, R.T.; Temple, H.J.; Treweek, J.; et al. Offsetability is highest for common and widespread biodiversity: Response to Regnery et al. *Conserv. Lett.* **2013**, *4*, 12026. [[CrossRef](#)]
100. Van Maasackers, M. *The Creation of Markets for Ecosystem Services in the United States: The Challenge of Trading Places*; Anthem Press: London, UK; New York, NY, USA, 2016; ISBN 978-1-78308-603-0.
101. Ives, C.D.; Bekessy, S.A. The ethics of offsetting nature. *Front. Ecol. Environ.* **2015**, *13*, 568–573. [[CrossRef](#)]
102. Bull, J.W.; Lloyd, S.P.; Strange, N. Implementation Gap between the Theory and Practice of Biodiversity Offset Multipliers. *Conserv. Lett.* **2017**, *10*, 656–669. [[CrossRef](#)]
103. Brown, M.A.; Clarkson, B.D.; Barton, B.J.; Joshi, C. Ecological compensation: An evaluation of regulatory compliance in New Zealand. *Impact Assess. Proj. Apprais.* **2013**, *31*, 34–44. [[CrossRef](#)]
104. Matthews, J.W.; Endress, A.G. Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. *Environ. Manag.* **2008**, *41*, 130–141. [[CrossRef](#)]
105. Sahley, C.T.; Vildoso, B.; Casaretto, C.; Taborga, P.; Ledesma, K.; Linares-Palomino, R.; Mamani, G.; Dallmeier, F.; Alonso, A. Quantifying impact reduction due to avoidance, minimization and restoration for a natural gas pipeline in the Peruvian Andes. *Environ. Impact Assess. Rev.* **2017**, *66*, 53–65. [[CrossRef](#)]
106. Bull, J.W.; Brauneder, K.; Darbi, M.; van Teeffelen, A.J.A.; Quétier, F.; Brooks, S.E.; Dunnett, S.; Strange, N. Data transparency regarding the implementation of European ‘no net loss’ biodiversity policies. *Biol. Conserv.* **2018**, *218*, 64–72. [[CrossRef](#)]
107. Froger, G.; Hrabanski, M. Biodiversity offsets as market-based instruments for ecosystem services? *Ecosyst. Serv.* **2015**, *15*, 123–124. [[CrossRef](#)]

108. Van Teeffelen, A.J.A.; Opdam, P.; Wätzold, F.; Hartig, F.; Johst, K.; Drechsler, M.; Vos, C.C.; Wissel, S.; Quétier, F. Ecological and economic conditions and associated institutional challenges for conservation banking in dynamic landscapes. *Landsc. Urban Plan.* **2014**, *130*, 64–72. [[CrossRef](#)]
109. Ulfeldt, E. Assessing Criteria of Offset Design and Implementation: Biodiversity Offsets in California from Stakeholder Perspectives. Master's Thesis, Environmental Planning, Environmental Assessment and Planning research Group, Technische Universität, Berlin, Germany, 2019.



© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).