The place of spatialized ecological information in defining and implementing biodiversity offsets policies. A comparative study of Colombia and France

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ABSTRACT

The objective of the research is to analyze whether the elaboration and implementation of biodiversity offsetting policies depend on the quality of spatialized ecological data. We compared the availability and use of such data in Colombia and France, at various stages of the process: (i) anticipation (policy elaboration), (ii) planning, and (iii) monitoring and control. We show that spatialized ecological data are used to implement offsetting policies (France), but may also be a tool to develop such policies, in particular through the elaboration of predetermined ratios based on available scientific data (Colombia). We also show, based on geographical, ecological and legal aspects of the data, that the geographical characteristics of a country and its legal framework are an important determinant of the efficiency of offsets. Where the offset ratio is high, the feasibility of the offsetting will likely depend on whether preservation, and not only restoration, measures are allowed, but also on space finiteness and availability. There is also a necessity to balance the need for legal certainty that predetermined ratios provide with policy effectiveness in terms of no net loss of biodiversity. We emphasize the need for a regularly updated public portal that centralizes environmental data. Further, we note that an important caveat is to ensure that the guidance purpose of offsetting-related land-use planning instruments is not diverted and used to replace fieldwork. We also show that the legal requirement of 'ecosystem' (Colombia) vs 'ecological' (France) equivalence has practical consequences.

KEYWORDS

Mitigation hierarchy, Biodiversity offsets, Policy, Spatialized data, Monitoring, Implementation

1. Introduction

The main drivers of biodiversity loss are well-known and documented: changes in land use (e.g., agricultural expansion, urbanization, infrastructure expansion); direct exploitation of organisms (e.g., logging, harvesting, over-fishing); climate change; air, water and soil pollution; and invasive alien species (IPBES, 2019; Tilman et al., 2017). Among these, the primary driver is land-use change, which results in the degradation, loss and fragmentation of habitats, causing a worldwide decline of biodiversity (Haddad et al., 2015; Joppa et al., 2016; Newbold et al., 2015), with the caveat that the effects of habitat fragmentation on biodiversity can nevertheless be delayed (Haddad et al., 2015; Semper-Pascual et al., 2021).

An approach that aims at tackling land use change-related biodiversity loss is through the adoption of biodiversity offsetting (BO) policies. The principle of 'no net loss' (NNL), which is linked to the application of the 'mitigation hierarchy', usually underlies such policies (Bull and Strange, 2018). The mitigation hierarchy is devised as a hierarchical sequence of actions designed to prevent the net loss of biodiversity: avoid its impact, minimize it if it cannot be avoided, restore/rehabilitate the impacted area, and, as a last resort, offset significant residual losses (Bull and Strange, 2018; Gardner et al., 2013). Its application is widespread and promoted by various international institutions (BBOP, 2009; IUCN, 2016; OECD, 2016; The World Bank, 2017).

The design and implementation of biodiversity offsets (BO) raises, however, a number of theoretical and practical concerns, such as choice of metrics and demonstrating equivalence between losses and gains (Bull et al., 2013; Calvet et al., 2015; Gardner et al., 2013; Maron et al., 2016). Ethical

issues are also raised (Maron et al., 2016), notably: offsets often fail to measure the multiple values that people assign to and associate with biodiversity, and viewing biodiversity as a tradeable commodity may lead to people having a lesser sense of obligation to protect it (Ives and Bekessy, 2015; Moreno-Mateos et al., 2015). Biodiversity offsetting presents potential social impacts, particularly in low-income countries, where local people depend on natural resources (Griffiths et al., 2019; Sonter et al., 2018). Offsetting can lead to the displacement of local people and negatively affect their livelihood or living area, in particular in the Global South (Tupala et al., 2022).

Academic research on offsets is now extensive (Calvet et al., 2015; Gonçalves et al., 2015). BO has also spurred the interest of policymakers, businesses and conservationists (Bull and Strange, 2018; Calvet et al., 2015; Lindenmayer et al., 2017; May et al., 2017; zu Ermgassen et al., 2019). Over 100 countries have already adopted or are currently developing such policies, where offsets may be a regulatory requirement (notably as part of the Environmental Impact Assessment –EIA– process) or may be used on a voluntary basis (GIBOP, 2019). Certain countries accept financial-based BO (see e.g., Pascoe et al., 2019). Some States are considered pioneers (e.g., USA, Australia) (CDC Biodiversité, 2016). Others adopted the mitigation hierarchy decades ago (e.g., France in 1976) but introduced the principle of NNL only recently (Dupont and Lucas, 2017; Quétier et al., 2014). In Latin America, some countries, such as Colombia and Peru, have formalized their offsetting policies in the last decade (Alonso et al., 2020). The majority (about 77%) of countries with offsetting policies do not, however, strictly require that the offsetting takes place in relation to the mitigation hierarchy (GIBOP, 2019).

A prerequisite for BO is to accurately quantify the biodiversity losses caused by development projects (Bull and Strange, 2018). The application of the mitigation hierarchy thus requires the ecological characterization of the territory under consideration. Although interoperability of databases can still be improved (Edwards et al., 2000), the geospatial revolution (Dangermond, 2011) renders data on biodiversity increasingly available. Remote sensing and geographic information system –GIS– technologies help to survey and monitor biodiversity (Geller et al., 2017; Laihonen et al., 2003; Turner et al., 2003). In turn, spatialized ecological information provides a resource for the implementation of offsetting policies. However, the manner in which such information is used in the framework of BO may vary from one country to another, confronting different approaches. Too often, it is assumed that highly precise and detailed information and data are needed to implement (good) offsetting, which may then lead to requiring always more precise integrated data (König et al., 2019). Improving information systems, however, is costly and can delay the implementation of a reference framework necessary for policy implementation. Furthermore, stakeholders need to be able to appropriate information systems in order to make an efficient use of them. Finally, the implementation of BO calls for a good articulation between existing, available information and the needs defined by legislation. This is notably the case in megadiverse countries where it is not always possible to obtain, manage and disseminate highly detailed data. This could support the view that rather than aiming at the highest ecological accuracy in the data, the focus should be on a good connection between ecological information and the implementation of legislation.

The objective of this paper is thus to analyze whether the elaboration and implementation of BO policies depend on the quality of spatialized ecological data, through a comparison of the availability and use of such data in Colombia and France, at every stage of the process (anticipation, planning, and monitoring/control).

The choice of study countries was based on various elements. First, the countries must have similar legislation to enable a comparison of the subtleties of the relevant legislation and its implementation. Second, there must be sufficient feedback on the implementation of BO policies to allow for an empirical analysis. We chose Colombia and France as they met the above criteria, with parallel trajectories since the early 2010s.

2. Methods, Data, Sources

2.1. Methods

We used a mixed method for our research. For both Colombia and France, we carried out an extensive literature review of primary legal sources, secondary sources, and expert and academic literature. This review was complemented by expert interviews in Colombia, whereas a case study of a specific project was undertaken for France. The reason for these differing methods lies with feasibility considerations. Although studying a specific project was possible in France, it was much more difficult in Colombia, especially in terms of access to the pertinent information. Nevertheless, both approaches, albeit different, allowed us to gather input on the use of spatialized ecological information in relation to our research question.

For Colombia, a total of 12 individuals with relevant experience in BO were interviewed between December 2021 and February 2022. The interviews aimed at understanding better the applicable legislation, its implementation by the various stakeholders involved, as well as the data available to them. The interviewees were identified based on the literature review and/or recommendations. An interview guidance document was sent to them ahead of the exchange. The interviewees pertained to the following categories: environmental authority, non-governmental organization (NGO), consulting firm, academia, scientific public institution, industry association. In order to comply with personal data protection regulations, their names and entities are kept confidential.

For France, we carried out, from June 2021 to May 2022, a case study of a linear infrastructure in the Allier department (center France), consisting in the conversion of an 88-kilometer stretch of the existing *Route Centre Europe Atlantique* (RCEA) into a highway (A79). Through this case study, we were able to follow and analyze the offsetting process in the framework of environmental licensing. The analysis enabled us to review the spatialized ecological data used.

We evaluated and compared how spatialized ecological data were used in Colombia and France in the framework of the elaboration and implementation of BO policies. We covered the three main phases of the process: anticipation, planning, and monitoring.

2.2. General framework for biodiversity offsetting in study countries

2.2.1. Colombia

In Colombia, the principle of BO first appeared in 1993, although the principles and rules governing it were first adopted in 2012.

Sources of biogeographical information. Colombia set up the Colombian Environmental Information System (SIAC), which regroups the Environmental Information System (SIA) and the Information System for Environmental Planning and Management (SIPGA) (Uribe Bustamante, 2007). The SIAC centralizes environmental information supplied by Colombia's Environmental Research Institutes, as well as Special Administrative Units, the National Parks System and the National Environmental Licensing Authority (ANLA) (IAvH and TNC, 2019a). The Biodiversity Information System (SIB) is a subsystem of the SIAC. The initiative emerged in 1994 as part of the process of creating the National Environmental System (SINA), and is developed and fed by the Alexander von Humboldt Biological Resources Research Institute (IAvH) (Colombia, 1994).

In addition, two free private GIS-supported tools were developed by international NGOs with the support of the government. Tremarctos-Colombia, an early warning tool that conducts a preliminary evaluation of the possible impact of a project on the environment, has been available since 2013 (IAvH and TNC, 2019a; Rodríguez-Mahecha et al., 2015). The Mapping of Alternatives for Equivalents (MaFE) is an open-source software tool that spatially identifies fragments of the same type of affected ecosystem where BO could be implemented (Colombia, MADS et al., 2012; IAvH and TNC, 2019a). Both tools are expressly mentioned in the BO manual (hereafter 'Manual' or 'BO Manual') adopted in 2012 (Colombia, MADS, 2012a).

Priority areas for BO. Following the adoption of the first BO Manual, certain Autonomous Regional Corporations (CARs), which are regional environmental authorities, developed portfolios of areas prioritized for BO. Some of the portfolios took the form of APICs (*Áreas Prioritarias para Inversión 1% y Compensación*), which are priority areas for BO promoted by ANLA and certain CARs (ANLA, 2017a, 2017b). Other CARs, to which the Manual did not apply prior to 2018, voluntarily adopted the principles set out in the Manual and developed portfolios of offsetting priority areas (Buitrago et al., 2019; CRA and PROMAC GIZ, 2015).

2.2.2 France

In France, the legal obligation for offsetting was first established in 1976. It was not until the late 2000s, however, that this obligation was really implemented in practice, with further development following the adoption of the Biodiversity Act in 2016 (France, 2016).

Sources of biogeographical information. The Biodiversity Act provided for the creation of the Biodiversity Information System (SIB), covering mainland and overseas France, with the objective to federate all available data on biodiversity from 31 public policies and make it freely accessible and reusable (Nature France, 2021). Other State information systems include the Water Information System and the Marine Information System (Nature France, 2021).

The Biodiversity Act introduced provisions according to which project owners must contribute to the National Inventory of Natural Heritage (INPN), a service of the SIB. The INPN covers both mainland France and its overseas territories. France has developed a national biodiversity search engine, OpenObs, which allows anyone to view and download species observation data (non-sensitive public data) available in the INPN (UMS PatriNat, n.d.).

Priority areas for BO. In 2021, France adopted a law on combating climate change and strengthening resilience to its effects (Climate and Resilience Act) (France, 2021). This Act provides that BO is to be implemented, as a matter of priority, within the 'preferential renaturation areas' identified in land-planning documents at inter-municipal and municipal level. These new provisions entered into force in December 2022, following the adoption of the required decree (France, 2022).

3. Results

3.1. General legal frameworks in Colombia and France

In Colombia, the obligation to offset biodiversity losses is governed by four distinct sets of regulations, as shown in Table 1. Colombia adopted the mitigation hierarchy and hence the principle of BO in 1993 through Law 99 (Colombia, 1993), later reaffirmed in Decree 1076 of 2015 (Colombia, 2015). The legislation refers to 'environmental effects and impacts', without any distinction based on biodiversity components (e.g., terrestrial, freshwater, marine ecosystems). It was not until 2012 and the adoption of the first BO Manual, however, that the principles and rules governing BO were established, but not for all biodiversity components. The Manual was updated in 2018 to broaden its scope and add the principle of additionality. The 2012 Manual applied only to environmental licensing that fell under the jurisdiction of ANLA. The updated version now covers projects (i) falling under the jurisdiction of ANLA and regional environmental authorities, in particular CARs, and (ii) regulated under various environmental permitting procedures (Colombia, MADS, 2018a, 2018b). The Manual applies, however, only to biodiversity loss in continental terrestrial natural ecosystems and secondary vegetation. It does not cover abiotic and socioeconomic aspects. The BO Manual also established predetermined BO factors (or ratios), to be applied to the baseline of the EIA conducted as part of the licensing process (Colombia, MADS, 2012a, 2018a).

Table 1: Comparative table of the legal frameworks on biodiversity offsetting in Colombia and France

	COLOMBIA	FRANCE
Main legal texts / regulations	**Law 99 of 1993** which organizes the Environmental National System (**SINA**, *Sistema Nacional Ambiental*) (Colombia, 1993) **Decree 1076 of 2015** (as amended) of the environment and sustainable development sector (Colombia, 2015) ⇨ The mitigation hierarchy applies to 'environmental effects and impacts' of projects (no distinction based on biodiversity components) 4 sets of **regulations** requiring biodiversity offsetting (Colombia, 2015; Colombia, MADS, 2022): - Environmental licensing (*licencia ambiental*) - Subtraction of forest reserve areas (*sustracción de áreas de reservas forestales*) - Single harvesting of natural forests (*aprovechamiento forestal único de bosques naturales*) - Exploitation of endangered species (*aprovechamiento de especies amenazadas*)	Law no.76-629 on **nature protection** (1976) – provisions incorporated into the Environmental Code Law no.2016-1087 for the reconquest of biodiversity, nature and landscapes (**Biodiversity Act**) (2016) (France, 2016) – provisions incorporated into the Environmental Code **Environmental Code**, article **L.110-1 II 2**°: it refers to 'damage to biodiversity', and offsetting must take into account 'the species, natural habitats and ecological functions affected' **Environmental Code**, articles **L.163-1** and onwards (first created by the Biodiversity Act) **Regulations** on environmental impact assessments, urban planning documents, Natura 2000 impact assessment, water law, protected species derogation, etc.
Guidance documents	**Biodiversity offsetting Manual** (2012) – *Manual para la asignación de compensaciones por pérdida de biodiversidad* (Colombia, MADS, 2012) **Updated Biodiversity offsetting Manual** (2018) – *Manual de Compensaciones del Componente Biótico* (Colombia, MADS, 2018) ⇨ National list of predetermined biodiversity offsets factors (ratios) for terrestrial natural ecosystems = Appendix 2 of the 2018 Manual **Proposal for a manual for marine biodiversity offsetting** (INVEMAR) (Vides et al., 2014)	Mitigation hierarchy (ERC) **doctrine** (MEDDE, 2012) National ERC **guidelines** (CGDD, 2013) Guide to define ERC measures (CGDD, 2018) Guide for a **standardized approach** to the dimensioning of biodiversity offsets (Andreadakis et al., 2021) **National method** for assessing **wetland** functions (Gayet et al., 2016a, 2016b) Guide on methods for designing offsets for **watercourses** (CGDD et al., 2018) Methodological guide for the definition of ERC measures for the marine environment (Alligand et al., 2023) **Water Development and Management Master Plans** (SDAGE, *Schéma Directeur d'Aménagement et de Gestion des Eaux*) Note: there can be guides specific to certain regions, such as the Guide on ERC measures in French Guiana (DGTM Guyane, 2020)
Principles applying to biodiversity offsetting	Mitigation hierarchy No net loss (NNL) Additionality Ecosystem equivalence Preservation and/or restoration measures, potentially accompanied by sustainable use measures	Mitigation hierarchy No net loss, and even net gain Additionality (implicitly recognized through the NNL objective (Dupont and Lucas, 2017)) Proximity (functional and geographical) Ecological equivalence

	COLOMBIA	FRANCE
		Restoration measures (restoration, remediation, rehabilitation) Obligation of results
By whom are biodiversity offsets implemented?	Project holder (directly) Operator (e.g., trusteeships, environmental funds, habitat banking, peace forests) (Colombia, MADS, 2018, 2017; Sarmiento et al., 2018)	Project holder (directly) Operator Acquisition of offsetting units in a natural offsetting site (SNC, *Site Naturel de Compensation*) (Cantuarias-Villessuzanne, 2018; Dutoit et al., 2015) (Environmental Code, articles L.163-1 II and L.163-3)

In France, the offsetting obligation was first established in 1976, with the adoption of the law on nature protection. This act introduced EIA for certain projects and required the application of the mitigation hierarchy (Combe, 2017; Longeot and Dantec, 2017). Only in the late 2000s, however, did this obligation start being implemented in practice (Semal and Guillet, 2017). The obligation appears in numerous other regulations (see Table 1). The Environment Ministry developed guidance documents on the mitigation hierarchy (ERC, *Éviter-Réduire-Compenser*, in France), as shown in Table 1. Through the Biodiversity Act, France clarified the principles that apply to BO. The legislation applies differently to France's overseas territories, which do not all have the same constitutional status. French laws and regulations apply to overseas departments/regions (DROM: French Guiana, Guadeloupe, La Réunion, Martinique and Mayotte), pursuant to article 73 of the French Constitution (France, n.d.). All BO legislative and regulatory requirements are therefore automatically applicable to DROMs. By contrast, overseas collectivities (COM: French Polynesia, Saint-Barthelemy, Saint-Martin, Saint-Pierre-et-Miquelon, and Wallis and Futuna) have their own statutory laws, as per article 74 of the French Constitution (France, n.d.). Depending on the COM, the French Environmental Code (FrEC) will be applied either totally, partially or not at all (Stahl, 2013). Finally, specific provisions are applicable to New Caledonia, the French Southern and Antarctic Lands and Clipperton Island (France, n.d.).

Colombia and France apply similar principles to BO (see Table 1). However, whereas France requires 'ecological equivalence', Colombia refers to 'ecosystem equivalence'. In addition, France also established an 'obligation of results' through the Biodiversity Act. Further, France only accepts restoration measures as BO measures, whereas in Colombia they may take the form of preservation and/or restoration measures, both being considered aspects of conservation.

3.2. Anticipation of biodiversity offsetting needs at public policy level

Biogeographical information and predetermined offset ratios. When developing its BO policy, Colombia relied on scientific information available in the country to elaborate mandatory guidance documents. It was reported that the ecosystem was considered the most relevant unit, because ecosystems had been mapped for the country. Conversely, habitats had not been defined, and information on fauna and/or flora was lacking for parts of the national territory. Colombia elaborated mandatory BO factors, included in the 2012 Manual, using the National Ecosystems Map, which was then at a scale of 1:500,000. The Manual was later revised to take into account the new National Ecosystems Map, at a scale of 1:100,000 (Colombia, MADS, 2012a, 2018a; IDEAM, 2017). Four criteria were used to calculate BO factors: (1) representativeness in the protected areas national system; (2) rarity, based on replicability and uniqueness in terms of species composition; (3) remanence (surface that remains under natural conditions); and (4) annual conversion (rate of cover loss) (Colombia, MADS, 2012a, 2018a).

In France, the legislation established the mandatory principles attached to BO. Scientific information is taken into account at the implementation stage, but there are no binding guidance documents, in particular documents related to offset ratios, with the exception of Water Development and Management Master Plans (SDAGE), which include mandatory ratios of 1:1 or 1:2 in relation to rivers and wetlands (see e.g., Agence de l'eau Loire-Bretagne and DREAL de bassin Loire-Bretagne, 2015). The rationale behind these ratios is not, however, explicit.

Legal certainty. Legal certainty conveys the idea that the law must be sufficiently certain, i.e., clear and precise with foreseeable legal implications, 'to provide those subject to legal norms with the means to regulate their own conduct and to protect against the arbitrary exercise of public power' (Fenwick and Wrbka, 2016). According to the case law of the Court of Justice of the European Union, the principle of legal certainty requires 'that rules of law be clear, precise and predictable as regards their effects', and the application of the rules of law must 'be foreseeable by those subject to them' (van Meerbeeck, 2016).

In Colombia, the mandatory BO factors led to greater legal certainty through clear rules, thus avoiding the criteria for BO being left to the discretion of the evaluator or the person designing the offsetting plan. The 2012 Manual applied only to ANLA projects. Consequently, certain CARs developed their own BO factors (CRA, 2017). However, with the broadening of the scope of the Manual in 2018, these regional factors were superseded by the national ones. In France, in the absence of general mandatory offsetting ratios, there is no legal certainty as to the extent of the offsetting that will be required for any given project. There are no homogenized ratios: they are jointly determined between the petitioner, consulting firm and evaluator, on the basis of the proposals in the licensing application (Eco-Med, n.d.).

The issue of legal certainty can also be assessed in terms of the effectiveness of BO. The French legislation provides a clear obligation of results, which entails that, should BO fail to meet their objectives, project holders will have to implement corrective measures to ensure the required results are reached. In Colombia, it is not clear from the 2018 Manual when offsetting is considered complete. It only provides that BO must be sustainable over time, and that the BO plan must include a monitoring and compliance plan (Colombia, MADS, 2018a).

Freshwater and marine BO. There is an information gap on marine and freshwater ecosystems in Colombia. The Manual only applies to continental terrestrial ecosystems with the exception of some freshwater ecosystems (e.g., floodplains), for which BO factors exist. There are no such ratios for rivers (Colombia, MADS, 2018a). The National Ecosystems Map includes information on marine ecosystems with the caveat that mapped marine ecosystems are close to the coastline and represent only 0.5% of Colombia's marine area (IDEAM, 2017). The Manual nonetheless requires the application of an offset factor of 10 (e.g., if 10 hectares of an ecosystem are impacted by a project, offsetting measures will have to cover 100 hectares) in case of impacts on certain ecosystems (e.g., mangroves, seagrasses, coral reefs), until specific regulations are adopted (Colombia, MADS, 2018a). Although the Institute of Marine and Coastal Research (INVEMAR) developed a proposal for a manual for marine BO (Vides et al., 2014), it has not been adopted through an administrative act and is therefore not binding.

In France, a national method for assessing wetland functions was elaborated (Gayet et al., 2016a, 2016b), as well as a guide on methods for designing offsets for watercourses (CGDD et al., 2018). The issue of marine BO was the subject of an official report (Avezard et al., 2017), which emphasized the lack of knowledge on the marine environment for a reliable assessment of the impacts of maritime activities. A guide on the implementation of the mitigation hierarchy for the marine environment was adopted recently (Alligand et al., 2023).

3.3. Planning of biodiversity offsets

Sources of mapped information for the elaboration of the EIA. In Colombia, the obligation to offset damage caused to biodiversity is applicable, whether or not a BO factor has been established

for the impacted ecosystem. Table 2 provides an overview of the public and private sources of mapped information that may be used by project holders when elaborating the EIA.

Table 2: Sources of mapped information and scale of relevant instruments when planning biodiversity offsets, in Colombia and France

	COLOMBIA	FRANCE
Sources of mapped information for the elaboration of Environmental Impact Assessments (non-exhaustive)	Colombian Environmental Information System (**SIAC**, ***Sistema de Información Ambiental de Colombia***) (public platform) http://www.siac.gov.co/ - Most complete and extensive official data; regularly updated by authorities - Possibility to generate official online reports (intersection of the foreseen project area with certain geographic information layers) through the SIAC portal. The reports can then be used in the environmental licensing process http://www.ideam.gov.co/web/siac/consultas-en-linea - Geoviewer, continuously updated http://sig.anla.gov.co:8083/ Private tools: - **Tremarctos-Colombia 3.0** http://200.32.81.75/repo-tremarctos-integrado/ - Mapping of Alternatives for Equivalents (**MaFE – *Mapeo de Formulas Equivalentes***) software - **BioModelos** http://biomodelos.humboldt.org.co/: allows users to consult and download geographic information on the distribution of species in the country - **BioTablero** http://biotablero.humboldt.org.co/: module being developed to provide an analysis of available biodiversity information from the SIAC and research conducted at IAvH. It provides the user with information on equivalent ecosystems, the number of hectares to be offset, available areas for offsetting and the type of offset measures (preservation, restoration, sustainable use), thus allowing the user to build an initial portfolio. (Corzo et al., 2018; IAvH and TNC, 2019)	National Inventory of Natural Heritage (**INPN, *Inventaire National du Patrimoine Naturel***) portal - Provides maps and geographical information as downloadable GIS layers (mainland and overseas France) https://inpn.mnhn.fr/telechargement/cartes-et-information-geographique Geoportal of the National Geographic Institute (**IGN**, ***Institut géographique national***) (mainland and overseas France) https://www.geoportail.gouv.fr/ - Data from the CORINE Land Cover – CLC– database (available up to 2018), a biophysical classification and inventory of land cover produced within the framework of Copernicus, the European Earth observation program. The change layer has a spatial resolution allowing the detection of changes on unit of 5 ha or more https://land.copernicus.eu/pan-european/corine-land-cover CLC covers mainland France and the overseas departments/regions (DROM: French Guiana, Guadeloupe, La Réunion, Martinique, Mayotte). However, in French Guiana, only the coastal strip is covered - Data on protected areas - Etc. **CARMEN** (*CARtographie du Ministère de l'Environnement*) https://carmen.naturefrance.fr/ - Data producers can share their data in the maps catalog
Scale of relevant documents for devising biodiversity offsetting plans	National Restoration Plan: **1:100,000** (Colombia, MADS, 2015) Offset factors map: **1:100,000** (Colombia, MADS, 2018) Regional portfolios for offsetting priority areas: **1:25,000 to 1:10,000**, depending on the regional environmental authority EIA / Offsetting plans: **1:1,000 to 1:10,000**, depending on the source documents (Colombia, MADS, 2018, 2012; CRA and PROMAC GIZ, 2017)	Maps and geographical information available on INPN portal: **1:10,000 to 1:100,000** Regional land-use planning instruments: summary map at a scale of **1:150,000** (General Code of Local Authorities, article R. 4251-3) Territorial Coherence Plans (SCoT, *Schéma de Cohérence Territoriale*) – inter-municipal level: **1:25,000 to 1:50,000** Local Urban Zoning Plan (PLU, *Plan Local d'Urbanisme*): **1:5,000**, with possibilities of finer scales for certain sectors

	For instance, in its guidelines on biodiversity offsetting, the Corporación Autónoma Regional del Atlántico (CRA), an environmental competent authority, specifies the cartographic scale depending on the size of the project intervention area (CRA and PROMAC GIZ, 2017): - Between 0,1 and 5 ha: 1:1,000 - Between 5 and 50 ha: 1:5,000 - Above 50 ha: 1:10,000 The 2012 Manual on biodiversity offsetting required that cartographic information contained in the offsetting plan (whether for conservation or restauration actions) be at a minimum scale of 1:10,000 (Colombia, MADS, 2012) The 2018 Manual does not specify a scale, but provides that the information must be at the most detailed scale possible	(Centre de Ressources TVB, n.d.) - EIA / Offsetting plans: no specification of cartographic scale in the French Environmental Code -> depends on each project. e.g., 1:5,000 for linear infrastructures

When elaborating the EIA, an environmental consultant reported that the SIAC was the primarily used platform. Certain information may nevertheless have limitations. For instance, the National Restoration Plan, expressly mentioned in the Manual, uses cartography prior to 2013 (Colombia, MADS, 2015). Since then, however, deforestation has been strong (IDEAM, 2021; Luque, 2021) with the result that many prioritized forests no longer exist and, consequently, some identified connectivity areas are no longer relevant. Further, three interviewees (from an NGO and from different environmental authorities) reported that Tremarctos and MaFE are not used so much now as they are not the most up-to-date as well as including non-official data. Moreover, MaFE focused on preservation and did not value restoration. Other private tools have since been developed by IAvH, such as BioModelos (IAvH and TNC, 2019a) (see Table 2).

In France, mapped information relevant to the EIA may be found on various portals, as shown in Table 2. A large number of typological reference systems exists, such as CORINE Land Cover –CLC– (Copernicus Programme, n.d.). Given these various typologies, France developed HABREF, the national habitats repository: it contains the correspondences between typologies and information on the presence status of each unit in the French territories (MNHN, n.d.). France also has a national taxonomic repository, TAXREF (MNHN, n.d.). In 2011, France launched the CARHAB project, whose objective is to map, by 2025, the country's natural and semi-natural terrestrial habitats (mainland and overseas territories), at a scale of 1:25,000 (MNHN, n.d.).

The situation in France is to be compared with Colombia, where an academic indicated that there are various ecosystems classifications, but none of them recognized as the official one (see also Castro Fernandez, 2013). Either one of them can thus be used as part of the EIA. This can lead to difficulties in the licensing process, as there are no guidelines on correspondences between the different classifications.

Devising BO in the licensing process. The Colombian legislation requires the petitioner to include a BO plan as part of the environmental license application (Colombia, 2015; Colombia, MADS, 2018a). Previously, the petitioner had up to one year after applying for an environmental license to submit the BO plan (Colombia, MADS, 2012b). However, one interviewee reported that offsetting plans included in the application were not necessarily very detailed and/or of good quality (e.g., no field investigations, use of recycled information), notably because of the additional costs that would be incurred before the license is granted, leading to a lack of knowledge of the proposed offsetting area.

The cartographic scale of instruments relevant to devising BO varies. The offsetting plans must be at a fine scale, which varies depending on the source document (as indicated in Table 2), ranging from 1:1,000 to 1:10,000 (e.g., CRA and PROMAC GIZ, 2017). However, where the 2012 Manual

required georeferenced maps at a minimum cartographic scale of 1:10,000 (Colombia, MADS, 2012a), the 2018 version provides that information in the BO plan must be 'at the most detailed scale possible' (Colombia, MADS, 2018a). Consequently, several interviewees indicated that the offset factors map included in the Manual should only be used as a reference point, and not as a map of equivalent ecosystems, given its coarse scale. This is important as some ecosystems (e.g., dry forest) are not reflected on the map. Similarly, project owners reportedly look for equivalence within the regional portfolios, despite regional offsetting guidelines providing a step-by-step approach (e.g., scaling down, fieldwork) (CRA and PROMAC GIZ, 2017). Furthermore, regional portfolios were said to be static and not necessarily representative of the reality of the territory, hence the necessity to use them only as guidelines. Fieldwork is therefore paramount when defining ecosystems and related offsets to assess their feasibility (see e.g., Vargas Tovar and González Peña, 2020). IAvH, with the support of other institutions, published guidance and recommendations in the form of a decision tree and via BioTablero (see Table 2), in order to determine what the most adequate offsetting measures would be (Corzo et al., 2018; IAvH and TNC, 2019a).

The French Environmental Code lists the mandatory content of the EIA (article R.122-5) but does not specify the cartographic scale of the environmental baseline. Before submitting a license application, the project owner can request from the competent authority an opinion on the scope and degree of detail of the information to be provided (FrEC, article L.122-1-2), including map scales (CGDD, 2013). In addition, according to a 1993 circular, the baseline 'must be based on field investigations and on-site measurements, and not solely on documentary and bibliographic data' (CGDD, 2013). Fieldwork (inventories) is therefore carried out. In the RCEA case study, sources of information for the EIA included (i) official platforms, such as the INPN (see Table 2), (ii) documents and bibliographies available on the territory (region and department concerned) and (iii) field investigations. The environmental permit granted by the competent authority includes, as annexes, cartographic representations at a scale of 1:5,000 (not. natural habitats and protected species, environmental concerns) or 1:25,000 for wetlands.

According to ERC guidelines, offset measures must be defined 'at the relevant territorial scale' (CGDD, 2013). In addition, the legal feasibility of the offsetting's implementation must be demonstrated: the offsetting sites must have been secured prior to the granting of the permit (CGDD, 2013). The EIA for RCEA (A79) provided eligibility forms (*fiches d'éligibilité*) for potential offsetting sites. The environmental permit granted included a map, at a scale of 1:10,000, with the localization of offsetting sites, as well as fiches describing each site with the contemplated offsetting measures and expected gains.

In case of an incomplete or insufficiently detailed EIA, the environmental permit could be challenged before the administrative court on the basis of the inadequacy of the impact study. Such challenges are not uncommon. As stated in the national ERC guidelines, 'an unsatisfactory baseline is likely to qualify the entire application file as insufficient' (CGDD, 2013). An analysis of case law showed that implementation of offset measures supposes control over the offsetting site; the mere identification of the location of the measures is not sufficient. Environmental permits have been invalidated on this basis (Lucas, 2018).

BO and land-use planning. The Colombian Manual provides that land-use planning instruments should be taken into account when identifying offsetting sites (Colombia, MADS, 2018a), with the objective to identify opportunities in the territory with which the offsetting process may be articulated (Vargas Tovar and González Peña, 2020). However, in the case of regional portfolios, their use to identify offsetting sites led to the design of multiple isolated offsets (Saenz et al., 2020). Such isolated offsets did not contribute significantly to improving ecological connectivity, let alone preserving a particular ecosystem or contributing to meeting regional conservation goals (Saenz et al., 2020). Some CARs, therefore, decided to develop regional offsetting programs in their respective jurisdictions. The objective is to pool BO, so they are implemented in an orderly and organized manner on sites prioritized by the environmental authority, provided the offsetting requirements are met at the level of each project. The CAR del Atlántico (CRA) adopted BolsaVerde Atlántico in 2020 (CRA, 2020; Saenz et al., 2020), and its initiative was followed by CORNARE, through its BancO2 program (BancO2, n.d.). Permit

holders may voluntarily comply with their offsetting obligations by adhering to the grouped offsetting plan (CRA, 2020; Saenz et al., 2020).

In France, EIAs must take into account existing land-use planning documents. Such documents exist at national, regional, inter-municipal, and municipal levels. France created the Green and Blue Infrastructure (TVB, *Trame Verte et Bleue*), an ecological network of terrestrial and aquatic ecological continuities (France, 2010, 2009). A framework document was drawn up at the national level (MTES, 2019). The TVB must then be defined in land-use planning instruments at the regional level and refined at the local level (FrEC, article L.371-3), which entails a scaling down, as shown in Table 2. Following the adoption of the Climate and Resilience Act, inter-municipal and municipal instruments must now identify 'preferential renaturation areas', where BO must be implemented as a matter of priority (FrEC, article L.163-1).

3.4. Monitoring and Control

Monitoring of offsets. The Colombian Manual provides that the BO plan must include a monitoring plan 'based on the effectiveness, efficiency and impact of the offsetting program' (Colombia, MADS, 2018a). It was reported, however, that in offsetting plans, there is usually a lack of monitoring programs and indicators to measure the effectiveness of proposed actions. Proposed indicators may be typical compliance indicators (e.g., x trees planted), but there fails to be indicators to determine whether the connectivity or condition of the ecosystem is being improved. Various initiatives address this issue. First, IAvH, together with The Nature Conservancy (TNC), has been developing SEMCA (see Table 3), a system to evaluate (through indicators) the loss or gain of biodiversity (Corzo et al., 2018; IAvH and TNC, 2019a, 2019b). Second, the regional offset programs elaborated by certain CARs aim to strengthen BO monitoring (monitoring by an operator and control of compliance by the CAR) (see e.g., Saenz et al., 2020). Third, voluntary biodiversity monitoring standards in oil blocks have been developed in the hydrocarbon sector (IAvH, n.d.).

Under French law, there is an 'obligation of results' attached to BO, which must be effective throughout the duration of the damage (FrEC, article L.163-1). In the case of a linear infrastructure such as a highway, the duration of the damage would then be the lifetime (potentially indefinite) of the road. In practice, it is common to see the environmental permit requiring the offsetting to last, e.g., for the duration of the concession. The baseline study requires the development of indicators to assess ecological losses and gains where BO are to be implemented (Andreadakis et al., 2021; CGDD, 2013). The Biodiversity Act does not, however, provide much of a framework for the obligation to monitor offset measures. The monitoring methods must be specified in the environmental permit (FrEC, article L.122-1-1). The monitoring program must include implementation and results indicators for each measure, against which the fulfillment of the obligation of results will be assessed (CGDD, 2018, 2013; MEDDE, 2012). Each indicator is constructed on a case-by-case basis, based on the proposals of the project owner and possibly supplemented by the competent authority (CGDD, 2013).

Controlling compliance. Colombian environmental authorities that granted the environmental license are in charge of ensuring that the project complies with its terms and applicable environmental regulations (Colombia, 2015). Table 3 lists the various tools at their disposal for checking compliance. The controls and oversight are notably based on the Environmental Compliance Reports (ICAs) submitted by license holders (Colombia, Ministerio del Medio Ambiente, 2005, 2002). The competent authority would then, if deemed appropriate, visit the offsetting site in order to verify the information (Suárez Castaño, 2019).

One reported challenge relates to strengthening remote sensing and geospatial information in order to have more input, such as mapped areas with high-resolution (multitemporal) images that can be used to assess compliance. Since 2020, ANLA conducts Spatial Documentation Monitoring (SDE, *Seguimiento Documental Espacial*) to establish progress (ANLA, 2021; Suárez Castaño, 2019). The claim of SDE is to verify, in a preliminary manner, a project's environmental compliance status, based on documentary and spatial information presented in the ICA, as well as information on file with ANLA and available official information (ANLA, 2021). If the ICA complies with the criteria for its establishment,

SDE is conducted by ANLA and, if there are no inconsistencies, controls will only take the form of a documentary review (Suárez Castaño, 2019). Prior to the use of SDE, ANLA was able to verify compliance for about 40% of projects under its jurisdiction, whereas a 100% follow-up is now projected (Suárez Castaño, 2019).

Table 3 presents various tools for compliance-checking in France. The competent authority controls compliance notably on the basis of the monitoring reports submitted by project owners. When a monitoring body is set up, it may make any observation or recommendation in order to ensure the effective implementation of ERC measures (FrEC, article R.125-37).

Project owners must contribute to the INPN. They must enter the raw biodiversity data they have acquired during impact studies, as well as during preliminary assessment or impact monitoring studies (FrEC, article L.411-1-A I) (DREAL PACA, 2020). Information from the national geographic information system, GéoMCE, is accessible to the public. The expected benefits of GéoMCE are, among others: to avoid the superimposition of several identical offset measures on the same site or avoid offsetting sites being subject to new developments; and improve implementation of the measures, as well as their control and monitoring (DRIEAT Île-de-France, 2020; Ego, 2020). Prior to GéoMCE, some regional services had elaborated their own cartographic tool to follow-up offset measures (Cerema, 2016; DREAL Normandie, 2016).

Table 3: Monitoring and control of biodiversity offsets in Colombia and France: tools for monitoring biodiversity offsets and controlling compliance

	COLOMBIA	FRANCE
Monitoring of biodiversity offsets	**Monitoring plan** to be included in the biodiversity offsetting plan **SEMCA** (***Sistema de Evaluación y Monitoreo de las Compensaciones Ambientales***) - System for evaluating and monitoring environmental offsets at various scales (project, regional, national) in order to enable informed decision-making - Focus on terrestrial ecosystems - Operation through automatic capture of monitoring data fed in geodatabases by companies subject to offset regulations - Thus far, information on offsets only from ANLA, the national environmental authority - Proposes and calculates 14 indicators, related to species composition, ecosystem structure/landscape context, and functions => to evaluate the loss or gain of biodiversity, as an approach to the principle of no net loss (Corzo et al., 2018; IAvH and TNC, 2019)	**Methods** for monitoring offsetting measures specified in the **environmental permit**, on the basis of the proposal in the environmental impact assessment. The monitoring program included in the EIA must include implementation indicators (effectiveness) and results indicators (efficiency).
Tools for compliance-checking	Registration of approved offsetting sites in the **REAA** (***Registro de Ecosistemas y Áreas Ambientales***) – part of the SIAC geoviewer (Colombia, MADS, 2018) Environmental Compliance Reports (**ICA,** ***Informe de Cumplimiento Ambiental***) submitted by license	**Monitoring reports** submitted by project owners to the competent authority – periodicity determined in the license (French Environmental Code, article R.122-3). These reports must cover both the implementation of the ERC measures and their effects on the environment

	holders to the competent environmental authority (Colombia, Ministerio del Medio Ambiente, 2005, 2002) - On a quarterly, semi-annual or annual basis for licenses granted by ANLA, depending on what the administrative act provides (Colombia, MADS, 2019) Periodical reporting of environmental compliance by license holders through the Single Environmental Register (**RUA, *Registro Único Ambiental***) - Environmental authorities carry out their environmental compliance assessment using the RUA - The information contained in the RUA need not be incorporated in the ICA Manual for Environmental Oversight of Projects (***Manual de Seguimiento Ambiental de Proyectos***) issued by the MADS (Colombia, 2015; Colombia, Ministerio del Medio Ambiente, 2002) - Environmental authorities must apply the compliance criteria defined in this manual Spatial Documentation Monitoring (**SDE, *Seguimiento Documental Espacial***) (ANLA)	(i.e., their results) (French Environmental Code, article R.122-13). ***Ad-hoc* monitoring bodies** for linear infrastructure projects (French Environmental Code, articles L.125-8) - Composition: public administrations concerned, economic players, representatives of chambers of agriculture, local authorities, environmental protection associations and, where appropriate, representatives of consumers and users, as well as environmental protection experts - The costs of any study or expertise mission that such a body would require fall on the operator of the infrastructure (French Environmental Code, articles L.125-8 and R.125-39). **GéoMCE** is the national geographic information system (French Environmental Code, article L.163-5). It includes cartographic data relating to offsets submitted to administrative authorities by project owners - Access to GéoMCE is reserved to evaluation and control services - Information from GéoMCE is accessible to the public through the IGN geoportal

4. Discussion

Quantifying biodiversity losses is a prerequisite for BO, especially in the framework of NNL policies (Bull and Strange, 2018). Spatialized ecological information thus plays an important role. However, the comprehensiveness of said information differs, notably –but not only– in the case of megadiverse countries. It raises the question of whether highly accurate and detailed information is needed for robust BO policies, or whether a more pragmatic approach is preferable, based on the extent of the available and validated information confronted with the requirements set out in the regulations. Through a comparative analysis of BO policies in Colombia and France, we analyzed the role of spatialized ecological data in such policies, touching upon geographical, ecological and legal aspects.

If ecological and conservation outcomes are the objectives of the mitigation hierarchy and NNL, they stem from political circles rather than a scientific discipline (Bigard et al., 2020; Calvet et al., 2015). Our research shows, however, that scientific data play a role in the elaboration of BO policies and not only in their implementation. In Colombia, spatialized ecological data are used when elaborating mandatory requirements for BO. Conversely, the approach adopted in France entails that spatialized ecological information is used only on a case-by-case basis for purposes of implementing BO regulations. We illustrate this point hereafter.

4.1. Predetermined offset ratios

Ratios are multipliers that constitute a way of dealing with uncertainty in relation to the outcomes of BO (Gonçalves et al., 2015; Maron et al., 2012; Moilanen et al., 2009; Quétier and Lavorel, 2011). However, as noted by Maron et al. (2012), there is not always clear justification for their value. Colombia has established mandatory predetermined ratios at the national level, based on available scientific knowledge. In France, the only mandatory ratios are those imposed in water management instruments.

However, these range from 1:1 to 1:2 and do not appear to have any scientific basis. There is no shortage of scientific literature demonstrating the often lack of success of BO, in particular restoration offsets (Lindenmayer et al., 2017; Maron et al., 2012; May et al., 2017; Moilanen and Kotiaho, 2018), a ratio of 1:1 being unlikely to deliver an outcome close to NNL (Moilanen and Kotiaho, 2018). Consequently, a ratio of 1:1 for certain restoration offsets in France does not reflect uncertainty in the outcome and, therefore, BO appears unlikely to be fully effective. On the other hand, applying a very high ratio (e.g., 1:10) would be difficult for several reasons. First, France does not authorize preservation measures as BO. Yet, a project owner is more likely to meet an offset ratio of 1:10 with preservation rather than restoration measures. Second, it is necessary to take into account space finiteness, which encompasses the idea that the reduction of natural surfaces reduces the possibilities of BO (Bezombes and Regnery, 2020; Ollivier et al., 2020). Colombia has twice the surface area of France, but its population density is less than half that of France (DANE, 2019; Insee, 2022a, 2022b). The issue of space finiteness may not therefore be apprehended in the same way in both countries.

Furthermore, it can be considered that ratios defined at the project level will be more in line with the reality of the territory and enable to go beyond mere surface ratios (Truchon et al., 2020).

4.2. Balancing legal certainty with policy effectiveness

Legal certainty. The principle of legal certainty requires clear rules. We show that predetermined BO ratios are a source of legal certainty, by allowing project owners to anticipate the extent of the offsetting that would be required and by eliminating the discretionary appreciation of the evaluator in the licensing process. Moreover, where there are knowledge gaps, such as for marine ecosystems, the imposition of a high ratio (1:10 in Colombia for coral reefs, seagrasses, etc.) may be viewed as an application of the precautionary principle. Legal certainty is, however, not limited to predetermined offset ratios. It may also be argued that the French obligation of results regarding BO outcomes also contribute to legal certainty: project holders will have to take corrective measures if the obligation is not met. By contrast, the Colombian legislation does not clearly establish when the offsetting is considered complete. There is nevertheless a necessity to balance the need for legal certainty with that of policy effectiveness, in particular in terms of contribution to NNL.

Policy effectiveness. Failure of offsetting can be a result of inappropriate design of the BO, but may also result from failure in implementation (Moilanen and Kotiaho, 2018). Our research highlights various issues to be taken into account.

Mapping. Mapped information may be too static and not necessarily up-to-date (e.g., Tremarctos-Colombia and MaFE), emphasizing the need for a public portal which centralizes environmental data and information and is regularly updated, such as the SIAC in Colombia. Mapping is nonetheless essential to keep memory and track BO, and thus avoid projects being later developed on BO sites. Mapping is also an important tool in integrating landscape ecology in relation to BO. There is a growing number of studies that illustrate the need for a strategic approach to avoidance and BO, through more strategic planning at the landscape level (Bigard et al., 2020). Landscape-level conservation planning was thus used to create conservation portfolios in Colombia, which are meant to help guide the application of the mitigation hierarchy (Saenz et al., 2013a, 2013b). We found that an important problem arises when the guidance purpose of conservation portfolios and other mapped information is diverted. Such portfolios and information are used to identify equivalent areas, without fieldwork being performed.

Isolated offsets. Another issue is that BO may result in isolated offsets (Gelot and Bigard, 2021; Saenz et al., 2020), lacking coherence from a conservation perspective. Certain CARs in Colombia have therefore developed regional offset programs as an offset-pooling mechanism tailored to the needs of the territory. The benefits of pooling and anticipating BO, by integrating landscape connectivity into the mitigation hierarchy, has recently been demonstrated (Bergès et al., 2020; Tarabon et al., 2021). In France, many authors consider that offset measures call for an articulation with land-use planning instruments and integration with the TVB (Bigard and Leroy, 2020; Dupont, 2017; Longeot and Dantec, 2017; Lucas, 2017). It is too early to assess the impacts and effects of the regional offset programs in

Colombia, and the new legislative provisions in France for the implementation of BO in renaturation areas identified in land-planning instruments. However, there is reason to be hopeful that they would contribute to rendering BO more effective, by integrating landscape strategic planning.

Quality of offsetting plans. Further, we have found that, in Colombia, BO plans in licensing applications are not necessarily of good quality (a more detailed plan is elaborated after the license is granted). Our results suggest that this may lead to a lack of robustness of the proposed BO as their feasibility (land tenure, current land use, etc.) is not assessed. The license is hence granted before sufficient information is available on whether the proposed BO could be effectively –and efficiently– implemented. Much more detail is required in permit applications in France, in terms of proposed BO measures, monitoring and control (e.g., the environmental permit granted in the RCEA case study includes detailed information on the secured BO sites). Litigation before French courts is likely to play a key role in ensuring that EIAs are extensive and detailed.

4.3. Ecological vs ecosystem equivalence: consequences on monitoring and compliance

In Colombia, the need to reinforce monitoring is an important issue. In addition to regional offset programs, this has led to the development of web applications such as SEMCA, which proposes a set of indicators that relate to species composition, ecosystem structure and function. They appear in coherence with the 'ecosystem equivalence' requirement adopted in Colombia. Conversely, indicators used in France tend to reflect the focus on species and habitats, as part of the 'ecological equivalence' requirement (Bezombes et al., 2018). Many scientific articles address ecological equivalence and related metrics (Boileau et al., 2022; Carreras Gamarra et al., 2018; Quétier and Lavorel, 2011). Our research nevertheless suggests that the legal distinction between ecosystem equivalence and ecological equivalence may have consequences in terms of the metrics used.

Additionally, our research suggests increasing reliance on remote sensing, which may nevertheless be impacted by whether the objective is ecosystem equivalence (Colombia) or ecological equivalence (France). The integration of remote sensing for assessing ecological equivalence has been recently analyzed (Boileau et al., 2022). An identified limitation is the replacement of fieldwork with remote analysis, while a positive aspect is the possibility to consider the entire landscape (Boileau et al., 2022). Although Boileau et al. (2022) indicate that remote sensing is not yet used in offsetting practice, we show that it is used in Colombia. The SDE mechanism established by ANLA is used to assess compliance with environmental permits, enabling ANLA to significantly increase the percentage of projects for which compliance may be effectively assessed. This mechanism appears coherent with the ecosystem approach adopted in Colombia. Remote sensing is indeed the basis of most land cover maps, in particular to generate maps of terrestrial ecosystems (Geller et al., 2017). According to Alleaume et al. (2013), finer resolution does not necessarily yield more accurate results. However, remote sensing, through an SDE-like mechanism, could not be the only tool used in France to assess compliance, as the main focus of BO is not on the ecosystem, but on fauna and flora (notably threatened species and their habitats). Fieldwork, potentially combined with remote sensing, is still indispensable, especially in the light of the French 'obligation of results'. Remote sensing to map where some species live is generally possible only for large organisms or populations of small organisms (Geller et al., 2017). Indirect remote sensing of biodiversity is a possibility (e.g., estimating potential species by crossing information about habitat requirements with maps of land cover) (Turner et al., 2003). However, it would not be sufficient to ensure compliance with the obligation of results, where the presence of fauna and/or flora species concerned by BO measures must be established with certainty.

4.4. International perspective

Offsetting schemes are country-dependent, the local context and regulatory requirements playing an important role (Carreras Gamarra et al., 2018; McKenney and Kiesecker, 2010). However, the approaches that some countries adopt can feed into the development of policies in other countries. Our findings could therefore be useful for studies about other countries.

Examples of countries that could be worth exploring, out of the +100 to have adopted BO policies (GIBOP, 2019), include Peru and South Africa. In Peru, ecological data was used to develop mandatory equivalence assessment methods per type of ecosystems (e.g., high Andean ecosystems, *bofedales*). Biodiversity losses and gains are assessed against benchmark values defined in the guidance document, based on existing spatialized ecological data (Peru, MINAM, 2016). In South Africa, a draft National Biodiversity Offset Guideline was published in 2022 (Center for Environmental Rights, 2022; South Africa, 2021), which focuses on ecosystems as the primary unit to devise offset requirements. One of the objectives of BO is to 'contribute to the expansion of South Africa's protected area network', with a focus on identified biodiversity areas (identified as such in a spatial biodiversity plan) (South Africa, 2021). The draft guideline provides a standard method to size BO, based on the calculation of an ecosystem-based offset ratio (the highest possible ratio is 1:30) (South Africa, 2021).

5. Conclusion

BO is directly linked to the objective of NNL. It requires to have the most accurate information possible at the finest spatial and temporal resolution. This information must, however, be adapted to the requirements established by national regulations. The way in which spatialized ecological information is used in the framework of BO national policies may vary, and it is possible to question the level of detail and precision needed to implement adequate offset measures. We compared offsetting policies in Colombia and France, and analyzed the availability and use of such information for the elaboration and implementation of such policies.

We have shown that the use of spatialized ecological data is not limited to the implementation of BO policies (France) but may also be used to develop such policies (Colombia). A case in point is the elaboration of mandatory predetermined BO ratios, which are based on the available scientific data in Colombia, but do not appear to have any scientific ground for those adopted in water management instruments in France. However, although a ratio of 1:1 is unlikely to contribute to NNL, where the multiplier is very high the feasibility of the offsetting will likely depend on whether preservation, and not only restoration, measures are allowed, but also on space finiteness.

There is nevertheless a necessity to balance the need for legal certainty with that of policy effectiveness, in particular in terms of contribution to NNL. Mapped information is essential, But regular updates are necessary to ensure the latest official information is available to users, through notably a public portal that centralizes environmental data. Further, where land-use planning instruments have been elaborated specifically for BO at the landscape level, an important caveat is to ensure that the guidance purpose of these documents is not diverted and used to replace fieldwork where field investigations are paramount.

Our study has also shown that, although the licensing application must include offsetting plans, these are not very detailed in Colombia, whereas a high degree of precision is required in France. In the first case, it suggests that the feasibility of BO is not thoroughly assessed, NNL appearing to be a distant objective. In the second case, the level of detail may be a result of recent case law where permits have been annulled because of a lack of sufficient information in the EIAs.

Finally, we have shown that the geographical characteristics and legal framework of a country are an important determinant in how BO are elaborated and implemented. Nonetheless, differing conceptions could feed into one another. For instance, the Colombian approach could be appropriate in French Guiana, as their geographical particularities (and ecosystems) have more similarities than French Guiana with mainland France. Further, although the scientific literature tends to refer only to 'ecological equivalence' in relation to offsetting, national legislations may adopt different stands. In this regard, we consider that future research could explore the practical consequences of the distinction between 'ecosystem equivalence', adopted in Colombia, and 'ecological equivalence' required under French law. Such distinction appears to have possible impacts on the set of indicators used to monitor BO, as well as the methods to assess compliance (e.g., remote sensing).

Given over 100 countries have adopted BO policies, our findings could be useful for studies about other countries. How countries other than Colombia use spatialized ecological data for BO policies would deserve to be explored further. We mention Peru and South Africa as examples.

Appendix: Supplementary material

Appendix A. Interview guidelines for expert interviews in Colombia

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