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# A Framework for Implementing and Valuing Biodiversity Offsets in Colombia: A Landscape Scale Perspective

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**Abstract:** Biodiversity offsets provide a mechanism for maintaining or enhancing environmental values in situations where development is sought, despite negative environmental impacts. They seek to ensure that unavoidable deleterious environmental impacts of development are balanced by environmental gains. When onsite impacts warrant the use of offsets there is often little attention paid to make sure that the location of offset sites provides the greatest conservation benefit, ensuring they are consistent with landscape level conservation goals. In most offset frameworks it is difficult for developers to proactively know the offset requirements they will need to implement. Here we propose a framework to address these needs. We propose a series of rules for selecting offset sites that meet the conservation needs of potentially impacted biological targets. We then discuss an accounting approach that seeks to support offset ratio determinations based on a structured and transparent approach. To demonstrate the approach, we present a framework developed in partnership with the Colombian Ministry of Environment and Sustainable Development to reform existing mitigation regulatory processes.

**Keywords:** biodiversity offsets; compensatory mitigation; landscape scale mitigation; mitigation hierarchy; sustainable development goals

## 1. Introduction

Biodiversity offsets are one important tool for maintaining or enhancing environmental values *in situ*ations where development is sought despite negative environmental impacts [1–3]. Offsets are intended as an option for addressing environmental impacts of development after efforts have been undertaken to minimize impacts on-site through application of the other steps of the mitigation hierarchy: avoid, minimize, and restore [4]. They seek to ensure that inevitable negative environmental impacts of development are balanced by environmental gains. Offset policies for environmental purposes have gained attention in recent years [3,5,6]. Although the use of offset activity remains relatively limited, offsets are increasingly employed to achieve environmental benefits, including pollution control, mitigation of wetland losses, and protection of endangered species [1,3]. Offset activity is most active for wetlands in the United States (USA), where methods and programs have been under development for the past two decades. Wetland offsets in the USA have increased dramatically, from 6000 ha/year in the early 1990s, increasing to an average of over 16,000 ha/year since 1995 [7]. Countries including the United States, Australia, Brazil, Colombia, South Africa, Netherlands, Sweden and the United Kingdom have established or are developing offset policies to protect both species and ecosystems. The cumulative influence of advancing these regulatory and voluntary policies is large and growing [8,9], but interest in offsets is not restricted to governments. Multinational corporations such as Rio Tinto [10] aim to have a "net positive impact on biodiversity" as part of their biodiversity strategy, and offsets will play an important role in meeting this objective.

Offsets offer potential benefits for industry, government and conservation groups alike [1–3]. Benefits for industry include a higher likelihood that permission would be granted from regulators for new operations, greater societal support for development projects, and the opportunity to more effectively manage environmental risks. Offsets provide governmental regulators with the opportunity to encourage companies to make significant contributions to conservation, particularly in situations where legislation does not require mandatory offsets. Conservation organizations can use biodiversity offsets to move beyond piecemeal mitigation, securing larger scale, more effective conservation projects. Offsets can also be a mechanism to ensure that regional conservation goals are integrated into governmental and business planning. When offsets are utilized, the objective is to ensure that offsets are ecologically equivalent to impacts, are consistent with goals of landscape conservation planning and will persist at least as long as onsite impacts, resulting in net neutral or positive ecological outcomes [2,3]. The aim is to identify offsets that will deliver the greatest contribution toward ecological gains and provide "additionality", an offset's new contribution to conservation, additional to existing values. Offsets that restore degraded ecosystems provide a new contribution to conservation over time as the offset reaches maturity. Offsets that preserve habitat also deliver conservation value when taking into account real-world conditions and threats, those offsets protect against an expected background rate of loss. For example, protecting an important habitat that was experiencing conversion delivers a new contribution to conservation by preventing loss.

While offsets have great potential as a conservation tool, their establishment requires overcoming a number of conceptual and methodological hurdles [3–11]. When onsite impacts warrant the use of offsets there is often little attention paid to make certain that the selection of offset sites provides the greatest conservation benefit, ensuring they are consistent with landscape level conservation goals [12]. In most offset frameworks it is difficult for developers to proactively know the offset requirements they will need to implement. Current accounting approaches are generally too detailed to be applied proactively making it difficult to identify situation where offset requirements would be relatively high and might incentivize developers to avoid impacts instead. They are either too inflexible to address the ecological context for impacts and offsets, or too open to subjective judgment.

## 2. Colombia: A Case Study in Offset Design

Colombia is one of the world's "megadiverse" countries, hosting close to 14% of the planet's biodiversity [13–15]. Colombia possesses a rich complexity of ecological, climatic, biological and ecosystem components. The country has ~41,000 vascular plants, ~479 mammal species, ~1801 bird species, ~763 amphibian species and ~506 reptile species [16]. Colombia also ranks as one of the world's richest countries in aquatic resources, which is partly explained by the fact that the country's large watersheds feed into the four massive sub-continental basins of the Amazon, the Orinoquía, the Magdalena and the Cauca. The largest source of biological diversity is found in the Andean ecosystem, characterized by a significant variety of endemic species, followed by the Amazon rainforest and the sub-humid ecosystem in the Choćo bio-geographical area. This varied richness presents Colombia with a unique opportunity for the implementation of sustainable development initiatives. However, a considerable part of these natural ecosystems have been transformed for agriculture and cattle ranching, primarily in the Andean and Caribbean regions. It has been estimated that almost 95% of the country's dry forests have been reduced from their original cover.

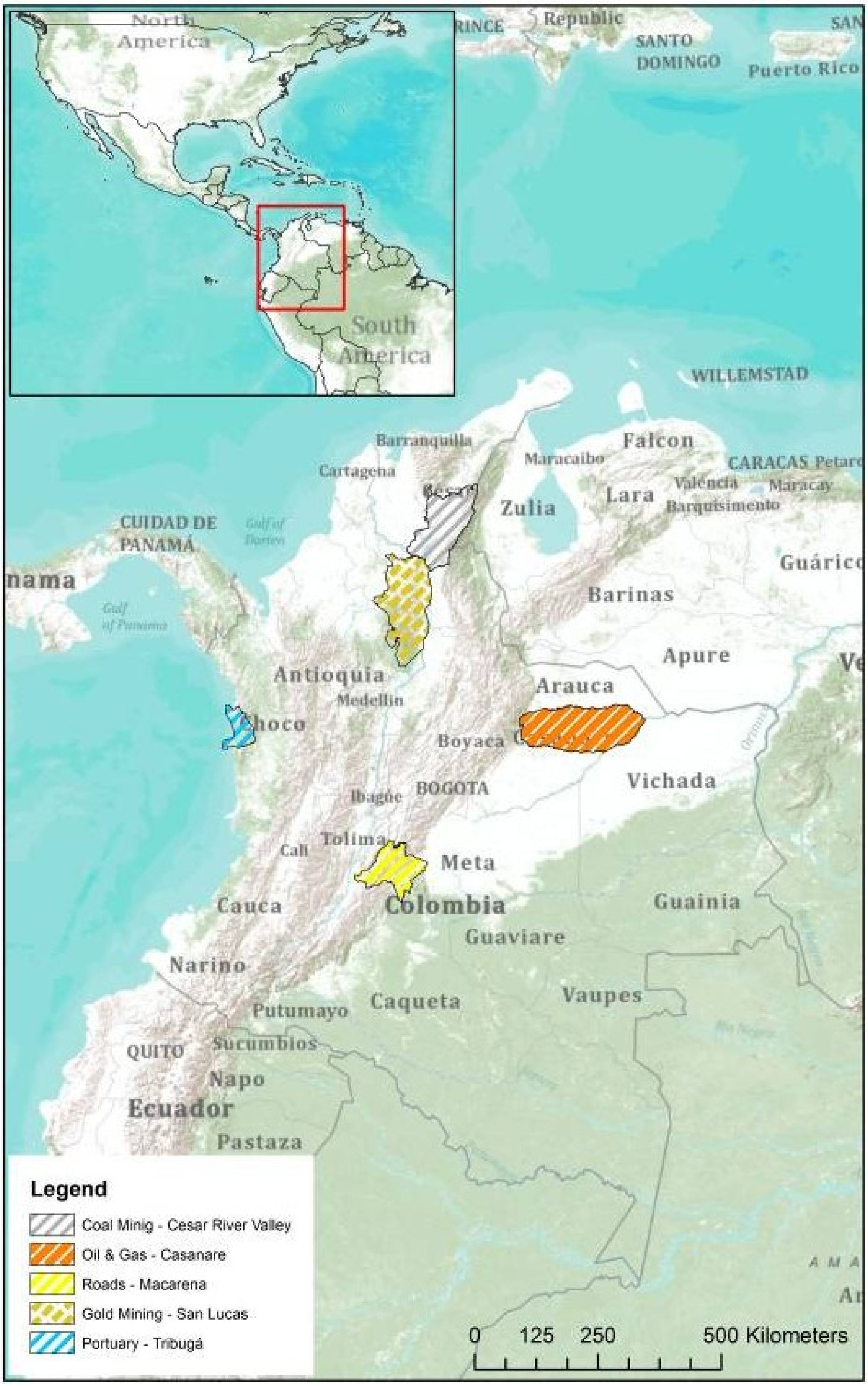
Like many Latin American countries Colombia's economy is expected to grow with a rapid pace of development driven by: agriculture, mining, energy, infrastructure, and housing [17]. Conservation of the biological diversity in the country is in question, in part, because the Colombian government has authorized exploration and development in ~24 million hectares of the ~79 million hectares still remaining in natural land cover [18]. The increase in development forecasted for Colombia though may yet be compatible with biodiversity if proper consideration is given to mitigation to ensure that offsets compensate for impacts which may cause habitat loss and fragmentation [18,19]. Past mitigation decisions in Colombia reflect the subjective nature in which offsets have been used. For example, when offsets have been utilized they only required that offsets provide security for a 3-year period [18], clearly inadequate to compensate for most development impacts. Little attention too has been paid to ensure that the offset sites are selected with the intention of accounting for the ecological equivalency of the impact sites or that offset actions would provide value equal to that lost as a result of development. For example impacts from mining in low elevation dry forest systems have directed offset funding towards the planting of fruit trees in high elevation forest headwaters [18]. In addition the location of offset sites is often not informed by the landscape or watershed priorities [18]. Using a conservation portfolio that was developed through landscape level planning could identify areas where development impacts could be compensated for through the use of offsets [12,20,21].

Recognizing the need to improve its existing regulatory framework for mitigation, the Colombian government asked The Nature Conservancy in 2008 to help develop an approach to guide better decision making around siting and mitigation of future development [18]. While the Colombian Ministry of Environment and Sustainable Development (MADS) sought to improve the current mitigation framework there were constraints to the changes that could be made. For example the current regulatory process caps the maximum offset to impact ratio at 10 to 1 and any changes we recommended were limited by this cap. Here, we propose a framework to address the current deficiencies in offset design and accounting. Our proposed framework for offset site selection includes using a series of rules developed for selecting offset sites that meet the conservation needs of potentially impacted biological targets (*i.e.*, size, condition, landscape context). We then discuss an accounting approach that seeks to support ratio determinations based on a structured and transparent approach. We focus on five landscapes where development is projected to increase over coming years. This includes the expansion of coal mining in the Cesar River Valley, gold mining in Sur de Bolivar, highway development in Macarena, oil and gas development in Casanare and expansion of a sea port in Bahia Tribuga (Figure 1 and Table 1). Finally, we provide an example from the Cesar River Valley to illustrate the implementation of this framework.

**Table 1.** Pilot project site descriptions.

| Pilot Project | Total Area (ha) | Conservation Portfolio Area (ha) | Number of Portfolio Sites | Future Potential Development (ha) | Area within Conservation Portfolio Overlapping with Future Potential Development (ha) | Area of Ecological Systems Impacted by Future Potential Development (ha) |
|---|---|---|---|---|---|---|
| Cold Mining in Cesar | 1,278,600 | 490,327 | 24 | 72,369 | 3,817 | 2,518 |
| Gold Mining in Sur de Bolivar | 1,662,421 | 959,625 | 9 | 701,382 | 315,497 | 64,200 |
| Port in Bahia Tribuga Choco | 343,878 | 166,007 | 17 | 1,639 | 1,300 | 11 |
| Macarena Road in Meta | 809,993 | 325,107 | 24 | 349 | 103 | 109 |
| Oil and Gas in Casanare | 1,871,326 | 715,108 | 18 | 687,367 | 186,758 | 242,192 |

**Figure 1.** Location of development by design pilot projects within Colombia.




## 3. Selecting Suitable Offset Sites

Our objective with this framework is to ensure that the use of offsets is ecologically equivalent to impacts and will persist at least as long as onsite impacts. To ensure offset selection results in conservation outcomes consistent with landscape-level conservation goals we seek to use landscape-level planning to guide to offset site selection in our 5 pilot landscapes (Figure 1) [21]. We utilized existing landscape conservation assessments that were available for all of the five pilot project areas and used biological target lists generated from these analyses as the focus of our offset analyses [22–28]. Landscape-level conservation planning is the process of locating, configuring and maintaining areas that are managed to maintain the viability of biodiversity and other natural features [29,30]. A conservation portfolio, the end product of conservation planning efforts, is a select set of areas that represents the full distribution and diversity of these systems [31]. The results of landscape-level conservation plans can be used to guide the application of the mitigation hierarchy [20,32]. Where plans have already been completed, proposed developments can be mapped and assessed relative to the conservation portfolio. After appropriate decisions are made regarding which impacts should be avoided or minimized [21], the portfolio can be used to guide the selection of offset sites. Impacts would be quantified based on impacts to biological targets identified in the landscape level plan and areas most similar to the impact site could be selected as offset sites [20].

The landscape conservation plans that we adapted selected a set of focal targets using the "coarse-filter/fine-filter" approach consistent with The Nature Conservancy's Ecoregional Planning approach [33]. *Coarse filter* generally refers to "ecosystems"; in a more practical sense, it refers to mapped units of vegetation. The basic idea is that conserving a sample of each distinct vegetation type, in sufficient abundance and distribution, is an efficient way to conserve the majority of biological phenomena in the target area [33]. *Fine filter* generally refers to individual species, with specific habitat requirements or environmental relationships that are not adequately captured by the coarse filters [33].

For our offset case studies, we adapted the list of biodiversity features using the coarse filter, fine filter criteria [22–26]. These biological features were defined using a combination of point survey data, vegetation cover estimations and predictive model estimations to represent the spatial distribution of selected targets. For all projects we utilized the national landcover data set with maps produced at the 1:500,000 scale [34]. At the pilot landscape level this was refined to capture the location and delineation of each ecosystem unit with a remotely sensed exercise focused on each of the five pilot areas [22–28]. For identification of ecosystems within each pilot landscape, we relied on a 1:100,000 scale land cover map generate with imagery from remote sensing sensors ASTER, and ETM + Landsat, taken between 2000 and 2008. The maps were obtained through the Landsat and TerraLook collections held in the USGS archive by using USGS Global Visualization Viewer -GLOVIS-, and remote sensing sensor Cbers2, obtained from Instituto Nacional de Pesquisas Espaciais (INPE) archive [22–26]. The remotely sensed data along with the national landcover map were used to generate a preliminary map of ecosystems units [22–26]. Where available, we also utilized ecoregional assessments conducted by Galindo *et al.* [27,28].

To select fine filter species targets we started with base species maps produced by NatureServe [35]. We also reviewed ecoregional assessments that were available for all of the five project areas and used species lists generated from these analyses [22–26]. Where existing species models were not available we settled on a simple approach of using deductive models by identifying the habitat preferences for each species creating binary models of suitable habitat through a series of GIS overlays based on: slope, aspect, topographic roughness, elevation (DEM), and vegetation type. The resulting species distribution models were subsequently validated by local experts [21]. Details on targets used in each case study can be found in Appendix 1.

In order to assess the relative value of patches of ecological systems impacted by development relative to potential offset sites we calculated several landscape level metrics: the patch size of the ecological system, the amount of surrounding habitat remaining in natural vegetation cover, species richness of patches, and potential for future disturbance. These metrics were calculated for every patch of every ecological system found within the portfolio of conservation sites [21–26]. To select potential offset sites for impacts associated with development in our pilot landscapes, we developed the MaFE (mapping alternatives for equivalents) tool in Model Builder in ArcGIS 9.0, which identified patches of the same type of ecological system and compared them as a function of the landscape level metrics mentioned above [36]. With this tool, offsets would be directed to patches of the same ecological system but only to sites with patches of equal or greater landscape level metric scores. This would ensure that offsets are directed to areas consistent with landscape-level conservation goals, since they would be restricted to areas within the conservation portfolio and would be directed to areas of the highest quality based on the landscape level metrics.

We choose to utilize available species data to supplement the selection of ecological systems. Once species models were compiled we summarized the species richness of these select target species across the pilot landscapes [35]. To facilitate the relative comparison of the species richness of different areas we placed the areas into categories based on Natural Jenks [37]. Natural Jenks break provides a method in which the loss of information is minimized [37]. Areas with the highest species richness were given priority since this would maximize the conservation benefit for a majority of the species. Details on the species richness categories used in each case study can be found in Appendix 1.

## 4. Identifying Offset Replacement Ratios

Offset benefits are often estimated using mitigation replacement ratios which establish the number of credit units that must be debited from an offset to compensate or replace one unit of loss at the project site. Replacement ratios are often determined by predefined ratios, such as those based on the type of conservation action (e.g., 1:1 ratio for restoration, 5:1 for preservation) or are subjective determinations formed at the discretion of regulatory authorities after multiple considerations such as proposed conservation actions and risk factors are accounted for [3]. Rarely do these consider landscape-level features that would ensure values delivered by offset action are consistent with broader conservation goals. Since most focus on site-level features related to the characteristics of the impact and/or offset site it is difficult to proactively calculate these metrics and it has been difficult for developers to build information about potential mitigation requirements into decisions on the feasibility of investing in a development site. Here, we outline an approach that utilizes readily available landscape-level data to proactively calculate a replacement ratio that will ensure offsets are consistent with landscape-level conservation goals. We based the ratio determination on an assessment of the amount of the ecological system currently within protected areas, the national-level and local-level rarity of the ecological system, the percentage of the ecological system that remains relative to its historic distribution and the rate of loss for the ecological system calculated over the previous 6 years. These estimates were based on the average of each patch of each ecological system within the entire country. Scores for all ecological systems were compiled and categorized based on natural breaks to one of five categories for each metric and each individual metric score was combined to create a final replacement ratio (Tables 2 and 3).

**Table 2.** Overview of offset ratio calculation. We based the ratio determination on an assessment of the amount of the ecological system currently within protected areas (Representation), the national-level and local-level rarity of the ecological system (Rarity), the percentage of the ecological system that remains relative to its historic distribution (Remanence) and the rate of loss for the ecological system calculated over the previous 6 years (Rate of Loss).

| **Representation** | **Compensation Factor** | **Remanence** | **Compensation Factor** | **Rarity** | | | | | **Rate of Loss** | **Compensation Factor** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Biome** | **Compensation subfactor** | **Ecological systems** | **Compensation subfactor** | **Compensation factor** | | |
| **Omission** (No representation) | 3 | Very high (≥90) (analysis units have an area of natural ecosystems greater than 90%) | 3 | Very rare (<0.1%) | 2 | Very rare (<5%) | 2 | The final compensation factor for each ecological system is the highest subfactor of the two components (biome or ecological system) | Very high (>0.5% ) | 2 |
| **Very high failure** (Achieves up to 1% of conservation goal) | 2.5 | High (90%–70%) (analysis units have an area of natural ecosystems between 90% and 70%) | 2 | Rare (0.1%–0.2%) | 1.75 | Rare (5%–15%) | 1.75 | | High (0.5%–0.2%) | 1.75 |

**Table 2.** *Cont.*

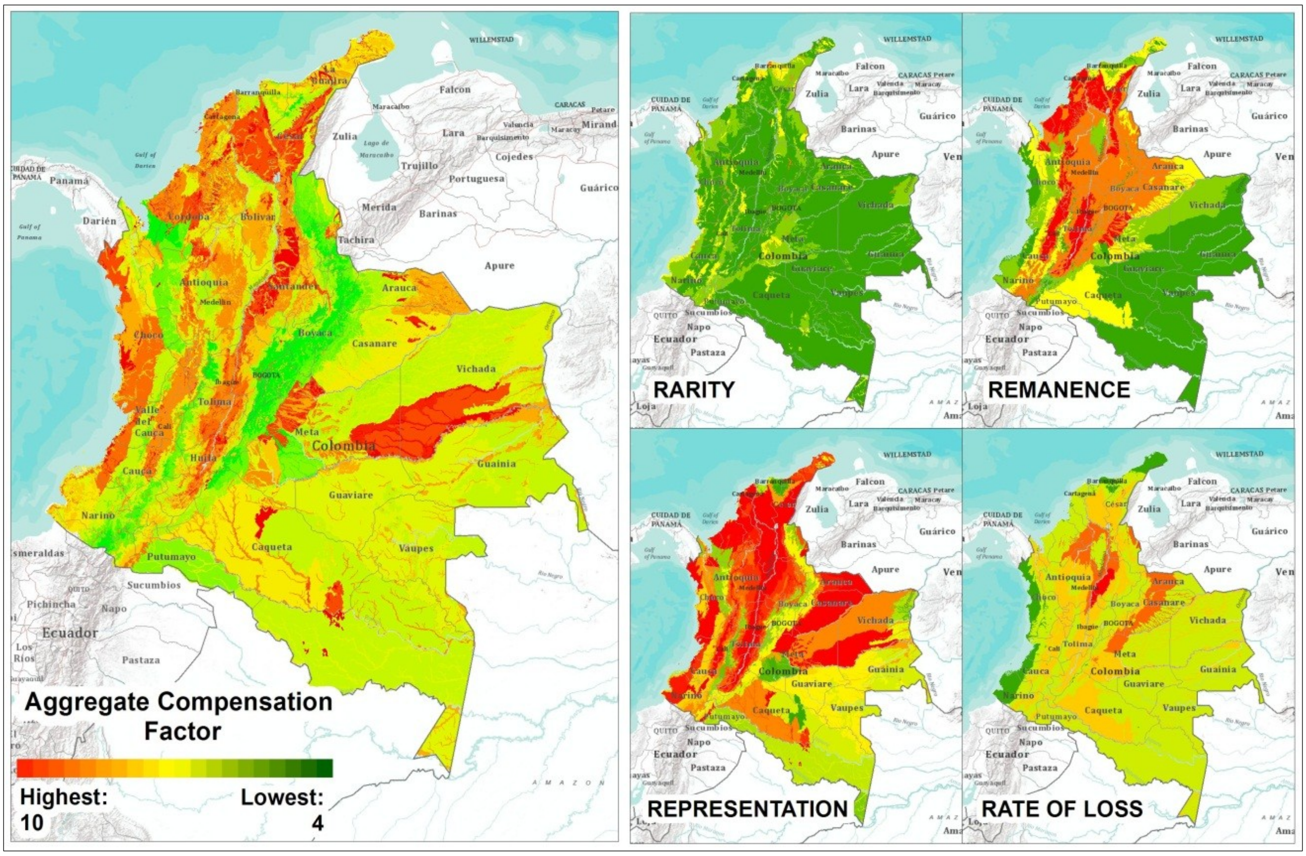
| Representation | Compensation Factor | Remanence | Compensation Factor | Rarity | | | | | Rate of Loss | Compensation Factor |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Biome | Compensation subfactor | Ecological systems | Compensation subfactor | Compensation factor | | |
| **High failure** (Achieves up to 10% of the conservation goal) | 2 | Mean (70%–50%) (analysis units have an area of natural ecosystems between 70% and 50%) | 1 | Mean (0.2%–0.5%) | 1.5 | Mean (15%–30%) | 1.5 | The final compensation factor for each ecological system is the highest subfactor of the two components (biome or ecological system) | Mean (0.2%–0.1%) | 1.5 |
| **Failure** (Achieves up to 50% of the conservation goal) | 1.5 | Low (50%–30%) (analysis units have an area of natural ecosystems between 50% and 30%) | 2 | Common (0.5%–1%) | 1.25 | Common (30%–75%) | 1.25 | | Low (0.1%–0.05%) | 1.25 |
| **Low failure** (Achieves up to 99.9% of the conservation goal) | 1.25 | Very Low (<30%) analysis units have an area of natural ecosystems below 30% | 3 | Very common (>1%) | 1 | Very common (>75%) | 1 | | Very low (<0.05 %) | 1 |
| **No gap** (conservation goal achieved) | 1 | | - | - | - | - | - | - | - | - |

**Table 3.** Example of offset ratio calculation for representative ecological system. Example from the Cesar River Region Coal Mining Pilot for the riparian forest Ecological System of the Caribe Helobiome and Shrub grassland in hills Ecological System of the Peinobiome Caribe.

| Biogeographical Ecosystem Districts | Ecological Systems | Representation | Rarity | Rate of Loss | Remanence | Compensation Factor |
|---|---|---|---|---|---|---|
| PeriCaribeño Ariguani_Cesar Magdalena and Caribe Helobiomes | Natural forest of the Mangdalena and Caribe Helobiome (Riparian forest of the Caribe helobiome) | 2.5 | 1.75 | 1.5 | 2 | 7.75 |
| PeriCaribeño Ariguani_Cesar Magdalena and Caribe Helobiomes | Shrub grassland of the Magdalena and Caribe Helobiome (Shrub grassland in hills of the peinobiome Caribe) | 2.5 | 2 | 1.5 | 2 | 8 |

The extent to which each ecological system is currently captured within the protected areas network is based on an analysis conducted by the Colombian National System of Protected Areas [38]. Impacts to ecological systems with lower coverage within protected areas would be expected to receive a higher offset ratio for an impact relative to an ecological system with a greater coverage within protected areas (Table 2). The measure of rarity was based on a national assessment of how rare an ecological system is relative to the area of the entire country. In addition, we calculated a local level of rarity based on the proportion of each ecological system within its biome. Both assessments were based on the biome and nested ecological system classification defined by the Colombian Institute of Hydrology and Environment Studies (IDEAM) [34]. These metrics were combined to ensure that ecological systems with higher rarity scores have a higher ratio of required offsets for impacts (Table 2).

**Figure 2.** Map of offset ratio calculation which includes a summary of each of the four sub-scores and final combined scores for the entire country of Colombia. See Table 2 for detail on how values are combined.




The measure of how much a given ecological systems remains in a natural state was based on an analysis conducted by IDEAM [34] where current distribution patterns were compared to estimates of historical patterns. Here, we sought to give higher offset ratios for both systems with high levels of its historic distribution maintained as well as to ecological systems with low levels of its historic distribution maintained (Table 2). It makes sense to maintain ecological systems with few remaining patches relative to their historic distribution; requiring higher offset ratios would help stem further loss. It also makes sense to seek to maintain ecological systems that have a high amount remaining of their historic distribution as these systems are likely to be highly intact, and requiring a higher offset ratio would encourage continued preservation of these systems. The estimation of how much loss each ecological systems has experienced over the last 6 years was based on analysis by the International Center for Tropical Agriculture (CIAT) and The Nature Conservancy that used remotely sensed data examined to indicate land use change over that period [39]. Ecological systems that experience a higher rate of loss over the last 6 years would be expected to receive a higher offset replacement ratio then those with lower rates (Table 2). These four metrics were combined into a final score indicating the required replacement ratio (Table 2 and Figure 2).

## 5. Applying the Framework in the Cesar Valley Region

The Cesar Valley Region (CVR) comprises ~1.2 million hectares, located in the basin of the Rio Cesar, in the Caribbean region of Colombia. The Nature Conservancy, along with key federal land management and wildlife regulatory agencies, Universities, and other conservation organizations, conducted an ecoregional plan for the CVR [26]. The portfolio of sites chosen during the ecoregional assessment consisted of 24 priority conservation areas covering a total area of 490,327 hectares, representing about 27% of the total area of the study site (Figure 3 and Table 4). The portfolio was dominated by conservation targets associated with the biome Helobioma Caribbean (Cesar). Of the 24 conservation areas selected about 10 consist of *floodplain forests* dominated by *gallery forests*, representing approximately 44% of the total portfolio. The area is also home to a number of threatened species such as the Blue-billed Curassow (*Crax alberti*), West Indian manatee (*Trichechus manatus manatus*), Cotton-top tamarin (*Saguinus oedipus*), Rio Magdalena River Turtle (*Podocnemis lewyana*) and Bocachico (*Prochilodus magdalenae*).

The CVR is also home to some of Colombia's richest coal deposits (Figure 3 and Table 4) [40] including some that intersect areas selected in the ecoregional assessment (Figure 3 and Table 4). According to the Mining and Energy Planning Unit (UPME) resources and geological reserves of coal for this area are estimated at 1933 million tons, the highest in Colombia [40]. The open pit coal production in the CVR between 1994 and 2005 rose from 8% to 46% of national production and is projected to continue increasing [40]. The coal potential in the area is considerable with 26.4% of the area currently under concession by title and another 23.6% currently under application license [41]. Conservation of the biological diversity in this ecoregion is in question, in part because the Colombian government has authorized exploration and development over such a large area. Developing the coal resource will increase social and environmental risks as open pit mining activities increase, because it is common to find high levels of contamination from the release of waste during the extraction and transport of coal and the loss of endemic fauna and flora and degradation in the surrounding ecosystems due to fragmentation [42,43].

Here we use the portfolio of sites selected in the plan (Figure 3 and Table 4) [26] to demonstrate how the application of the framework outlined above will apply the mitigation hierarchy to balance conservation objectives with impacts associated with future coal development. Since only 27% of the ecoregion was selected as part of the conservation portfolio, conflicts could potentially be resolved by simply re-designing the portfolio to meet target occurrence goals in areas having lower coal development potential (Figure 2c and Table 1). In the CVR the intersection between the conservation portfolio and the short term scenario of current mining concessions is minimal with a total of 3817 hectares representing 5% of the portfolio (Figure 3 and Table 4). Given the significant amount of habitat that has already been converted to other uses, all concession areas overlapping with the conservation portfolio would be expected to have impacts avoided [21].

However, the portfolio does not represent the only biologically valuable areas in the CVR. In fact there are 2518 hectares outside of the conservation portfolio where ecological systems remain in the natural state that are also currently in areas that coal mining concessions have been granted (Figure 3 and Table 4). In these sites, development could proceed to managing residual impacts through the use of on-site restoration and offsets. Requiring that impacts offset any residual impact would ensure that mitigation is consistent with landscape level conservation goals. To ensure that offsets provide benefits to biodiversity equivalent to that impacted as a result of development we quantified the size, composition and current condition of each patch of habitat found in the 2518 hectares described above. These variables were then used as inputs in the MaFE tool [36] to select areas that match for the composition of biodiversity within the conservation portfolio that have higher condition, higher species diversity and are located in larger patches of habitat (Figure 3 and Table 4). Applying the replacement ratio framework discussed above and outlined in Table 2 would require 12,890 hectares of offset for the 2,518 hectares of areas impacted outside of the conservation portfolio (Figure 3 and Table 4).

**Figure 3.** Landscape-level recommendations for the application of the mitigation hierarchy in the Ceasr Valley pilot area. Portfolio of conservation sites selected by the ecoregional assessment in purple. Development potential outlined in red showing overlap between potential development and conservation priorities. Natural areas not within the conservation portfolio but requiring offsite mitigation shown in green. Bottom middle and right panel show required compensation ratio for impacts to natural systems and areas best suited to offset these impacts.

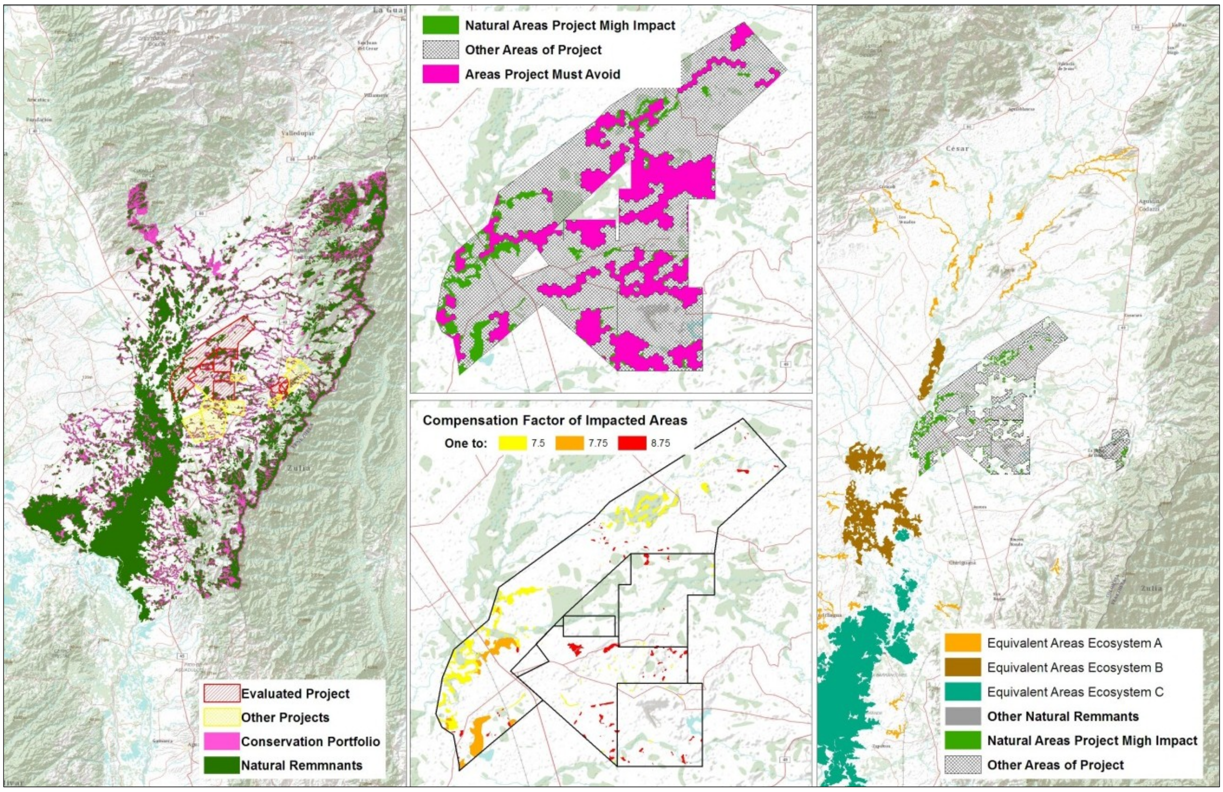


**Table 4.** Application of mitigation framework for coal mining in the Cesar Valley Region.

| | Area (ha) |
|---|---|
| Study area | 1,278,600 |
| Portfolio area | 490,327 |
| Size of the future mining scenario | 72,369 |
| Portfolio or avoid area in the future mining scenario | 3,817 |
| Ecosystems that could be impacted by future mining scenario outside portfolio | 2,518 |
| Compensation factor | Between 7–9 for natural ecosystems and 4 for secondary vegetation |
| Compensation area | 12,891 |

## 6. Discussion

Our results are intended to facilitate ecologically appropriate siting of development, while ensuring that key ecological features impacted as a result of development are preserved or restored. The increase in mining, energy and infrastructure development forecasted for Colombia may be compatible with biodiversity, if development activities are properly sited [21]. This presents a challenge for conservation however, because the area projected to be impacted by habitat loss and fragmentation is large. Many such impacts can be mitigated or eliminated with appropriate planning for development [20,44]. For example, many of the tilled agricultural areas within the country represent low-quality habitats incapable of supporting populations of imperiled species and no longer support natural plant or animal communities. New development would likely have substantially less potential to impact biodiversity if sited in these areas [32]. Our approach also describes how impacts from development to ecologically important areas in Colombia could be offset. But in order for a project to apply the mitigation hierarchy there are areas that must first be avoided by development. Our criteria for avoidance are based on the best available science regarding known high priority conservation targets in these landscapes [21]. Our analysis follows best practices for conservation planning [29], by considering multiple conservation targets designed to preserve both whole landscapes and particularly sensitive areas. More importantly, our analysis offers a transparent proactive assessment of mitigation requirements that will be easy to use by both regulators and industry. Our approach also proactively estimates the amount of offset that would be required for impacts of a particular project to achieve the necessary mitigation of habitats. These offsets must seek to provide high returns on investment, such as conservation easements and restoration practices that can be implemented by land managers with conservation payments from developers. Regulators that implement this framework must call for offsets to represent new or additional contributions to conservation [3]. For example, for offset to deliver additionality they must either protect areas at risk of future conversion or restore degraded areas to improve conditions for biodiversity. While our framework guides offset sites towards high quality areas within the conservation portfolio there is still ample opportunity to protect against future conversion or restore areas that are degraded and in turn deliver additionality.

As this framework is implemented a more sophisticated approach to quantifying additionality may need to be developed to ensure comparable value of offsets and impacts. We recommend that the Colombian government improve their existing offset accounting approach so in addition to the landscape level metrics conservation projects are valued based on their additionality [3]. When offsets restore degraded ecosystems, they provide a new contribution to conservation over time as the offset reaches maturity. Success of restoration projects can vary greatly depending on the ecosystem, restoration techniques, and other factors. In some cases, restoration approaches are known to be effective, but in other situations there may be great uncertainty due to a lack of experience [45,46]. Where restoration experience is comprehensive, this probability could be estimated with some accuracy, and where experience is more limited, a high-medium-low probability ranking process might be used. Incorporating probability of success into offset accounting would ensure a more realistic appraisal of how offsets, contribute to ecological gains. Restoration offsets may take many years before conservation benefits mature. This time lag represents a loss for biodiversity and should be accounted for in estimates of ecological gains [47]. We propose that the Colombian government account for this loss by estimating the time to maturity of a restoration action and apply a discount rate, a commonly used method for estimating the present value of future values. Offsets that preserve habitat also deliver conservation value when, taking into account real-world conditions and threats, those offsets protect against an expected background rate of loss. For example, protecting a 1000-hectare forest area that was experiencing an average deforestation rate of 1 percent per year delivers a new contribution to conservation of 10 hectares per year (1 percent of 1000 hectares). Such rates of loss can be estimated using standard threat assessments [12,20,32,48].

A landscape level perspective on mitigation can offer a variety of improvements for conservation over typically site by site mitigation. Landscape-level plans provide an opportunity to design offsets that address residual adverse impacts arising from more than one development project [20]. Aggregated offsets might be advantageous when an area is subjected to cumulative impacts from several individual developments, particularly those in the same sector, at roughly the same time. In this situation, impacts on biodiversity are likely to be of a similar type, and aggregating offsets may provide better mitigation at lower cost, with a higher probability of success given the concentration of the management skills needed to deliver the offset and synergies in project management. Such assessments can also reduce costly delays due to protracted environmental review. A landscape approach to compensatory mitigation planning can lead to a better ecological outcome. If mitigation needs from multiple projects are pooled, then larger, less fragmented parcels can be acquired, contributing to both ecological integrity and fiscal savings. There is evidence that small, isolated fragments of habitat tend to have lower overall biodiversity than larger patches [49]. A focus on aggregated offsets from multiple project impacts has potential to improve the ecological gains offset deliver.

By pooling funds and facilitating their strategic and geographic application of offsets, conservation outcomes are maximized, while mitigation costs for developers are reduced. Estimates of the amount of mitigation described here could be proactively incorporated into the business costs of individual projects. Given that the overall investment for a commercial development (e.g., mining, oil and gas and infrastructure) is commonly hundreds of millions of dollars we estimate that the cost of mitigation is less than a few percent of development costs (Saenz and Walschburger unpublished data). More importantly, developers can use the results of this analysis to proactively reduce the need for mitigation by siting projects in areas that would not warrant mitigation. This could substantially reduce the cost of mitigation across projects. For example, we recognize that the amount of offset required per ha for some impacts will be high (ratios of 10:1). They provide an opportunity for developers to proactively avoid these areas whenever possible. In addition, areas with the highest impact to offset ratios (9/10 to 1) comprise a small percentage of the land area in Colombia (3.2%). Consequently, impacts to these areas may be avoided through appropriate micro-siting of a projects footprint in otherwise suitable project areas.

Our goal with these analyses was to illustrate a way in which gaps in the existing siting and mitigation regulatory framework for Colombia could be improved using available data and tools. The pilot sites selected to illustrate these concepts were chosen jointly by The Nature Conservancy and the Colombian Ministry of Environment and Sustainable Development (MADS) because they are expected to experience significant increases in development pressure. Prior to this analysis, offsets were required only for forested areas, often directed to areas dissimilar to impacted areas [18]. For example, in some cases, forest clearing resulted in the planting of fruit trees as a way to compensate for impacts [18]. As a result of this work, MADS adopted a resolution and a methodology to incorporate the principles of biodiversity offsets outlined in our analyses into its licensing process for terrestrial projects [50,51] (Colombia, 2012–Resolución 1517 de 2012) [52]. For the first time, mitigation decisions will be made in accordance with an explicit science-based framework. It will also push MADS to place impacts of development into a landscape perspective, highlighting the cumulative impacts of development revealing the potential losses and the need for mitigation, including avoidance but also compensation of impacts. There will also be a structured decision-making framework to determine when projects could proceed or should be avoided [21]. Now the guidelines can proactively identify proposed development that are incompatible with conservation goals and seek to avoid those impacts [19,51,53]. In addition to decisions about avoidance and minimization, the framework will support MADS in determining ecologically equivalent offset opportunities, locations where these offsets can best contribute to landscape conservation goals, and the amount of compensatory mitigation needed to address impacts. This change in the licensing process should drive both a significant increase in, and more effective use of, funding for biodiversity conservation across Colombia [21,53].

Our approach illustrates that it is possible to proactively implement a science-based system that supports and guides development to avoid, minimize, and offset ecological impacts. The approach outlined here, updated with new information as it becomes available, could be used to guide projects that follow this protocol. Given the coarse scale nature of the species data utilized in our analysis and our decision to use species data to supplement the selection of ecological system offset sites there is a very real chance that at risk, rare and underrepresented species could be disfavored by this offset methodology [50]. As this framework is implemented and development plans in the pilot landscapes are refined, it is likely that biodiversity assessments will also be refined. These refinements may make it possible to design development activities that minimizes impacts to rare and/or sensitive species or design offsets that better captures their requirements. The final choice of any offset site must be supported by field surveys and would need consensus from local communities and the regional environmental authority. Implementation by MADS may help to improve the licensing process by facilitating the completion of individual projects sited to avoid sensitive areas as well as protecting areas of critical biodiversity and ecosystem services within Colombia. The effectiveness of a formal offset program demands a responsible administrative entity with firm requirements for adequate oversight, performance accountability, and process transparency and fairness. Achieving these objectives requires several administrative functions, including: (1) communication and maintenance of standards and protocols; (2) application of standards to individual projects to analyze impacts and determine needs for mitigation; (3) coordination and oversight of mitigation planning to target mitigation funding toward projects with high conservation return on investment; and (4) oversight of mitigation funds to ensure appropriate fiduciary management and impartial allocation. An independent third-party entity that oversees these functions will be essential.

## 7. Conclusions

Balancing growing development demands with biodiversity conservation necessitates a shift from the business as usual process. By first avoiding or minimizing impacts to occurrences of biological targets with high irreplaceability and/or vulnerability, then ensuring that impacts are restored onsite using the best available technology, and finally offsetting any remaining residual impacts, we can provide a framework truly consistent with sustainable development. By blending a landscape vision with the mitigation hierarchy, we move away from the traditional project-by-project approach. A landscape vision is essential because it ensures that the biologically and ecologically important features remain the core conservation targets throughout the process. Without this blueprint we could lose sight of overarching conservation vision, have difficulty establishing priorities and tracking progress. By adopting the framework outlined here we balance development with conservation and provide the structure to fund conservation commensurate with impacts from development.

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## Conflicts of Interest

The authors declare no conflict of interest.

## Appendix

**Appendix 1.** Details on the ecological systems and species that were the focus of mitigation activities in each pilot project. The number of species is included by taxa along with species richness categories that are represented as a range of the number of species included in each category. Species richness values were binned into categories based on the Jenks natural breaks classification method [38].

| Case study area | Total area (ha) | Ecological systems | Species (species richness categories) |
|---|---|---|---|
| Coal Mining in Cesar | 1,285,592 | Riparian lake<br>Aquatic vegetation<br>Swamp forest<br>Riparian forest and shrubland<br>Grassland riparian forest<br>Shrub grassland (en lomerio ondulo)<br>Shrub grassland (en lomerio quebrado)<br>Shrub grassland in foothills<br>Dry savanna<br>Semi dense dry forest in lomerio<br>Semi dense dry forest in mountain<br>Riparian dry forest<br>Semi dense sub-andean mountain forest<br>Dense sub-andean mountain forest<br>Riparian sub-andean mountain forest<br>Dense Andean mountain forest<br>Riparian andean mountain forest<br>Mountain grasslands (paramos) | Mammals (17): Callicebus torquatus, Leopardus tigrinus pardinoides, Lontra longicaudis, Myrmecophaga tridactyla Arteta, Panthera onca centralis, Saguinus oedipus, Tremarctos ornatus, Trichechus manatus , Ateles hybridus hybridus, Tapirus terrestris terrestris, Puma concolor concolor, Mazama americana, Bradypus variegatus, Alouatta seniculus, Cabassous centralis, Leopardus pardalis, Leopardus wiedii. Birds (23): Pauxi pauxi, Anthocephala floriceps floriceps, Ara militaris, Basileuterus conspicillatus, Campylopterus phainopeplus, Capito hypoleucus, Chauna chavaria, Clytoctantes alixii, Crax alberti, Dendroica cerulea, Metallura iracunda, Odontophorus atrifrons, Ognorhynchus icterotis, Oroaetus isidori, Gypopsitta pyrilia, Schizoeaca perijana, Vultur gryphus, Vermivora chrysoptera, Pyrrhura pantchenko, Ortalis garrula, Chlorostilbon gibsoni, Picumnus cinnamomeus, Synallaxis candei. Reptiles (3): Crocodylus acutus, Geochelone carbonaria, Podocnemis lewyana. Amphibians (3): Centrolene tayrona, Eleutherodactylus cuentasi, Cryptobatrachus boulengeri. fishes (10): Abramites eques, Ageneiosus pardalis, |

**Appendix 1.** *Cont.*

| **Case study area** | **Total area (ha)** | **Ecological systems** | **Species (species richness categories)** |
|---|---|---|---|
| Coal Mining in Cesar | 1,285,592 | Mountain grasslands (paramos) | Brycon moorei, Curimata mivartii, Ichthyoelephas longirostris, Plagioscion magdalenae, Prochilodus magdalenae, Pseudouplatystoma magdaleniatum, Salminus affinis, Sorubim cuspicaudus. Plants (25): Acrocomia aculeata, Astrocaryum malybo, Aspidosperma polyneuron, Brosimum alicastrum, Bulnesia arbórea, Cedrela odorata, Elaeis oleífera, Guaiacum officinale, Podocarpus oleifolius, Aspidosperma megalocarpon, Cedrela fissilis, Haematoxylum brasiletto, Pradosia colombiana, Parinari pachyphylla, Swietenia macrophylla, Sabal mauritiiformis, Espeletia periajaensis, Libanothamnus divisoriensis, Puya grantii, Hypericum baccharoides, Pentacalia perijaensis, Aragoa romeroi, Belencita nemorosa, Chaetolepis perijaensis (1–4, 5–8, 9–12, 13–16, 17–27) |
| Gold Mining in Sur de Bolivar | 1,668.565 | Riparian lake (bogs) | Mammals (12): Ateles hybridus brunneus, Saguinus leucopus, Tapirus terrestris, Tremarctos ornatus. Birds (10): Ara militaris,Capito hypoleucus carrikeri, Cercomacra parkeri, Chauna chavaria, Clytoctantes alixi, Crax alberti, Habia gutturalis, Melanerpes pulcher Phylloscartes lanyoni, Pionopsitta pyrilia. Reptiles (2):Geochelone carbonaria, Podocnemis lewyana. Fishes (11): Abramites eques, Ageneiosus caucanus, Cochilodon hondae, Curimata mivartii, Salminus affinis, Sorubim lima. Plants (24): Aniba perutilis |
| | | Flood plain forest | |
| | | Alluvial valley forest | |
| | | Wetlands | |
| | | swamp vegetation | |
| | | Alluvial plain savannas | |
| | | Forest in structural and erosional mountain | |
| | | Mountain forest in warm weather fluiogravitational | |
| | | Mountain forest in moist warm fluiogravitational weather | |
| | | Mountain forest in temperate wet fluiogravitational | |
| | | Mountain forest in temperate fluiogravitational very wet | |
| | | Mountain forest in a temperate climate fluiogravitational | |

**Appendix 1.** *Cont.*

| Case study area | Total area (ha) | Ecological systems | Species (species richness categories) |
|---|---|---|---|
| Gold Mining in Sur de Bolivar | 1,668.565 | Acuatic vegetation in mountain | Cariniana pryryformis, Caryocar amydaliferum, Cedrela odorata Guaiacum officinale, Isidodendron tripterocarpum Juglans neotropica, Pachira quinata, Prioria copaifera Quercus humboldtii, Swietenia macrophylla, Clatrotropis brunnea Peltogyne paniculata, Dipterix oleifera, Catostema digitata, Gustavia romeroi, Lecythis tuyrana, Lecythis mesophylla, Licania platypus Caryocar glabrum, Vascivaea podocarpa, Astrocaryum malibo Elais oleifera, Brosimum alicastrum. (1–4, 5–9, 11–14, 14–20, 20–26) |
| | | Savannas vegetation | |
| | | In fluviogravitational hills forest | |
| | | Forest in structural and erosional hills | |
| | | Aquatic vegetation | |
| | | Forest in Lomerio in mountain forest | |
| | | Dry forest in hills | |
| | | dry forest in mountain | |
| | | Foothill forest in dry forest wetland biome | |
| | | Aquatic vegetation in dry forest | |
| | | Savanna in dry forest biome | |
| Port in Bahia Tribuga Choco | 343,265 | Estuarine Forest | Species (18): Bird communities of the tropical rainforest and mangroves, Community amphibians, Panthera onca, Puma concolor, Community mammalian prey, terrestrial turtle, Community psittácidos sharks, megaptera, deep-water shrimp, shallow-water shrimp, dolphins tursinus, hake, turtle nesting beaches, groupers and grouper, other bony fish, Breeding birds. (Not Applicable) |
| | | forest in Monocline Crestones dissected | |
| | | forest in Monocline and Composite Spine Anticline | |
| | | Halobiome forest | |
| | | Riparian forest | |
| | | estuarine forest in grasslands | |
| | | forests on slopes and hills | |
| | | forest in erosional mountains | |
| | | forest in branched mountains | |
| | | forest in mountains and hills branches | |
| | | forest in aluvio-coluvial foothills | |
| | | forest in beach | |
| | | Littoral beaches | |
| | | Wetlands | |
| | | soft bottoms | |
| | | coral formations | |
| | | mangroves | |
| | | beaches | |
| | | secondary vegetation | |
| | | rocky Coastlines | |
| | | freshwater systems | |
| | | Riscales | |

**Appendix 1.** *Cont.*

| **Case study area** | **Total area (ha)** | **Ecological systems** | **Species (species richness categories)** |
|---|---|---|---|
| Macarena Road in Meta | 811,457 | Humid tropical rainforest in hills and hillsides | Mammals (15sp.): Aotus griseimembra, Aotus lemurinus, Ateles belzebuth belzebuth, Callicebus cupreus ornatus, Cuniculus taczanowskii, Dynomis branickii, Lagothrix lagothricha lugens, Leopardus tigrinus pardinoides, Leopardus wiedii, Marmosops fuscatus, Myrmecophaga tridactyla, Panthera onca, Priodontes maximus, Pteronura brasiliensis, Tapirus pinchaque, Tapirus terrestris, Tremarctos ornatus. Birds (24 sp.): Aburria aburri, Aburria pipile (Pipile pilpile), Anhima cornuta, Ara macao, Ara severus, Cissopis leverianus, Crax alector, Dendroica cerúlea, Gallinula melanops, Grallaria alleni, Gypopsitta pyrila (Syn. Pionopsitta pyrilia), Harpia harpyja, Hypopyrrhus pyrohypogaster, Mitu tomentosa, Morphnus guianensis, Patagioenas fasciata (Syn. Columba fasciata), Rupicola peruvianus, Sporophila plúmbea, Touit stictopterus, Vermivora chrysoptera, Wilsonia Canadensis. Reptiles (5 sp.): Crocodilus intermedius, Geochelone carbonaria, Geochelone denticulata, Podocnemis expansa, Podocnemis unifilis. Amphibians (10 sp.): Atelopus guitarraensis, Bolitoglossa altamazonica, Ceratophrys cornuta, Cochranella adiazeta, Dendrophryniscus minutus, Gastrotheca nicefori, Hemiphractus johnsoni, Phyllomedusa tarsius, |
| | | Humid Tropical rainforest in erosional mountains | |
| | | Humid Tropical rainforest on alluvial fans and terraces | |
| | | Humid tropical rainforest in fluvio-erosional mountains | |
| | | Pluvial tropical rainforest in fluvio-erosional mountains | |
| | | Humid tropical Rainforests in alluvial terraces | |
| | | Humid to pluvial tropical rainforest on hills and low hillsides | |
| | | Pluvial tropical rainforest in fluvio-erosional mountains | |
| | | Pluvial tropical rainforest in intra-mountain alluvial valleys | |
| | | Humid tropical in non-dissected alluvial fans | |
| | | Humid tropical rainforest on alluvial plains of meandric rivers | |
| | | Xerophitic vegetation and shrubland on sandstone | |
| | | Xerophitic vegetation and shrubland on fluvio-erosional mountain | |
| | | Xerophitic vegetation and shrubland on non-dissected alluvial fans | |
| | | Subandean pluvial forests in structural hillsides | |
| | | Subandean humid forests in hills and mountains of the Sierra de la Macarena | |
| | | Subandean Humid Forests in structural hillsides | |
| | | Sub-andean Humid Forests in fluvio-erosional mountains | |
| | | Andean humid and pluvial forests in fluvio erosional mountains | |
| | | Highland humid grasslands (páramos) in glacial mountains | |
| | | Humid forests and subparamos (grasslands) in glacial mountains | |

**Appendix 1.** *Cont.*

| Case study area | Total area (ha) | Ecological systems | Species (species richness categories) |
|---|---|---|---|
| Macarena Road in Meta | 811,457 | Humid forests and subparamos (grasslands) in glacial mountains | Pristimantis, savage, Rahebo glaberrimus. Fishes (10 sp.): Apteronotus macrostomus, Brycon amazonicus, Curimata mivartii, Ichthyoelephas longirostris, Prochilodus magdalenae, Pseudoplatystoma fasciatum, Salminus affinis, Salminus hilarii, Sorubim cuspicaudus, Trychomycterus migrans. Plants (33 sp.): Alzatea verticillata, Aniba perutilis, Aspidosperma polyneuron, Attalea insignis, Axonopus morronei, Bactris gasipaes var. Chichagui, Billia rosea, Cattleya trianae, Cedrela odorata, Ceroxylon alpinum, Ceroxylon vogelianum, Eschweilera cabrerana, Espeletia cabrerensis, Heliconia marginata, Hyptis melissoides, Iriartea deltoidea, Juglans neotropica, Minquartia guianensis, Myrocarpus venezuelensis, Pachira quinata, Passiflora arbórea, Passiflora tolimana, Pitcairnia arenícola, Pitcairnia tolimensis, Podocarpus oleifolius, Pterocarpus officinalis, Quercus humboldtii, Schizolobium parahybum, Scutellaria parrae, Syagrus sancona, Terminalia amazonia. (1–4, 5–10, 11–15, 15–20, 21–32) |
| Oil and Gas in Casanare | 1,892,780 | High Dense Rainforest in structural-erosional hills | Birds (23 sp.): Anas cyanoptera, Anas discors, Anhima cornuta, Anthus lutescens, Ara severa, Aratinga acuticauda, Basileuterus cinereicollis, Cacicus uropygialis, Cercibis oxycerca, Ciconia maguari, Cissopis leverianus, Cranioleuca vulpina, Crax alector, Mitu tormentosum, Myrmotherula cherriei, Neochen jubata, Phacellodomus rufifrons, Pionopsitta pyrilia, Polystictus pectoralis, Sporophila plumbea, Vermivora chrysoptera, Seiurus noveboracensis, Sayornis nigricans, Jabiru mycteria Reptiles (5): Crocodilus intermedius, Podocnemis unifilis, |
| | | High Dense Rainforest in structural—erosional mountain | |
| | | High Dense Rainforest in fluvio-gravitational mountain | |
| | | High Dense Rainforest in antique tectonized foothill | |
| | | High Dense Rainforest in alluvial valleys | |
| | | Medium dense Rainforest in dilluvial-alluvial foothill | |
| | | Medium dense Rainforest in antique foothill | |

**Appendix 1.** *Cont.*

| Case study area | Total area (ha) | Ecological systems | Species (species richness categories) |
|---|---|---|---|
| Oil and Gas in Casanare | 1,892,780 | Medium dense Rainforest on alluvial terraces of Andean rivers | Podocnemis expansa, Podocnemis vogli, Geochelene carbonaria Amphibians (10): Dendropsophus mathiassoni, Pseudopaludicola llanera, Scinax wandae, Scarthyla vigilans, Pipa pipa, Dendrophryniscus minutes, Rhaebo glaberrimus, Physalaemus fischeri, Pristimantis medemi, Bolitoglossa altaamazonica Fishes(26 sp):Aequidens metae, Apteronotus galvisi, Apteronotus_macrostomus, Astyanax integer, Bryconamericus alpha, Bryconamericus cismontanus, Bryconamericus cristiani, Bryconamericus loisae, Bujurquina mariae, Cetopsis orinoco, Charax metae, Creagrutus bolivari, Farlowella vittata, Hemigrammus barrigonae, Lasiancistrus tentaculatus, , Mikrogeophagus ramirezi, Moenkhausia metae, Orinocodoras eigenmanni, ,Oxydoras sifontesi, Parodon apolinari, Prochilodus mariae, Pyrrhulina lugubris, Semaprochilodus laticeps, Trychomycterus_dorsostriatus, Trychomycterus_migrans Plants (15): Piranhea trifoliata, Parahancornia oblonga, Inga gracilifolia, Hymenachne amplexicaulis, Fissicalyx fendleri (Benth), Bowdichia virgilioides, Bactris major (Jacq.), Bactris guineensis, Attalea insignis, Andropogon bicornis, Attalea butyracea, Acosmium nitens, Mauritia flexuosa, Carapa guianensis, Caraipa llanorum. (1–4, 5–10, 11–15, 15–20, 21–32) |
| | | Medium dense Rainforest on low terraces of Andean rivers with eolic influence | |
| | | Forested savanna in low terraces with eolic influence | |
| | | Savanna in dilluvial-alluvial foothill | |
| | | Savanna on dunes in alluvial plains | |
| | | Savanna in antique tectonized foothill | |
| | | Flooded savanna in low terraces with eolic influence | |
| | | Seasonal flooded savanna on high alluvial terraces of Andean rivers | |
| | | High Dense Forest in floodplain of andean rivers | |
| | | Medium Dense Foretst in floodplains of in alluvial plains with eolic influence | |
| | | Forested savanna in floodplains of andean rivers | |
| | | Flooded savanna in floodplains of andean rivers | |
| | | Swamp vegetation in andean river depressions | |
| | | Swamp vegetation in depressions with eolic influence | |

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