Biodiversity offsets: overview and critical analysis of opportunities and risks

Géraldine Froger[1], Sophie Ménard[2]

[1]CEMOTEV, University of Versailles, France; geraldine.froger@uvsq.fr, [2]CEMOTEV, University of Versailles, France; sophie.menard@uvsq.fr

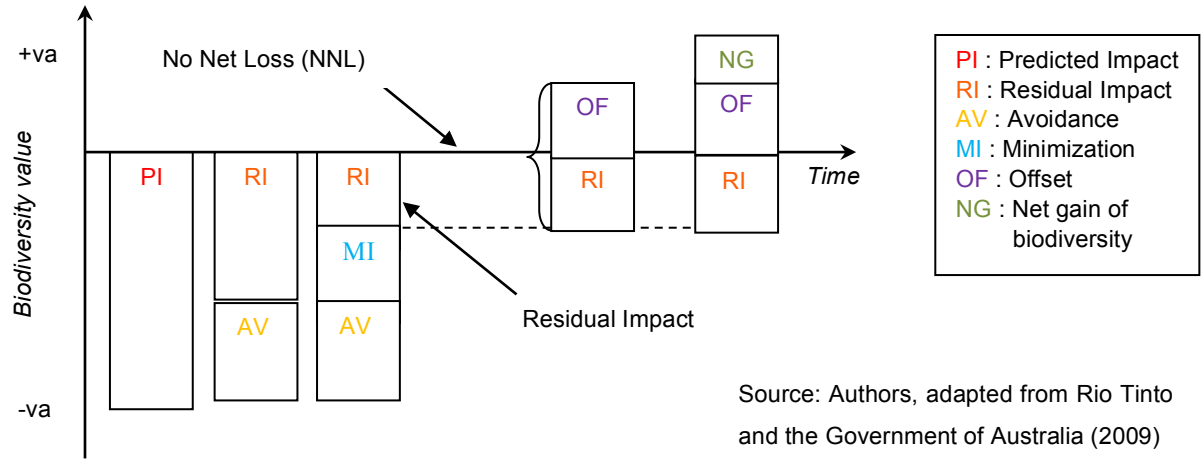
***Abstract**: Biodiversity offsets were developed to meet the objectives of biodiversity conservation and of economic development in tandem. However, little attention has been paid to their design or to the effects of pro-market narrative on environmental policy instruments. The recommendation to develop biodiversity offsets can lead in practice to a variety of institutional forms. The purpose of this article is to analyse the development of biodiversity offsets, to evaluate their implementation to date in the light of several institutional arrangements and to synthesize outstanding theoretical and practical challenges.*

***Keywords**: Compensation, mitigation, offsets, institutional arrangements, no net loss, biodiversity conservation*

1 Introduction

Although the term of biodiversity offsets (BO) was used for the first time in 2003 by ten Kate, compensatory biodiversity conservation mechanisms were progressively implemented in more and more countries since the 1950s (Madsen et al. 2011). Indeed, the idea is to compensate biodiversity damages caused by developers' projects by implementing offset schemes in-site or off-site.

Figure 1. The mitigation hierarchy



Source: Authors, adapted from Rio Tinto and the Government of Australia (2009)

Integrated into a global mitigation hierarchy process, BO are "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 and preferably a net gain of biodiversity on the ground with respect to species composition, habitat structure and ecosystem function and people's use and cultural values associated with biodiversity" (BBOP 2009a, 2009b, 2012). To enable the no net loss (NNL), the mitigation hierarchy process is composed of three steps which should be realized progressively: (1) avoid as far as possible impacts on biodiversity caused by developers, (2) minimize their extend duration and intensity, and (3) compensate for any residual significant and/or adverse impacts that cannot be avoided and minimized.

Over time, various and different schemes were developed by engineers, developers, NGOs members, researchers and lawyers to offset impacts on biodiversity. So, BO are an increasingly popular yet controversial tool in conservation. Their popularity lies in their potential to meet the objectives of biodiversity conservation and economic development in tandem; the controversy lies in the need to accept ecological losses in return for uncertain gains (Bull et al., 2013). Our review of BO evaluates implementation to date and synthetizes outstanding conceptual and practical problems. We begin by discussing the development of compensatory measures and the use of BO. We find that biodiversity offset schemes are very diverse and heterogeneous. We clarify their meaning, objectives, methodologies and delivery. We also propose a framework that integrates the consideration of theoretical and practical challenges in the offset process and analyse opportunities and risks of BO with an institutional perspective.

1. How biodiversity offsets were implemented?

To analyse BO it is necessary to highlight the development of compensatory measures and the various steps contributing to their expansion at the international level. We identify three major periods in the development of BO: the first one deals with the idea of compensation supported and promoted by wildlife specialists, the second states the emergence of compensatory measures under the influence of economists, and the last one emphasizes the globalization of BO in discourses and practices.

1.1 A wish to maintain ecosystems functions

In the 1950s, few wildlife specialists (such as Beverton 1953, Thomas 1956) had becoming to alert national and international actors on the necessity to limit exploitation and natural resources considered unlimited until this moment. They highlighted the importance of preserving ecosystem functions to maintain the global balance. In their conclusions, they emphasized the link between an unprecedented phase of economic growth and the reduction of biological diversity and ecosystem functions. Indeed, after the World War II, northern countries have been rebuilt using row materials and spreading infrastructures in more and more rural areas. This exponential increase in the consumption of natural resources conducted to an environmental crisis in the 1950s-1960s.

In the second part the 1960s, a greater number of biologists and wildlife specialists (such as Cain 1968, Berwick 1969) have been added that industrial activities had reached an unprecedented level of natural resources use. These specialists have given a role of service provider to the environment aiming at keeping the attention of economists. Their discourses make it possible for economists to value biological diversity to emphasize the importance of each element. This change in dialectic allows biologists to draw the attention of actors to the impacts of human activities on the environment. Thanks of the increase of funding destined to conservation, the idea of giving prices to environmental elements was first accepted by wildlife specialists.

This context of researches on environmental services encourages the genesis of biodiversity offsetting policies (Mc Kenney and Kiesecker 2010). Even if the term was not yet employed, the process of BO started with the public awareness of environmental damages and the aspiration to make restoration. We identify three major events contributing to the media coverage of this necessity to make compensatory measures: the book of R. Carson in 1962 – *Silent Spring*[1], the popular revolts against the American Interstate Highway System[2], and the International Biological Program[3].

Thus, it was in the 1960s that the idea of BO first emerged, even if the literature did not use this term yet. Indeed, this period highlights the wish to have a zero impact on the environment. Some specialists have underlined natural resources should not be extracted unreasonably and sustainable thresholds should be respected to reach a sustainable development.

Thanks to these movements, lawyers had becoming to implement laws in favor of biological diversity preservation. In all the development steps of BO, the legislation will play a key role in creating and multiplying laws governing the implementation of infrastructure projects.

According to researchers and lawyers' recommendations, developers integrate the environmental preservation within their plans. By this process, the first scheme of BO had been emerging under the in-kind compensation (IKC). IKC represents a non-cash form of compensation aiming at preserving, restoring, enhancing or creating biological diversity when developers' projects have significant

[1] This book has contributed to launch the contemporary American environmental movement. The author underlined for the first time the necessity to take into account the damages of developers on the environment. This book had known a huge success that led to the development of many conservation organizations and make the American more aware of the importance of the environment.

[2] A larger number of environmental organizations and American inhabitants decided to manifest against the implementation of the American Interstate Highway System (AIHS). Indeed, in the early 1960s and particularly in 1964, numerous uprisings broke out along the path of the AIHS to protest against the destruction of ecosystems by bulldozers.

[3] The conservation perspective led few biologists to develop, from 1964 to 1972, the International Biological Program (IBP) under the aim of coordinating ecological and environmental studies at larger scale. In first time, the Canadian and European researchers were principal participants. Then, the American ones were progressively integrated in the program since 1968. Whereas, this program was largely criticized by numerous biologists because questions were not based on strict scientific questioning but on an accumulation of general questions.

impacts. This compensation should be ideally realized at the same place of injuries and should aim at recreating the same environment than the destructed one.

1.2 An emergence supported and promoted by economists

From the early 1970s to the first years of the 1990s, we identify a second development phase of BO. Lawyers became increasingly important and economists were trying to integrate more and more biological diversity in economic plans. Building on the extensive work carried out to date by wildlife specialists, economists (such as Furubotn and Pejovich 1972, Anderson and Hill 1975) decided to include the environment and its functions into the economic reasoning[4].

In this second phase, economists have become to work on the monetization of biological diversity and ecosystem functions with biologists to develop a transaction system (Gomez-Baggethun et al. 2009, 2010). The emergence of biosphere monetization was based on biological conclusions and included in a global thinking of natural resources conservation. This process led specialists to implement metrics corresponding to services provided by the environment (Méral 2012).

In parallel with several events[5], some economists have been increasingly working on environmental issues in the market failures perspectives. According to their work, environmental damages could be seen as negative externalities and a lot of papers published between 1974 and 1977 dealt with internalizing externalities and no-social-cost. Thus, mobilizing the Pigou's tax (1932) and Coase's studies (1960) economists (such as Atkinson 1983, Crocker 1971, Randall 1972) have improved the inclusion of environmental damages in market failures. Internalizing negative externalities is to ensure depollution or restoration costs in an assessment of economic opportunity. Thus, these economists had been pursuing the monetization of the environment through working on economic assessments and generated two major methods to valuate nature's elements: indirect and direct valuations[6].

In parallel, some economists (such as Caste 1978, Pearse 1988) decided to focus attention on property rights issues. Indeed, Hardin, an influent American ecologist, published *The Tragedy of the Commons* in 1968 which conducted to a number of studies in economics. His article has highlighted the overexploitation of natural resources due to their free access. Economists recommend developing private or common property rights.

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[4] However, we notice that this integration has been existed since the 19th century. Effectively, economists have already included the environment in their study in accordance with the rent theory approach.

[5] Such as the creation of the U.S. Environmental Protection Agency (1970), the Ramsar Convention (1971), the Meadows Report (1972), the Stockholm Conference (1972) and the oil crisis of 1973.

[6] The indirect valuation was developed in 1966 by Clawson and Knetsch to observe individual behavior and to analyse their choices as an expression of their revealed preferences for environmental goods and services. This valuation method assumes that environmental goods have market substitutes bought by consumers revealing their willingness to pay for an environmental asset or to compensate an environmental degradation (e.g. water filters, transportation costs…). This method has been completed in 1982 by Smith and Desvouges. The direct valuation method (contingent valuation method) was proposed by the National Oceanic and Atmospheric Administration (NOAA) in 1993. It aims at collecting declared preferences gathered from surveys.

At the same time, we identify four major laws accompanying the economists' findings progressively: the Ramsar Convention (1971), the Washington State Environmental Policy Act (SEPA – 1971), the Clean Water Act (CWA – 1972) and the Endangered Species Act (ESA – 1973). These laws[7] are related to wetland definition and conservation plans. The key law has concerned the compensatory process in the CWA that established the idea of a compensatory mitigation[8] with the possibility to offset residual impacts. The more wildlife specialists' conclusions are important, the more economists and lawyers use them to complete their knowledge and broaden their scope of influence. From a legal point of view, this second phase was the most productive period in term of founding laws but in term of experienced and localized guidelines. Not forgetting the neutral impact objective, lawyers should be able to adapt guidelines to the changing societies and dominant actors in the governance process.

This intellectual evolution led to the development of a second scheme of BO: the financial compensation (FC). FC aims at offsetting injured biodiversity by financial transfers from developers to environmental entities (NGOs, Environmental Agencies…) assessed with economic valuation. These stakeholders will use funds in order to make actions in favor of the environment in general and not necessarily directed to injured ecosystems. By this way, FC adds flexibility for developers but reduce the importance of ecological equivalence[9].

1.3 A globalized increase of BO in discourses and practices

Since the beginning of the 1990s, BO is entered in the era of globalization. This integration in this international process represents the third development phase of BO. This transition to international level was largely operated by the implementation the International Union for Conservation of Nature (IUCN – 1980), the Brundtland Report (1987) and the Earth Summit in Rio (1992). They contributed to determine a global strategy for conservation, to reinforce the international interest on sustainable development and environmental preservation, and to gather scientists and actors to find solutions for biodiversity conservation. Therefore, the common conclusion is the need to tackle swiftly.

The increased globalization also highlights the emergence of new actors on the mitigation scene. Indeed, this third phase reflects a shift from an inner circle (wildlife specialists and economists) to a large circle of BO' actors involved. Actors are no more researchers and lawyers only, but also cities, think tanks, NGOs, Environmental Agencies, Financial Banks, investors, Ministries and consultants.

[7] Concerning wetlands, laws are rather guidelines than restrictive and mandatory laws.
[8] During this second phase, we progressively observe a dialectic change: from mitigation and zero impact on the environment (1960s) to compensatory mitigation (1980) biodiversity (1986) and offset/offsetting (1986).
[9] Figure 1 illustrates how assessing ecological equivalence requires that losses due to impacts (RI) and gains generated by offsets (OF) be measured using the same metric.

In this context, financers, developers and think tanks[10] especially recommended an increase of flexibility in BO and more solutions to offset environmental damages. Institutions have increased incentives and market-based instruments to enlarge the number of compensatory measures. NGOs have also recommended several practices of compensation for biodiversity conservation (Karsenty 2004). More and more firms have deliberately adopted the mitigation hierarchy for six principal reasons: (i) respect the exploitation agreement and adopt a good environmental practice for their reputation, (ii) acquire expertise and reduce operational costs, (iii) reach the requirements of international donor, (iv) enhancing their competitive edge, (v) be pro-active in terms of laws, and (vi) prove the compensation quality by making transparent offsets (Crowe and ten Kate 2010).

Thus, multinational companies, NGOs, economists, lawyers and wildlife specialists constitute the most active players in BO development. To meet the different challenges, the third phase corresponds to the biodiversity banking scheme implementation. This scheme is included in a larger global framework than IKC and FC. Indeed, in the context of market globalization, the financial sector has also been enlarging at the international scale. Henceforth, economists will endeavor to deepen their researches concerning the market-based instruments destined to conservation (Geniaux 2002). As usual, lawyers developed laws or complements to give a jurisdictional or legal framework to practices. Hough and Roberston (2009) have highlighted this connivance between lawyers and other actors by pointing out the relationship between the EPA and the USA Corps. These American entities have hugely contributed to spread the notion of mitigation banking[11].

The third scheme of BO is rooted in mitigation banking, an American process where developers could compensate their environmental damages on wetlands (Weems and Canter 1995), by purchasing biodiversity credits to intermediary entities in charge of realizing compensatory measures (inspired by IKC mechanisms). The mitigation banking reached a peak in 1995 with the publication of the Federal Guidance for the Establishment, Use and Operation of Mitigation Banks (USA Corps). This guidance lays down the foundation of biodiversity banking (BB) such as the impact studies, the different steps of mitigation banks' implementation, the competent authorities, the monitoring, financial insurances, etc. Since the early 2000s, investors have sought to invest in stable assets such as the environment to avoid reiterating the previous economic falls of the liquidity crisis and the burst of the Internet bubble[12]. This need of financial security lead investors to take decision in favor of biodiversity banking development while enhancing the development of biodiversity units – turned into biodiversity credits to be put on sale (Dalang and Hersperger 2012). So, offset "banks" are essentially when providers have created offset projects in exchange fro biodiversity credits (units) or which can subsequently be sold to compensate for developments with comparable residual ecological impacts. The concept of utilizing a

[10] Think tank is an organization that performs research and advocacy concerning topics such as social policy, political strategy, economics, military, technology, and culture. In our study, think tanks on BO are increasing in number.
[11] We decide to use the term "biodiversity banking" to characterize the third phase of BO's development because "mitigation banking" is too related to wetlands, and "conservation banking" to endangered species.
[12] This phenomenon has been dramatically growing for the international crises of 2007.

banking mechanism for offset schemes predates the concept of offsets itself by 10 years (Environmental Law Institute 2002, as outlined by Bull et al. 2013).

2. Which biodiversity offset schemes to compensate damages?

After presenting the characteristics of BO development according to three identified steps, we detail each scheme by analyzing them with an institutional framework. For each compensation scheme, we determine the mechanism, the valuation method(s), the institutional arrangement, and finally we illustrate each BO scheme with practical study case in France[13]. We first analyse IKC, then the FC and finally the BB.

2.1 Presentation and governance of in-kind compensation

First, the wish to accomplish a local and ecological equivalency has led to create a quantitative-based instrument: the in-kind compensation (IKC). It aims at restoring the ecosystem functions from an ecological point of view through the restoration (Maron et al. 2012), the rehabilitation, the creation and/or the preservation of environment implemented to offset the injured site (UICN 2011)[14].

When a developer's project negatively impact biodiversity and the IKC is selected, the developer is seeking experts to conduct assessments and definitions of the needed compensation measures according to their impact study. Before asking the competent administrative authority an authorization, the project and the mitigation hierarchy should be integrally detailed in the impact study. Once having this authorization, the developer carries out the project before or after making the compensatory measures, with or without the assistance of an intermediary (expert in compensation mechanisms). In a final step, a committee in charge of monitoring and evaluation is mandated (by the developer) to comply with the authority's guidelines. This committee will establish a set of follow-evaluations to assess the realization of compensatory measures and their effectiveness linked to the NNL goal.

This BO scheme is included in a framework based on Ecological Assessment (EA) requiring that information on separate indicators should be integrated into comprehensive yardsticks or indices. EA is extremely complex because of regional and temporal variation in vulnerability of ecosystems as well as limited understanding of ecosystem functioning and health (Pullin and Knight 2009, Suding 2011). Despite these difficulties, two valuation methods based on taxonomy are used to assess biodiversity: service-to-service (S-S) and resource-to-resource (R-R).

[13] To illustrate the variety of institutional arrangements in BO, we decide to choose one country (France) where each biodiversity offset scheme is differently employed despite of a common legislation. See also Quétier et al. (2013) for a critical review of the French no net loss policy.

14 The restoration, rehabilitation and creation measures generally make a significant additionality while conservation measures have uncertain ecological value.

Service-to-service approach (HEA: Habitat Equivalency Analysis) was implemented by the American National Oceanic and Atmospheric Administration (NOAA) in 1995 to offset injured habitat. This approach uses biological indicators (vegetation cover, presence or density of critical species…) representing the affected ecosystems or species and their links with other entities (in this case the evaluation of losses and gains focus on the ecological services it produces). It is a widespread approach which can be used in any type of habitat including freshwater streams (Allen et al. 2005), salt marshes (Penn and Tomasi 2002), seagrass beds (Fonseca et al. 2000), and coral reefs (Milon and Dodge 2001). Thus, an amount of biodiversity offsets is estimated to balance the total loss of environmental services and resources resulting from the project and the gap between damages and matured compensatory measures. It may also be a composite indicator using a compound index of resources and/or services. Resource-to-resource approach (REA: Resource Equivalency Analysis) was created in the USA to assess and offset resource losses. The REA method can use a proxy for a specific species, a number of species, or a species characteristic (biomass, lifetime...).

For practical reasons, the experts often use in practice the Service-to-Service (S-S) approach. The general methodology is to assess the ecological value of the impact (through the development of geographic segmentation) by ecosystem inventories (proxies and physical measures). There are many ways to evaluate the temporary loss of biodiversity between degradation and implementation of compensation measures. Based on the granting of non-monetary values, they allow a comparison of the values of the site at different stages. Three main methods are used in the North countries: the Habitat Equivalency Analysis (HEA) developed by the National Oceanographic and Atmospheric Administration (NOAA) in the United States in 1997, the Uniform Mitigation Assessment Methodology (UMAM) developed by the United States Army Corps of Engineers (USACE) between 2000 and 2005, and finally, the Simplified Assessment Method (SAM) created more recently by a group of researchers to assess the impacts of reduced scale. Based on these valuations, compensatory measures are more accurate when they are located in similar biodiversity (ecosystems and habitats) and close geographic area (Quétier et al. 2013).

To illustrate this historical first BO scheme, we explain the framework of this compensatory measure with the example of the “Bassin de Thau” in South of France. In France, there is no direct recommendation on compensatory measures to implement, although there is usually a preference order going from the rehabilitation or restoration to preservation or creation. In the case of the infrastructure project of wind farm "Conques et Quatre Bornes", and its extension "Bassin de Thau", the developers are the IRIS Energy France and the EDF Energies Nouvelles Group.

In this case, although applications for building permits are established by each municipality, the impact study of the wind farm should be cumulatively assessed adding the existing park and all future projects (wind turbines, tracks and stations). According to this framework, an analysis was conducted

to determine the best location to implement the wind farm[15]. Indeed, as the mitigation hierarchy performed iteratively, the French Guideline on compensation should had been completed (see MEEDDM, collection and analysis of cases, 2010).

However, all impacts that could not be avoided or reduced constitute the residual impacts. According to IKC framework, these residual impacts have to be compensated, in particular on the natural avifauna. Two main residual impacts are identified: the first on the natural heritage as described in the impact study, the other in terms of reduction of continuity/connectivity of ecosystem functions. Thus, the main impacts raised by the LPO (the French association of birds' protection) are: the potential impacts on prenuptial and post-nuptial migration, the small breeding birds on the breeding of raptors nesting (very low level for the Montagu's Harrier), and foreseeable impacts on hunting areas where the Golden Eagle and Vulture (medium to low level) fly.

In this work based on the requirements of Natura 2000, a distinction is made between the compensatory measures (placed in the non-technical summary) and the mitigation measures reducing the residual impacts (in the middle of the impact study). These assessments conducted to implement IKC subdivided in three compensatory measures:

- Restoring the heritage of birds favorable to the patrimonial avifauna opening the optimization of reproductive success by supporting actions to pastoral activity habitats. This measure applies to about 450 ha accumulated over 5 years and is based on EA but the implementation is estimated at about 45 000 euros over the 5 years. It includes the restoration of moorland and rangeland, the support to pastoral activities (specific equipment, seeds...), and the consolidation of existing on-site pastoral sheep farms.
- The restoration of breeding sites of Kestrel falcons. To ensure this measure, the development of artificial deposits will be made for an amount close to 5 000 euros.
- Other accompanying measures and reduction. These include more devices followed the evolution of the flora and habitats (18 000 euros), the monitoring of birds (40 000 euros), the eco-tourism activities management (56 000 euros).

Generally, France uses the four types of measures included in the IKC scheme. Concerning framework, IKC is constantly on change according to successive conclusions and return on experiences.

2.2 Financial compensation as particular financial transfers

The financial compensation (FC) is the second biodiversity offset scheme offered to developers. In this case, a developer decides to pay a sum as compensatory measure, he does not need later to justify the proper implementation of measures resulting from this payment.

[15] The objective is to ensure the lowest impact on the environment (e.g. the mitigation hierarchy).

Financial transfers could cover three sub-devices corresponding to the legislation of the countries (Morandeau and Vilaysack 2012): financial transfers exceptionally accepted as a last resort, financial transfers tolerated but prioritized for action in nature, and financial transfers considered as a mode of compensation in itself. If this BO scheme is chosen by the developer, experts (consultants, researchers, experts...) realize the economic valuation of impacts. Once the impact study has been completed, an authorization is requested by the developer to the competent authority to implement the project (taking up more or less all compensation measures presented in the impact study). With this approval, the developer realizes his project before implementing compensatory measures and transfers the determined amount to a financial intermediary. This intermediary will be in charge of operating actions for the whole protection of the environment. The last phase is the meta-evaluation that is carried out independently by the committee who should follow compensatory measures.

Unlike EA focusing on biodiversity loss, the economic valuation could use the value-to-value (V-V) or the value-to-cost (V-C) approaches. The V-V method seeks to measure the economic value ascribed by someone to a degraded natural resources and to a restored one (e.g. indirect and direct valuation methods). Otherwise, the V-C method estimates the cost of compensatory measures maintaining biodiversity along the project's impact (Bas et al. 2013). Thus, a first phase deals with the assessment of biodiversity loss and a second one focuses on the cost of environmental damages. At first, specialists should gather the largest inventory of flora and fauna as possible in the affected site. In most cases, the use of direct valuation method is preferred for its speed and lower cost in realization. Thus, the economic valuation generally leads to the development of non-environmental equivalence between compensatory measures and injured biodiversity.

In France, financial compensation is forbidden, but when we precisely analysed the impact study monitoring, the Land Planning Tax (LPT) seems to be included in this category. The LPT is the evolution of the old urban tax applied on the net surface of infrastructure project. In fact, every public and private entity (except "public utility" project such as a school) must pay taxes corresponding to the impacted area multiplied by 724 euros since December 21th, 2012 (added to an additional 10% for the Ile-de-France, so 821 euros). This tax, harvested by municipalities after giving the building agreement, is divided into communal, departmental and regional parts. The departmental part (5% of the LPT) includes 1.3% destined to the biodiversity conservation[16] and is called the TDENS - the Departmental Tax for Sensible Natural Areas. The amount of this tax is partly given to the General Council of the Department (the General Treasury) to establish departmental policies and guidelines to protect and manage woodlands, natural sites and landscapes. Particularly, this TDENS could be used by communities or coastal conservatories to acquire, develop and maintain natural areas and lake shores (e.g. French Articles L.142-1 et seq. of urbanism). Thus, this TDENS may be considered as a very particular form of financial compensation[17] because developers have to pay this tax which is used for

[16] The rest of the LPT is divided between the regional part (about 1% to finance various infrastructures) and the communal part (about 2% to create cultural or social projects).
[17] The FC is not common in France but is authorized in other countries such as the USA, Russia, Norway (Morandeau and Vilaysack 2012).

the environment as a whole. The concept of tax is totally away from the voluntary approach of BO but could be an opportunity to finance environmental conservation.

2.3 Specificities of biodiversity banking

Based on existing offset schemes, biodiversity banking (BB) encompasses IKC and FC. Since the early of 1990s, BB has been an increasingly popular tool in conservation as a so-called market-based instrument for the provision of environmental services (Boisvert et al. 2013). Created as an innovative incentive, BB generates a supply of biodiversity units by realizing compensatory measures before developers' degradations. In first times, biodiversity unit term is more appropriate than biodiversity credit due to the non-commercial and single-user status of the first developer and banker (the American Department of Transportation). With the creation of a biodiversity unit's supply, this economic instrument should theoretically enable the achievement of NNL, in other words, to reach ecological equivalence. Integrated in the mitigation hierarchy, BB still depends on legal and regulatory national frameworks. Laws on species protection and ecosystem conservation are still under construction because of the continuous innovations associated with this instrument.

We distinguish several banking schemes within BO. This identification helps to clarify practices in a context of non-standardized schemes. We differentiate two major status of bank: public or private bank, and commercial or non-commercial bank (Froger et al. submitted). Public biodiversity banking might be created by one public entity or several (public umbrella bank) to sell biodiversity credits on the "open-market" (public commercial bank) or to use biodiversity units to offset developers' damages (public single-user bank if biodiversity units are created and used by the same entity). Similarly, private biodiversity banking may be implemented by one private entity or several (private umbrella bank) to sell biodiversity credits on the "open-market" (private commercial bank) or to offset its own environmental damages (private single-user bank).

To assess biodiversity units and create biodiversity credits, BB mostly uses the EA and the V-C methods (Ménard et al. submitted). EA should precise included environmental elements, and V-C approach is used by private BB to attribute a price to biodiversity units. The institutional arrangement of BB is essential because it determines the construction, the monitoring and the exchange of biodiversity (Heller and Zavalda 2009). The more the BB is private and commercial, the less the EA is used for time and cost reasons (Ménard et al. submitted). Concerning the monitoring and controls, there are no regulations governing the practices of BB yet. Thus, in the vast majority of cases, the competent authority shall issue guidelines and not constraints on the results.

Since 2008, France is experiencing a public commercial bank through the CDC Biodiversité (a subsidiary of the Caisse des Dépôts et Consignations): the supply of compensation system aims at facilitating developers' searches of ecological equivalence and helping to develop compensatory measures (biodiversity units). Basing on the American model, the main objective is to give visibility to

biodiversity units accompanying developers to achieve the NNL by anticipating the potential demand for compensation in high-pressed areas. To create a compensation supply, the CDC conducts a process of consultation with civil society, experts (scientists, consultants...) and environmental authorities to develop a visible and accessible system of compensation for developers and NNL-friendly entities. Once the certifications obtained by the competent authority, the CDC Biodiversity acquires land or uses public land with potential to develop recovery processes of the existing biodiversity. In France, IKC measures are particularly employed, including the restoration and rehabilitation of abandoned orchards in the Cossure areas. After having sufficiently improved biodiversity (according to the recommended ecological ratio), experts intervene to monetize biodiversity units and place them for sale on the open market, leaving the possibility of making a profit on units sold. Therefore, the developer, after appealing to various experts, transmits its impact study to the competent administrative authority (accordingly to the scale of the impact). Subsequently, the developer may request the assistance of the CDC Biodiversité to offset its impacts by buying the amount of biodiversity units recommended in the impact study.

3. Which theoretical and practical challenges for biodiversity offsets?

According to international guidelines, BO should achieve the NNL goal. Despite the increasing popularity of BO, some controversies lie in the need to accept ecological losses in return for uncertain gains. We propose an institutional framework that considers theoretical and practical challenges in the offset processes.

3.1 Theoretical challenges facing the biodiversity offsets

At theoretical level, the first key challenge is to reach an ecological compensation itself. Indeed, some biologists refuse the idea of recreating injured biodiversity by man-made measures (Morenos-Mateos et al. 2012). According to this biological impossibility, some researchers consider compensatory measures as solutions where nothing else could be made. So, we could reasonably make the hypothesis that compensatory measures will not compensate environmental damages but could be one solution comparing to nothing.

Furthermore, the identification of biodiversity elements and connections is very complex and valuation methods are not stabilized. Another theoretical challenge is multiplicity of metrics (Kiesecker et al. 2009). Even if numerous biologists and ecologists are studying on biological inventories, the knowledge is jeopardized by the huge uncertainty on ecosystem interactions over the medium to long terms. Static inventories do not to take into account all services given by biodiversity such as minimization of disaster floods, filling of groundwater, pollinization, etc. V-C method does not valuate these dynamic elements and does not reflect all the biodiversity opportunities by a reduction of the compensatory measures costs (remuneration of time of experts' analysis and dynamic compensatory

measures costs). This technical difficulty adds flexibility to developers. If the developer is a globalized firm, BO should generally be as transparent as possible to avoid potential contestations of environmental associations. In the case of small-scaled development project, compensatory measures will be cheaper and not extremely specified in the statement of the authorization (compensatory measures is still mostly destined to large-scaled impacts).

Wildlife experts face problem of fixing the compensation trajectory to reach the NNL goal. Potential evolutions of biodiversity (compensatory measures) serve as the referential for comparing the levels of biodiversity before and after compensatory measures. This comparison is based on ecological and/or economic assessments. In the case of economic valuation, a theoretical challenge is to attribute distinctive prices to ecosystems, habitats and species. Indeed, each biodiversity element represents an environmental good or service in biological inventories.

Concerning biodiversity credits, there is a potential instability linked to land prices, attractive areas, financial markets. According to some economists (Palmer et al. 1995), the State is the turning point between developers and compensation experts to guarantee the zero social cost and the provision of environmental services. The theoretical challenge is to find the most effective regulation to value ecosystems and preserve financial markets from deviations. Thus, we could question the ability of financial market to prevent the environment from irreversible damages. Indeed, even if financial markets provide funding, counter-intuitive effects of financial assets could lead to unfavorable speculative behavior.

Another theoretical challenge for BO is the inclusion of social criteria in compensatory measures because local population is also impacted by the development projects. This concern for social cost is particularly important while experts determine the most appropriate scale for compensatory measures. Indeed, we understand that the more the scale is large, the more the total costs for developers will be high. As a result, the mitigation hierarchy should also take into consideration the consequences for inhabitants and social connectivity.

3.2 Practical challenges facing the biodiversity offsets

The theoretical problems outlined above are associated with practical challenges. Our purpose is to highlight the gap between discourse and practice in BO.

The pursuit of the NNL achievement underlines a positive engagement of actors (administrative authorities, lawyers, developers, etc.) who would like to meet the objectives of biodiversity conservation. However, actors follow the theoretical guidelines only if the mitigation hierarchy is respected and, for the sake of transaction costs reduction, a lot of developers and environmental authorities reduce the detail level of valuations and monitoring.

The compliance of guidelines and recommendations depends on the ability of environmental and administrative authorities to control compensatory measures. As international and national recommendations are constantly in evolution, BO are not stabilized and practical elements are still in movement. According to some authors (Levrel et al. 2012), BO is not sufficiently steadied to assess their environmental performance. Currently prevented by unstoppable improvements, compensatory measures are in constant evolution to answer financers and economists' demands.

Another key element is the operational monitoring of biodiversity units. Supposed to follow the ideal trajectory of biodiversity improvement, compensatory measures are in reality assessed according to the replaced biodiversity objectives, not on biological certitudes. Biological knowledge is hugely restricted and the incertitude is too high to give assurances on environmental results.

Results of BO are also influenced by developers who take the final decision in the choice of consultants. Developers are not disposed to implement project where compensatory costs are high. Compensatory measures might be accepted by the competent authority on a second-choice location regarding the ecological equivalence criteria. Effectively, the competent authority often quickly delivers the project agreement in the reason of the lack of financial means and staff. Thus, developers have a real impact on the BO quality because their consciousness and willingness to achieve the NNL will be determinant in the time and expenditure accorded to compensatory measures. Due to the assessment complexity, the compensation is often realized on a little part of environmental damages. According to S-S method, only services are inventoried and BO are realized to restore/enhance or maintain ecosystem services, habitats or species. This complexity sometimes seems to be used as an excuse for maintaining quick valuations and reducing the total cost.

Conclusion

Our paper has highlighted the development and the heterogeneity of BO by identifying three main phases and by characterizing three main schemes with an institutional perspective.

Biodiversity offsets are economic instruments evolved according to several stakeholders and different institutional arrangements. Thus, successively promoted and supported by biologists, economists and financiers, several institutional arrangements include a range of facilities to enable developers to offset the damage caused by the implementation of an infrastructure project. More or less flexible and transparent, they reflect the ambitions laid by the initiators, public or private, of various compensatory measures. Currently, if IKC appears to be the preferred scheme, BB is becoming more and more popular promising the emergence of many structures and governance modes, objectives and scale variables. According to Bull et al. (2013, 1), "we are at a critical stage: BO risk becoming responses to immediate development and conservation needs without an overriding conceptual framework to provide guidance and evaluation criteria".

Our paper has also underlined theoretical and practical challenges that face these schemes. In the case of some of these challenges, some recommendations can be made.

First, an offset scheme could be implemented to retain biodiversity, function and services but these three goals are not always compatible. More research is required to determine when it is possible to conserve them simultaneously and offset schemes should be clear about which aspect(s) they aim to conserve (Bull et al. 2013).

Second, compensatory measures need to be improved according to the return on experiences and the evolution of the interdisciplinary knowledge. In practice, we identify a quick evolution in BO schemes. A time of stabilization could contribute to evaluate the key elements that need to be improved. Current perpetual change in practices does not live time to find better solutions achieving the NNL goal.
Third, environmental laws on compensation requirements should be specified and reinforced in order to impose sanctions on developers who do not realize compensatory measures. Currently, most countries often formulate objectives in term of biodiversity level over the years. Thus, the Law should include requirements on results of compensation and not only on biodiversity level objectives (objectives meeting do not always reflect the NNL achievement[18]).

Finally, international actors and think thanks request actually more operational framework (legislation, scale, compliance, etc.) on BB to encourage sustainability behavior by adopting the mitigation hierarchy process.

Acknowledgments

This research was funded by the ERA-Net BiodivERsA, with the national funder Agence Nationale de la Recherche, part of the 2011 BiodivERsA call for research proposals.

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[18] In some countries such as France, compensatory measures objectives are used to potentially reach the NNL but the compensation result assessment is often based on the gap between these objectives and the assessed biodiversity level.

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