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Evaluating the Biodiversity Implications of Nature-Based Carbon Credits

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Signature Page

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Dr. Andrew MacDonald

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I. Abstract

Biodiversity loss and climate change are two of the greatest challenges our global environment faces today (Portner et al., 2023). The carbon credit market is a growing method for organizations to reach their carbon offsetting goals, yet a similar system for companies to reach their biodiversity goals has been slow to emerge (BCA Issue Paper No. 2, 2024). Thus, there is an increasing demand among companies to purchase carbon credits that produce co-benefits for biodiversity (Procton, 2024). In this study, we identified metrics of analysis that assess the biodiversity co-benefits of nature-based carbon credit projects through a detailed literature review. We then created a framework of analysis that evaluates aspects of carbon credit projects' location and design by selecting eight project location metrics and 10 project design metrics that are suited to analyze these biodiversity co-benefits. Finally, we applied this framework to five case study carbon credit projects. The results of our analysis are positioned to inform companies' carbon credit purchasing decisions by revealing projects' biodiversity co-benefits. A buyer decision-support tool prototype, available online, walks carbon credit purchasers through project characteristics that determine the potential for a carbon credit project to include biodiversity co-benefits. It then allows buyers to indicate their credit-purchasing priorities, and finally provides recommendations for which biodiversity-supportive carbon credits to purchase. This project provides guidance for companies wishing to jointly achieve their carbon and biodiversity goals through purchasing carbon credits that hold biodiversity co-benefits. As the carbon market continues to expand, the results of this study and the accompanying buyer decision-support tool can aid companies in supporting biodiversity as they work towards climate change mitigation.

II. Project Objectives and Significance

Climate change and biodiversity loss are two of the most important existential challenges that humanity faces (Portner et al., 2023). In response to climate change, carbon markets have emerged as a possible solution, and so too have carbon credit projects that prioritize carbon sequestration and storage (BCA Issue Paper No. 2, 2024). Biodiversity solutions of a similar scale have yet to emerge. Therefore, if carbon markets can provide co-benefits for biodiversity, nature-based carbon credit projects could advance the twin goals of climate change mitigation and biodiversity protection. However, whether these projects benefit biodiversity, and what key characteristics of these projects might be associated with biodiversity benefits, is poorly understood.

This project seeks to address this gap by exploring the intersection of nature-based carbon credit projects and biodiversity through the following questions:

- Which characteristics of project design and location provide potential for biodiversity benefits or risk biodiversity loss?
- How do these characteristics manifest in five carbon credit project case studies?
    - How can these case studies inform a framework for a decision-support tool for carbon credit buyers wishing to purchase carbon credits with biodiversity co-benefits?

The voluntary carbon market (VCM) is an important mechanism for mitigating climate change by facilitating the purchase of carbon credits from projects that remove carbon dioxide from the atmosphere (Bose et al., 2021). Carbon credits can be purchased by individuals looking to reduce their personal carbon footprints or by companies as part of their plan to achieve climate commitments. Nature-based carbon credit projects, as opposed to technology-based carbon projects such as carbon capture, can improve the management of ecosystems like forests, wetlands, and grasslands. These credits provide value to buyers because of their carbon sequestration and potential co-benefits. Such co-benefits include restoring or conserving biodiversity, although certain carbon credit projects could have potential biodiversity risks depending on project design and location.

Nature-based carbon credit projects conduct activities that promote carbon sequestration, such as habitat restoration, reforestation, afforestation, and conservation (World Resources Institute). Avoided deforestation through conservation, as outlined through the United Nations Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) framework, and habitat restoration, such as mangrove restoration projects, generally have been found to benefit biodiversity (Rahman et al., 2021). However, reforestation and afforestation, often consisting of monoculture tree plantations, can lead to a loss of biodiversity by replacing native habitats with single-species plantations. This decrease in biodiversity can increase ecosystem vulnerability to extreme weather and fire, ultimately reducing ecosystems' resiliency (Doerr, 2016). Further complicating the issue is the risk of planting trees in areas that did not historically support forests through afforestation. This can disrupt local ecosystems, altering fire regimes and reducing habitat suitability for native species among other consequences (Perez-Silos, 2021).

Within the VCM, there is increasing demand for carbon credits that also provide biodiversity benefits, particularly from companies wishing to meet United Nations Sustainable Development Goals (SDGs) (World Economic Forum, 2023). The potential to couple biodiversity conservation with carbon sequestration could have economic benefits for carbon credit project developers, leading to increased incentives to prioritize biodiversity in project design and project siting.

The lack of a standardized framework for evaluating biodiversity within carbon offsetting projects complicates efforts to ensure that carbon credit projects support biodiversity. While some third-party carbon credit organizations have begun developing biodiversity standards, there is no clear consensus on best practices or ways to measure their success. This project investigates several differerent biodiversity metrics, including characteristics that assess species presence, threats to those speces, and the potential to restore those ecosystems. The analysis explores these metrics through case study evaluation to see how they might be used to assess a carbon project's potential to support biodiversity.

III. Background

History and Current State of the Market

The carbon market traces its roots back to the beginning of the 1990s, specifically gaining traction at the 1992 United Nations Framework Convention on Climate Change (UNFCCC). It was there that concerns were raised about human activities increasing atmospheric concentrations of greenhouse gasses (GHGs). No binding targets were set but it was decided that “policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.” This led economists to develop an international carbon market (Calel, 2013).

The Kyoto Protocol in 1997 was the first international agreement to set binding targets and introduced the Clean Development Mechanism (CDM) which allowed developed countries to invest in developing countries for emissions offsets (UNFCCC, 2024). From here, global carbon markets began to take form, shaping the market into what it is today.

Currently, the VCM is a mechanism that facilitates carbon credit sales between carbon credit project developers and buyers. One carbon credit equates to one equivalent tonne of CO2 reduced, avoided, or removed. Over the past decade, it has been reported that the market has grown significantly, with “issuances reaching nearly 300 million tonnes per annum in 2021” (Carbon Direct, 2023).

In recent years, several trends have started to emerge, defining the state of the market today. The first is the quality of projects over the years. According to an analysis by Carbon Direct (2023), fewer than 10% of projects met or exceeded their high quality standards. High quality, as defined by Carbon Direct, includes projects that follow these principles:

- **Harms and Benefits:** Projects should avoid negative impacts on the environment and work to promote enhancing ecosystem services.
- **Environmental Justice:** Projects should cause minimal social harm to surrounding communities and people.
- **Additionality and Baselines:** Projects should be additional compared to the baseline. Removals through projects are considered to be additional if they would not have occurred without carbon finance, and the baseline is the estimate of what the carbon and GHG impacts would be without carbon finance.
- **Durability:** Projects should be durable. Durability of the project indicates the extent to which the carbon storage mechanism has the capacity to sequester carbon long-term.
- **Leakage:** Projects should minimize leakage. Leakage is the failure to sequester GHG emissions at the project site compared to planned sequestration amounts.

Lower-quality projects often do not meet their intended carbon sequestration goals and therefore do not produce proper climate action, “increasing the reputational risks of participating in the market” (Carbon Direct, 2023). In addition, fewer credits have been issued and retired recently: issuances fell from 72% in 2021 to 53% in 2023. This may be due to buyer skepticism and scrutiny.

Furthermore, buyers are beginning to develop purchasing strategies with clear quality criteria that steer them towards removals purchases or projects that remove carbon using specific processes. It has been estimated that the focus on obtaining removals has grown five fold from 2021 to 2023.

Overall, the VCM today can be understood as two separate segments. The first is an emissions reduction and avoidance market that is beginning to slow down as a result of criticism and skepticism. The other is a market that has set its focus on high quality projects and removal, which has begun to take shape rapidly.

Carbon pricing can be used to capture the externalities of carbon emissions. This includes previously unaccounted-for public costs such as climate-related property damage or healthcare expenses; carbon pricing presents an opportunity to shift these financial burdens back onto carbon emitters.

Carbon pricing in real world applications can be viewed in a few different ways: the social cost of carbon, carbon taxes/cap and trade, voluntary carbon market (VCM) pricing, and internal carbon pricing (UNFCCC, 2023).

- **Social Cost of Carbon**: The social cost of carbon is a monetary estimate of the potential economic damage of emitting one additional tonne of carbon dioxide into the atmosphere. Most commonly, the cost is derived based on estimated future emissions due to population and economic growth. Future climate responses are also taken into account, based on factors such as temperature increase and sea level rise. A variety of circumstances can shift the cost of carbon dramatically and/or infrequently (Rennert & Kingdon, 2019).

- **Carbon Taxes/Cap and Trade**: The cost of carbon can also be influenced or imposed by policy. A carbon tax directly sets the price of carbon by implementing a tax rate on GHG emissions or the carbon content of fossil fuels. An emissions trading system allows emitters to trade carbon units to meet their targets. This creates a supply and demand, therefore establishing a market price for carbon units.

- **Voluntary Carbon Pricing:** The VCM is a distributed marketplace for individuals, companies, and organizations to buy and sell credits. Carbon pricing varies depending on the type of project (Dawes, 2024). The size of the project, location, and project quality are examples of some variables that can determine the pricing of a project.

- **Internal Carbon Pricing**: Internal carbon pricing is used by companies to assess the financial implications of their carbon emissions and account for them in their business operations. Internal carbon prices are set by organizations internally and differ widely across organizations (Trinks et al., 2022)

Consumer Distrust in Voluntary Carbon Credits

The VCM is increasingly recognized as a potential tool for mitigating climate change by facilitating the reduction of net carbon dioxide emissions. However, consumer participation in these markets remains notably low, largely due to pervasive distrust among consumers regarding the efficacy and integrity of voluntary carbon credits (Dong et al., 2023).

The issue of trust is compounded by the lack of transparency and consistency in the communication surrounding these programs. The voluntary nature of these payments and the absence of standardization lead to doubts about the actual application and impact of the collected funds. Providers often fail to supply detailed and clear explanations about how the offset payments are utilized, leading to skepticism about the authenticity of environmental claims (Torabi et al., 2016). Consumers may interpret this information gap as carbon offset providers being primarily profit-driven, rather than result-driven, which may lead to distrust in carbon credit projects.

Research indicates that consumer perceptions of the altruistic motives of carbon offset providers significantly influence their trust levels (Truong-Dinh et al., 2022). When providers are perceived as genuinely committed to environmental causes rather than driven by profit, consumer trust increases, thereby enhancing their willingness to pay for carbon offsets. This trust is influenced not only by perceived altruism but also by social norms and the effectiveness of the carbon offset programs themselves. One differentiating variable in the perception of “altruistic” carbon offset providers is the presence of co-benefits, or additional benefits that accompany a carbon offset project beyond carbon sequestration, such as biodiversity conservation benefits (Peixoto, 2024).

The VCM additionally deals with issues of standardization. The voluntary nature of the market means that there is no single regulatory framework governing these initiatives, leading to a plethora of different standards and certifications that can confuse and overwhelm consumers. This lack of uniformity often leads to questions about the rigor and comparability of the offsets, making consumers hesitant to participate (Ernst & Young, 2023). While registries such as Verra, ACR, and CAR exist to review project submission and aggregate data, and third party auditors exist to ensure carbon sequestration outcomes for an additional price, there is no overarching governance or standardization between registries or verifiers, leading to increased consumer distrust of verification systems. Furthermore, within these registries exist different crediting methodology standards, ranging from conservative to generous in regard to the quantity of carbon credits generated. These crediting methodologies are often unclear to many retail consumers, which may enhance distrust among carbon credit consumers.

To overcome these challenges and enhance consumer trust in VCMs, several strategies could be employed. Providers could invest in clear reporting and verification mechanisms to demonstrate the impacts of consumer contributions, including biodiversity co-benefits, which highlight the dual advantages of carbon offsets for ecosystem resilience and carbon sequestration. Standardizing the market through international regulations could further clarify and unify criteria, making it easier for consumers to trust the carbon credits they purchase. Additionally, educating consumers on the interconnected benefits of carbon offsetting, including its role in supporting biodiversity, may help build stronger, more informed advocacy for these environmental practices.

Relationship Between Carbon Offsets and Biodiversity Impacts

Interest in preserving biodiversity has increased rapidly in recent years, driven by a growing awareness of biodiversity loss and its profound ecosystem impacts (Waterford et al., 2023). This growth was further catalyzed by the adoption of the Kunming-Montreal Global Biodiversity Framework (KMGBF) during COP 15, which established 23 global targets to be achieved by 2023. Notably, Targets 2 and 3 of the KMGBF aim to restore, conserve, and manage at least 30% of terrestrial and aquatic ecosystems (United Nations Environment Programme, 2022). As the market seeks to meet these ambitious targets, there is a growing focus on the prioritization of biodiversity conservation within carbon credit projects (World Economic Forum, 2023). This shift towards projects that explicitly consider biodiversity in their design is particularly important, as some existing carbon credit projects may not fully address the nuanced requirements of biodiversity conservation. For example, eucalyptus plantations in the Amazon can sequester carbon rapidly, but compromise the region's biodiversity by introducing an invasive monoculture that does not support the native ecosystem (Osuri et al., 2020).

The relationship between biodiversity and the carbon market is still evolving. A primary challenge in integrating biodiversity benefits with carbon credits is accurately measuring the biodiversity impact of a carbon credit project. Improved data accessibility and quality can aid in identifying carbon credits that are likely to deliver positive biodiversity outcomes. For carbon credits to effectively support biodiversity protection, it is essential for nature-based project developers to consider not only the carbon removal potential of the project, but also factors that support biodiversity such as their locations in relation to biodiverse areas and the design of the project and its effects of that design on the local ecosystem. A noteworthy 2012 study investigating the potential overlap between carbon credit projects and biodiversity initiatives revealed that carbon credit projects that do not explicitly consider biodiversity generally yield significantly lower biodiversity benefits compared to biodiversity-centric programs (Siikamäki & Newbold, 2012). The study also highlighted a divergence in project locations, indicating that carbon credit projects do not always align geographically with biodiversity-rich areas (Siikamäki & Newbold, 2012). While some carbon credit registries have begun to develop biodiversity standards, there is currently no universally accepted framework for evaluating biodiversity within carbon credit projects (Tedersoo et al., 2024).

While carbon-focused initiatives may not be explicitly designed to create biodiversity benefits, some nature-based carbon credit projects possess characteristics that also promote biodiversity. For example, they may support habitat connectivity or protect critical ecosystems. These projects have the dual benefit of supporting biodiversity alongside carbon sequestration. Although this biodiversity benefit may not stand alone as a biodiversity credit, it can significantly increase the impact, credibility, and value of specific carbon credit projects. This may strengthen consumer trust and appeal to purchasers interested in carbon credits with biodiversity co-benefits.

The Emerging Biodiversity Market and Associated Metrics

There has been a rise in market-driven mechanisms aimed at addressing biodiversity loss (Verra, 2023). Broadly referred to as biodiversity credits, these units of exchange represent positive biodiversity outcomes and are designed to attract investment in biodiversity-positive projects (Verra, 2023). The Biodiversity Credit Alliance (BCA) defines a biodiversity credit as a certificate that reflects a measurable, evidence-based improvement in biodiversity that is additional and durable, or long-lasting (BCA Issue Paper No. 3, 2024). While this market is still evolving, a central challenge is agreeing on the metrics to measure biodiversity, which is complex because ecosystems vary widely (BCA Issue Paper No. 2, 2024). Despite these challenges, the same metrics used in biodiversity credits can also be applied to carbon credit projects, offering a way to assess their potential to support biodiversity alongside carbon offset goals.

The KMGBF, adopted at COP16, sets goals and indicators for protecting biodiversity (United Nations Environment Programme, 2022). Goal A focuses on maintaining ecosystem and species health, aiming to restore ecosystem integrity, connectivity, and resilience, while increasing the biodiversity of natural ecosystems and boosting native species populations by 2050. Key indicators include a red list of ecosystems (measuring risk of collapse based on factors like land-use change), the extent of natural and semi-natural ecosystems, and the red list index for threatened species and their genetic diversity. Other indicators assess ecosystem services, biodiversity benefits, and governmental actions.

In the United Kingdom, legislation was passed in 2021 mandating a net gain of biodiversity (BNG) for new development, and a uniform standard (the "Biodiversity Metric") was put forth for use by landowners and the burgeoning assessor and restoration industries. The UK Biodiversity Metric specifies three core habitat components: distinctiveness, condition, and strategic quality (Department for Environment, Food & Rural Affairs, 2024). Each component has a scoring rubric, and scores are aggregated to determine if a landowner is able to meet the BNG requirements or must create or enhance habitat otherwise.

Another system of biodiversity credit valuation, the SD VISta Nature Framework, has been published by Verra, an important player in the carbon market standardization space (Verra, 2023). This system equates one "Nature Credit" with one quality hectare (Qha). Similar to the Biodiversity Metric, a Qha is defined by its extent, condition and significance.

Plan Vivo, another carbon market participant, set forth a biodiversity crediting methodology in 2023. Each biodiversity certificate is based on the "multimetric", which includes 5 pillars: species richness, species diversity (including relative abundance (Chao et al., 2014), taxonomic dissimilarity (genetic distinctiveness), habitat health (usually vegetation cover calculated by Normalized Difference Vegetation Index), and habitat spatial structure (connectivity, calculated using the CPLAND Index (Wang et al., 2014).

Other debates in this space pertain to the question of whether improved or protected biodiversity in one location can be used to offset biodiversity loss in another. Verra takes a firm stance that its methodology may not be used to offset, and is intended for voluntary, net-positive action only. Plan Vivo makes no such disclaimer. The BCA states that biodiversity credits are "non-offset driven" but also acknowledges that companies may pursue biodiversity credit projects to compensate for past or continuing ecological damages (BCA, 2023). Debate continues in this space, and there are sure to be more developments in the leadup to COP16.

These methodologies and questions serve as a helpful framework for identifying the most effective metrics to assess the biodiversity impacts of nature-based carbon credit projects. This Group Project explored the key metrics currently used to quantify biodiversity in line with the methodologies outlined above. The following metrics were considered: Mean Species Abundance (MSA), IUCN Red List status, Species Richness, Rarity-Weighted Richness (RWR), the Ecosystem Integrity Index (EII), the Human Modification Index (HMI), the Biodiversity Intactness Index (BII), Net Primary Productivity (NPP), Nature's Contributions to People (NCP), Species Threat Abatement and Restoration (STAR), Proximity to Protected Areas, Biodiversity Monitoring Plans, Target End State, Regeneration Type, Project Type, Project Activities, and Species Type. While all of the above metrics were calculated, not all were included in the final analysis. Metrics not included in the analysis are attached in the appendix.

This Group Project aims to bridge the gap in understanding how nature-based carbon credit projects intersect with biodiversity conservation. Specifically, it seeks to identify which aspects of project design and location offer potential biodiversity benefits or pose risks to biodiversity. The metrics explored in this analysis help to determine which projects are best positioned to support positive biodiversity outcomes. Each metric was carefully examined by the research team, followed by a thorough evaluation of its relevance and value for the analysis. The Methods section (p. 14) provides a description and justification for the inclusion of each metric, as well as the rationale behind excluding certain metrics.

Corporate Alignment to Nature-Based Goals

Corporate purchases of nature-based carbon credits have emerged as a strategy for companies aiming to meet sustainability goals and offset their emissions. The VCM has experienced rapid growth, with nature-based solutions viewed as a promising solution due to the co-benefits attached (Perkins Coie). Despite a drop in overall carbon credit transactions, the market for nature-based carbon credits has continued to show resilience, with companies increasingly recognizing the value of these credits in achieving both their sustainability targets and nascent biodiversity initiatives (WEF, 2023).

However, recent research has raised serious concerns about the quality and effectiveness of these credits. A study by Trencher et al. (2024) revealed that companies predominantly sourced their offsets from low-quality avoidance activities, with only 2.3% of all retirements being from removal projects. This risk is particularly present in REDD+ offsets, which have been shown to be prone to over-crediting and exaggerating their additionality (West et al., 2020; Wunder et al., 2021). These findings, in addition to critical examination by publications such as the Guardian and New Yorker, have resulted in corporations shying away from low-quality carbon credits, leading to a drop in retired credits in 2023 (Procton, 2024).

Despite these challenges, there is potential for increased investment in high-quality nature-based carbon credits that have positive biodiversity implications. Companies motivated by additional non-emission impacts place greater value on co-benefits and are willing to pay more to achieve them (Seddon et al., 2020). Projects certified for biodiversity co-benefits command a 78% price premium over those without such certifications, and credits linked to the UN Sustainable Development Goals (SDGs) show an 86% higher price than non-SDG projects (Procton, 2024). By investing in high-quality nature-based solutions that generate both carbon credits and biodiversity benefits, companies can demonstrate a comprehensive approach to environmental stewardship in order to gain market competitiveness through reputational benefits

Similar to voluntary climate reporting standards, corporations pursue biodiversity reporting certifications to enhance their reputation, gain competitive advantages, and align with regulatory requirements. These certifications provide a structured framework for organizations to assess, manage, and disclose their biodiversity impacts and dependencies, demonstrating their commitment to environmental stewardship and sustainable business practices. The main certifiers offer distinct approaches to biodiversity reporting. The Global Reporting Initiative (GRI) focuses on comprehensive sustainability reporting, providing detailed guidelines for biodiversity disclosure within a broader environmental, social, and governance context. The Taskforce on Nature-related Financial Disclosures (TNFD) specifically targets nature-related risks and opportunities, aiming to shift financial flows towards nature-positive outcomes. The Science Based Targets Network (SBTN) emphasizes setting measurable, actionable, and time-bound objectives for nature, aligning corporate targets with global conservation goals. The Climate Disclosure Standards Board (CDSB) primarily focuses on integrating environmental and climate-related information into mainstream financial reports, ensuring that environmental data is reported with the same rigor as financial information. More information on these certifiers can be found in **Table 1**.

Table 1. Biodiversity criteria as considered by four key biodiversity certifiers (GRI, TNFD, SBTN, and CDSB).

Reporting Aspect	GRI	TNFD	SBTN	CDSB
Biodiversity Impacts	✓	✓	✓	✓
Biodiversity-related Risks	✓	✓	✓	✓
Biodiversity Strategy	✓	✓	✓	✓

Metrics for Biodiversity Loss/Gain	✓	✓	✓	✓
Ecosystem Services Assessment	✓	✓	✓	✓
Supply Chain Biodiversity Impacts	✓	✓	✓	✓
Stakeholder Engagement on Biodiversity	✓	✓	✓	✓
Location-specific Biodiversity Data	✓	✓	✓	✓
Financial Impacts of Biodiversity Loss	✗	✓	✗	✓
Scenario Analysis for Biodiversity	✗	✓	✗	✓
Biodiversity Action Plans	✓	✓	✓	✓
Biodiversity Offset Reporting	✓	✓	✗	✓

Biodiversity-related Financial Disclosures	✗	✓	✗	✓

Equity & Community Involvement

The success of carbon credit projects may be impacted by how the project engages with its local community. The long-term sustainability of a carbon credit project can be improved when its nearby community is supportive of its efforts, through employment or other community engagement initiatives (Guterres Lopez da Cruz, 2024). While carbon credit projects can support the mediation of excessive GHG emissions, nature-based projects may also hold a number of community benefits alongside a host of equity and community welfare issues (Wittman & Caron, 2009). The impacts of carbon credit projects on nearby communities can be categorized as follows: Indigenous impacts, benefits to local communities, negative impacts on communities, and proposed solutions.

- **Indigenous concerns:** Efforts to protect against biodiversity loss can exclude Indigenous communities, sometimes aggressively, or push Indigenous groups off their ancestral lands (Sena, 2015). These types of conservation-related evictions in Kenya have sparked fear among Indigenous communities that forest carbon credit projects will cause dispossession of their lands (Sena, 2015). Researchers in recent years have called for rights-based approaches to carbon credit project development, especially in regions of Indigenous residence, that enhance community participation in these projects (Waterford et al., 2023) (Sena, 2015). While these approaches seek to include Indigenous communities in developing and monitoring carbon credit projects, it is critical to note that Indigenous communities are not contributing drivers to climate change (Sena, 2015). It raises moral questions, therefore, to strongly encourage Indigenous participation in carbon credit projects as a remedy to an issue which they did not cause.

- **Benefits to local communities:** Nature-based carbon credit projects can provide benefits to neighboring communities. Labeled 'beyond-carbon impacts' by Senadheera et al., forest carbon credit projects can provide benefits aside from carbon sequestration that are becoming increasingly valued by credit buyers (Senadheera et al., 2019). Namely, carbon credit projects can supplement the livelihoods of locals by offering opportunities for additional income streams, as well as providing training programs for locals to develop project-related skills (Senadheera et al., 2019). One such project in Sri Lanka pays locals who provide care for planted trees; this project claims that 73% of its carbon credit sales go to the local community (Senadheera et al., 2019). Additionally, this Sri Lankan project trains locals on organic and efficient farming techniques and provides them trees to plant that can coexist with their current land use practices, offering locals support for their current livelihoods while also fostering supplementary income-increasing practices (Senadheera et al., 2019). It is relevant to note that involving local communities in a fair manner is also in the interest of project developers: as locals integrate into projects as a source of income, undesirable forest extraction behavior may decrease (Senadheera et al., 2019).

- **Equity issues:** Despite providing benefits to neighboring communities, some carbon credit projects also pose significant equity concerns (Wittman & Caron, 2009). A study by Mather et al. utilized empirical evidence from carbon credit projects and found that some host communities are challenged to protect their interests, including land rights and agricultural practices, and tend to benefit little overall from carbon credit projects (Mather et al., 2009). Locals are typically excluded from the project design process and are thus unable to dictate changes in local land use and their livelihoods (Lee et al., 2015; Waterford et al., 2023). Carbon projects additionally present gender equity complications, as results by Lee et al. find that accessibility of carbon credit project involvement was lower for women compared to men (Lee et al., 2015). Women, therefore, may have decreased access to the benefits of carbon credit projects described above.

- **Equity solutions:** Researchers have brought to light several solutions to address these Indigenous and community equity concerns. These solutions can stem from policy reform or through enhanced focus on the inclusion of local communities in the design and development of carbon credit projects (Mather et al., 2013) (Lee et al., 2015). Solutions may also include small and large-scale frameworks that involve government, private sector, and public stakeholders (Brown & Corbera, 2013); some researchers propose the utilization of liaisons between local communities and project developers (Mather et al., 2013). While many proposed solutions seem to adequately address carbon credit projects' equity issues, some researchers purport that equity issues may prove ever-present due to "the nature of the market itself" (Lee et al., 2015).

Project Types

Verra categorizes carbon credit projects into six key categories based on project activities. These project types are: Afforestation, Reforestation, and Revegetation (ARR), Agricultural Land Management (ALM), Improved Forest Management (IFM), Reduced Emissions from Deforestation and Degradation (REDD), Avoided Conversion of Grasslands and Shrublands (ACoGS) and Wetland Restoration and Conservation (WRC). The Climate Action Reserve (CAR) and American Climate Registry (ACR) also have several different project types, though our case study analysis only covers the CAR Forestry and the ACR Forest Carbon project types.

Reforestation involves replanting trees in areas that were previously forested but have been cleared, while afforestation refers to establishing forests in areas that were not historically wooded (Chazdon et al., 2016). Both practices can potentially enhance biodiversity by creating habitats and corridors for wildlife, though their effectiveness depends on the species planted and the local ecosystem context (Brockerhoff et al., 2008).

ALM, a holistic land management approach focusing on improving soil health, water management, and biodiversity, has gained traction as a carbon sequestration method. Practices such as cover cropping, reduced tillage, and crop rotation can increase soil organic carbon while potentially benefiting biodiversity through improved habitat quality and reduced chemical inputs (LaCanne & Lundgren, 2018).

IFM involves enhancing carbon stocks in existing forests through practices like extended rotation periods, reduced-impact logging, and fire management. While IFM can increase carbon sequestration, its impact on biodiversity varies; some practices may benefit certain species by creating more diverse forest structures, while others might negatively affect species adapted to specific forest conditions (Putz et al., 2012). In some cases, IFM projects have also resulted in a tradeoff between carbon storage and biodiversity, with projects that highly value carbon sequestration efficacy negatively affecting biodiversity (Ezquerro et al., 2024).

Both the CAR Forestry and ACR Forest Carbon project types cover a broad array of methodologies that include practices similar to IFM, ARR, and REDD+ Verra project types.

For REDD, WRC, and ACoGS projects containing conservation elements, there are potential biodiversity benefits due to additional protections. Still, data gaps exist due to the uncertainty of business-as-usual scenarios, and additional restoration is not taking place (Panfil et al., 2015). ARR and IFM projects with significant commercial timbering elements are more likely to prioritize yield over ecosystem integrity (Schwenk et al., 2012). Commercial timbering often results in habitat fragmentation, increased edge effects, and the interruption of successional processes. Additionally, commercial projects often include planting monoculture species in patterns that reduce ecosystem complexity and function, negatively impacting biodiversity (Seddon et al., 2020). While the biodiversity outcomes of these project activities are context-dependent and require careful consideration of local landscape-level dynamics, projects that include the creation, improvement, and protection of habitat, as well as support ecosystem integrity, have been shown to benefit biodiversity overall.

Case Study Descriptions

This analysis assesses the potential biodiversity implications of nature-based carbon credit projects by assessing how different characteristics of biodiversity manifest in five carbon project case studies. Below are descriptions of the five case studies that will be analysed in this Project. Details on the selection process of these case studies can be found in the Methods section of this report. **Figure 1** shows the locations of these case study projects on a global scale.

ARR Horizonte

The ARR Horizonte Carbon Project, developed by Suzano, is a privately-owned initiative launched in 2017 in Mato Grosso do Sul State, Brazil. Registered with Verra under ID number 33501, this ARR project covers 15,517.87 hectares within the Tropical Savanna biome. The project aims to sequester 2,686,131.95 tCO2e over 30 years by converting pasturelands into eucalyptus plantations and restoring degraded land with native vegetation. Spanning 14,427.66 hectares of eucalyptus plantations and 999.10

hectares of native vegetation restoration, the project seeks to increase forest cover and reduce greenhouse gas emissions in the region. However, the large-scale conversion to eucalyptus monocultures in the biodiverse Cerrado savannah raises concerns about potential impacts on local ecosystems (WayCarbon Soluções Ambientais e Projetos de Carbono LTDA, The ARR Horizonte Carbon Project).

Bandai Hills Bamboo Reforestation Project

The Bandai Hills Reforestation Project. Developed by EcoPlanet Bamboo Group, encompasses 7,818 hectares in the Ashanti Region of Ghana. This project sits adjacent to the North Bandai Bamboo Reforestation Project, and the projects are jointly managed with a total of 10,681 hectares of land destined for reforestation. The pre-reforestation landscape includes heavily degraded shrublands with invasive grasses, as well as some small remaining forest patches. The remaining forest patches are not included in the active project area. The land that has been highly degraded for at least 10 years is being planted with 1.5 million seedlings of giant clumping bamboo. Bamboo planting will occur for a 3-5 year period dependent on the duration of the rainy season during this time period. The remaining degraded land will be set aside for the planting of native plants and the conservation of biodiversity. The 20 year project is projected to sequester 188,926 tCO2e each year with a total of 3,778,511 tCO2e (EcoPlanet Bamboo Group, Bandai Hills Reforestation Project, Ghana).

Beed

The ALM Project in Beed District, India represents a comprehensive approach to sustainable agriculture, environmental stewardship, and community empowerment, offering significant ecological and socio-economic benefits. Implemented by Godrej Properties Ltd. in collaboration with the National Bank for Agriculture and Rural Development (NABARD) and the Center for Environment Education and Development (CEED), the project focuses on holistic watershed development aimed at integrating carbon sequestration practices while enhancing the livelihoods of smallholder farmers in the drought-prone villages of Bavi, Jamb, and Zapewadi. The project spans a total area of 3,274.65 hectares within a semi-arid biome, characterized by distinct seasonal variations: a cold season from December to February, a hot season from March to May, a southwest monsoon from June to September, and a post-monsoon period from October to November.

Launched on July 28, 2017, with a rollout period of three years, the project is set to have an operational lifetime of 20 years, with a VCS crediting period running until July 27, 2036. The project aims to achieve estimated annual greenhouse gas (GHG) reductions of 33,764 tCO2e, totaling 675,272 tCO2e over its lifetime. Over its three-year implementation phase, the project will utilize Sustainable Agricultural Land Management (SALM) practices, which include residue and nutrient management, agronomic practices, and agroforestry. These initiatives are designed to enhance soil and tree carbon stocks, mitigate greenhouse gas emissions, and improve food security while providing farmers access to carbon markets for revenue generation. Community engagement is a key aspect of the project, operating through a participatory framework that involves local farming communities and establishes a Village Carbon Project Committee (VCPC) to ensure active involvement and capacity building (CEED, Agricultural Land Management Project in Beed, India).

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Conhuas

The Conhuas project, developed by Toroto, is a 47,000 hectare restoration and conservation project in the Calakmul region of southern Mexico whose primary project activities are reforestation and conservation after years of timber harvesting and associated forest degradation. The majority of the project area is currently forested, with varying proportions of native species, natural structure and succession. The project is sited in a region with native tropical rainforests and several species of mammals, reptiles, birds, and amphibians, many of which have a threatened or endangered status. The project documentation also notes that the project is sited in a location that is connective between other patches of conserved habitat. The project includes mostly low to medium sub-evergreen and sub-deciduous vegetation, which displays some characteristics of evergreen and deciduous vegetation respectively, but not all.

Project activities include restoration, conservation, and sustainable extraction. Restoration includes replanting, thinning, weeding, and seeding, with the goal of attaining natural species composition, function, and structure. Conservation activities include biological monitoring, surveillance and illegal logging enforcement, and fire prevention and suppression. Sustainable use includes the harvesting of dead plant materials and approved cuts from silvicultural management, beekeeping, harvesting of certain animal species as game, and ecotourism. There is a strong community involvement component; the project documentation states that local communities will be trained on the economic and stewardship activities relating to the project.

Land tenure items are resolved through the “ejiditario” system, wherein heads of local households adjudicate certain matters and which governs much of rural Mexico. Carbon credits may not be issued on land that is disputed. The project began in 2021 and has a projected project length of 100 years. The project area has estimated carbon stores of 17.7 million tons of CO2e, and the agreement stipulates that the carbon will not be released for 100 years. The project document does not stipulate additional carbon sequestered (Toroto, Conhuas).

Thompson River

The Green Diamond Thompson River project is a conservation effort developed by the Green Diamond Resource Company in early 2021 focused on preventing development along the Thompson River basin in Northwest Montana. The project aims to reduce GHG emissions using IFM techniques to optimize carbon sequestration and saleable offset while maintaining ecosystem function. The techniques include decreased harvest relative to historical and legal harvest levels and retaining of existing species composition. The project is approximately 81,000 acres and represents a carbon stock of approximately 2.7 million tCO2e per project documentation (Green Diamond Resource Company, Thompson River IFM).

The initiative is being implemented in two phases. The first phase, with an estimated cost of $6 million, is supported by federal funding through the Forest Legacy Program and is the highest priority for federal funding in the region (Scott, 2022). The second phase builds upon ongoing conservation efforts in the broader Thompson River drainage area, which includes the Montana Great Outdoors Conservation Project and the Lost Trail Conservation Area.

Upon completion, the project will ensure that the Thompson River corridor remains open to the public while fostering continued forest management through responsible timber harvesting, thus balancing environmental protection with sustainable land use practices (Green Diamond Resources Company, U.S. Forest Project Data Report).

Carbon Credit Project Case Study Locations

Figure 1. Map showing the locations of the five nature-based carbon credit project case studies.

IV. Methods

Case Study Selection

The five case studies in this analysis were chosen from an approved list curated by Carbon Direct. The projects were selected on the basis of having valid geospatial data and active "registered" status in the carbon market. These five case studies in particular were chosen to represent a diverse range of locations and project types. It is important to note that the objective of this Group Project is not to compare these specific case studies and extrapolate findings to the entire carbon market using a sample of five, but rather, to use these case studies as a means of exploring the impacts of certain characteristics on carbon credit projects. **Table 2** shows the range of case study location and project types.

Table 2. Table showing the different case study projects and their project type, location and register.

Project Name	Project Type	Project Location	Registry
ARR Horizonte	Afforestation, Reforestation, and Restoration (ARR)	Mato Grosso do Sul State, Brazil	Verra
Bandai Hills	Agriculture, Forestry and Other Land Use (AFOLU)	Ashanti Region of Ghana	Verra
Beed	Sustainable Agricultural Land Management (SALM)	Beed District, Southwest India	Verra
Conhuas	Reforestation and Conservation	Calakmul region of Southern Mexico	Climate Action Reserve (CAR)
Thompson River	Improved Forest Management (IFM)	Northwest Montana	Verra

Rationale

This Group Project evaluated a variety of metrics, analyzing each one to determine its effectiveness in describing the biodiversity within a carbon project area or design. **Table 3** outlines the justification for including specific metrics, along with the rationale for excluding others, providing a comprehensive explanation of the selection process. More information on each metric, and its methodology for analysis can be found after **Table 3**.

Table 3. Provides a description and justification for the inclusion of each metric, as well as the rationale behind excluding certain metrics.

Metric	Description	Status	Rationale
IUCN Red List	Shows the number of threatened species in each project area.	Included	Uniquely assesses species threat levels, highlighting the urgency of biodiversity conservation in an area based on the number of threatened species present.
Species Richness	Measures the number of species within a specific area.	Included	A key indicator of biodiversity, species richness emphasizes the importance of conserving an area based on the diversity of species it supports.
Rarity-Weighted Richness (RWR)	Identifies areas that support species with limited geographic ranges.	Included	This is the only metric that focuses on species with restricted geographic ranges, highlighting the importance of conserving areas that support species with limited distributions.
Biodiversity Monitoring Plan	Identifies the projects that have specific biodiversity monitoring plans in the project documentation.	Included	Highlights carbon projects that actively monitor their biodiversity impacts, serving as a valuable indicator of accountability and commitment to conservation goals.
Global Human Modification Index (HMI)	Measures how humans have altered the terrestrial landscape of an area.	Included	Indicates the level of ecosystem degradation, emphasizing the urgency and importance of restoring biodiversity in areas that have suffered significant degradation.
Proximity to Protected Areas	Shows how far a carbon project is from its closest protected area.	Included	Highlights the importance of conserving or restoring biodiversity in areas that serve as critical links between protected regions, enhancing habitat connectivity and ecosystem resilience.
Species Threat Abatement and Restoration Metric (STAR)	Indexes threats to terrestrial biodiversity across the world.	Included	This metric identifies areas with the highest restoration potential and those most at risk from human development. It shows the importance of protecting vulnerable regions and restoring areas with significant restoration potential, both of which support biodiversity.
Biodiversity Intactness Index (BII)	Quantifies changes in ecosystem composition, providing a measure of species richness and abundance relative to undisturbed ecosystems.	Included	Measures the health and integrity of ecosystems, identifying areas that are crucial for preserving existing biodiversity. It highlights regions where conservation efforts can maintain or restore natural ecological functions.

Nature's Contributions to People (NCP)	Describes the positive and negative contributions of living nature to human's quality of life.	Included	Demonstrates how each project influences the local community, providing valuable insight into whether the project actively engages with and supports the community. It also evaluates whether potential biodiversity benefits extend to and positively impact local populations.
Primary Use of Invasive Species	Demonstrates whether carbon projects are primarily using invasive species.	Included	Highlights whether a project is primarily using species which threaten the local ecosystem and lead to biodiversity loss.
Extractive vs. Non-extractive	Determines whether projects have extractive activities taking place in addition to generation of carbon credits.	Included	Extractive activities may interfere with biodiversity supporting activities such as conservation.
Polyculture vs. Monoculture	Determines whether project activities use a polyculture vs. monoculture in planting activities.	Included	Monoculture activities may limit potential biodiversity uplift..
Project Types	Categorizes project activities into standardized types as defined by Verra.	Included	Explains the project's management approach as defined by Verra.
Mean Species Abundance (MSA)	Measures local terrestrial biodiversity intactness based on the abundance of original species in an ecosystem under a given threat regime compared to the abundance of species in a pristine environment.	Not incl…	Overlaps heavily with the BII results but is less comprehensive.
Ecosystem Integrity Index (EII)	Reflects the overall health of ecosystems, encompassing their structural, functional, and compositional elements.	Not incl…	This metric combines the BII, HMI, and NPP, but it is more informative to evaluate each score individually. Doing so allows for a clearer understanding of the distinct differences between the metrics within each carbon project, rather than relying on an aggregate that may obscure important nuances.
Net Primary Productivity (NPP)	Reflects the amount of energy plants capture	Not incl…	An indirect measure of biodiversity. Other metrics measure biodiversity

	through photosynthesis.		more directly.
Habitat Fragmentation	Shows the degree to which a specific area of habitat has been fragmented.	Not incl…	Beyond the resources of this project. This metric could be interesting to consider in a future analysis.
Regeneration Type	Describes the process for ecosystem recovery and restoration.	Not incl…	The details of this metric are captured by other metrics.
Target End State	Set be project developers prior to project creation to determine the type of ecosystem that will be developed on the project site.	Not incl…	The details of this metric are captured by other metrics.

Standardizing Metrics for Comparison

The following metrics produced numerical outputs: IUCN Red List, Species Richness, RWR, the global HMI, proximity to protected areas, the STAR metric, and the Biodiversity Intactness Index. Z-scores were used to standardize the different metrics, making it easier to compare values that may have different units or scales.

Z-scores transform data into a common scale with a mean of 0 and a standard deviation of 1, enabling researchers to identify how far each value deviates from the average. **Formula 1** was used to calculate the z-score, or standard score, of each carbon credit project's score for each quantitative metric.

$$Z = \frac{x - \mu}{\boldsymbol{\sigma}}$$

Formula 1. *Equation used to obtain the Z-score, or standard score, of data point x, where* µ *is the mean value and* $\boldsymbol{\sigma}$ *is the standard deviation of the dataset.*

The means of the entire dataset for the species richness, RWR, BII, STARr, STARt rasters were calculated in ArcGIS Pro using the Get Raster Properties tool, with property type set as 'mean of all cells.' To obtain the standard deviation of these datasets, the Get Raster Properties tool was used with property type set as 'standard deviation of all cells.' Next, in RStudio, the Z-score for each raw score of each quantitative metric was calculated using **Formula 1**.

Metric Grouping for Buyer's Interests

This Group Project assesses 18 metrics of analysis which have been divided into two key categories: project location and project design. The metrics were grouped into either of these categories based on whether their value revealed more about the region where the project is geographically located, or about specific project design elements that are not contingent on location. The metric division is shown in **Table 4**.

Table 4. Table showing the division of 18 metrics into two key categories: project location and project design.

Project Location	Project Design
● Species Richness ● Biodiversity Intactness Index (BII) ● Species Threat Abatement and Restoration (STARt) ● IUCN Red Listed Species ● Rarity-Weighted Richness (RWR) ● Species Threat Abatement and Restoration (STARr) ● Global Human Modification Index (HMI) ● Proximity to Protected Areas	● Monoculture vs Polyculture ● Extractive vs Non Extractive ● Primary Use of Invasive Species ● Materials, Companionship, Labor ● Learning & Inspiration ● Physical & Psychological Experiences ● Supporting Identities ● Biodiversity Monitoring Plan ● Additionality ● Verification Body

Within these two categories, the metrics were further divided into six sub-categories which grouped together metrics looking at similar aspects of the project. This grouping allows for key biodiversity themes to emerge, and plays an important role in aligning a project's biodiversity potential with a credit buyer's specific biodiversity objectives. The sub-category division can be found in **Table 5**.

Table 5. Table showing the grouping of 18 metrics within two key categories into six further categories based on metric similarity.

Project Location	**Project Design**
Species Presence ● Biodiversity Intactness Index (BII) ● Species Richness	Primary Project Attributes ● Monoculture vs Polyculture ● Extractive vs Non Extractive ● Primary Use of Invasive Species
Species Threat ● Species Threat Abatement and Restoration (STARt) ● IUCN Red Listed Species ● Rarity-Weighted Richness (RWR)	Nature's Contributions to People ● Materials, Companionship, Labor ● Learning & Inspiration ● Physical & Psychological Experiences ● Supporting Identities
Restoration Potential ● Species Threat Abatement and Restoration (STARr) ● Human Modification Index (HMI) ● Proximity to Protected Areas	Additionality & Assurance ● Biodiversity Monitoring Plan ● Additionality ● Verification Body

Species Presence

Biodiversity Intactness Index

The BII dataset, measuring species present in a given location, was produced by the Projecting Responses of Ecological Diversity in Changing Terrestrial Systems (PREDICTS) project. BII can be used to quantify changes in ecosystem composition, providing a measure of Species Richness and abundance relative to undisturbed ecosystems similar to the MSA (Newbold et al., 2016). The dataset was created by inputting the results of ecological studies on species presence and abundance worldwide, including 54,000 species of animals, plants, and fungi, into models that reflect the extent to which human activities have altered species communities. The output was then combined with data on human pressures and their intensity, yielding a value that indicates how those human pressures correlate to species loss. The result was aggregated into a publicly available global geospatial layer.

The objective of this analysis was to assess the BII for specific project sites using Geographic Information Systems (GIS), with the goal of evaluating the health and integrity of biodiversity relative to a baseline of minimal human disturbance. The primary data source for the BII was a dataset provided by the Natural History Museum (Helen et al, 2021), which lacked a coordinate system when imported into the GIS software. This was reprojected to WGS 1984. The dataset was then converted into a raster format to facilitate spatial analysis and alignment with the project area. Next, the BII data was clipped to each project's geographic boundaries using shapefiles for each project area, ensuring that only relevant data within the project limits was included. Finally, the mean BII value for the project area was calculated using the Calculate Statistics tool in GIS, providing an overall assessment of biodiversity integrity for the site. This process allowed for a clear estimation of the extent to which the area retained its natural biodiversity, which is critical for understanding the ecological health of the project sites.

Species Richness

Species Richness measures the number of species within a specific area (Roswell, 2021). It can be used in conjunction with other metrics, such as species evenness or abundance, to provide a broader picture of species diversity (Deland, 2012). Species Richness is one of the simplest indicators of community and regional diversity, so is often an explicit goal of conservation efforts (Gotelli, 2001).

In the context of carbon credit projects, understanding current Species Richness levels can help predict the potential for biodiversity conservation of different regions (Fleishman et al., 2006). It is important to note that comparing Species Richness across regions is challenging due to factors such as area size, sampling scale and intensity, taxonomic grouping, and estimation methods, as well as the dynamic nature of species populations (Fleishman et al., 2006). However, when considered alongside other metrics, Species Richness can be valuable in prioritizing areas for biodiversity conservation; similar consideration of Species Richness can be taken in identifying the importance of conducting biodiversity-positive practices within carbon credit projects (Fleishman et al., 2006).

This analysis assessed the total number of species present within each carbon credit project using species presence data sourced from the IUCN Red List version 2024-2. The raster data counts all species that could be present in an area based on their known geographic ranges, per 900km^2 pixel globally. This analysis of Species Richness is terrestrial and excludes marine, aquatic life, and fish species. The Species Richness raster includes amphibians, birds, mammals, and reptiles. In ArcGIS Pro, the Merge tool was used to combine multiple features within each project's shapefile into a single polygon feature. To create polygons that are more contiguous than the highly fragmented project shapes for our analysis, the Buffer tool was used on each project's polygon to create a 5km buffer around each project, with dissolve type set to dissolve all output features into a single feature. Next, the Project Raster tool was used to re-project the Species Richness raster into WGS 1984 for consistency with the other shapefiles. The Zonal Statistics (Spatial Analyst) tool was used with the Species Richness raster as the input raster and each buffered carbon credit project polygon as the feature zone data. Setting the Statistics Type as maximum was used to obtain a value for the most species present within each carbon credit project's area. The output of this analysis provided the maximum Species Richness for each carbon credit project site. One limitation of this analysis is that some of the case study sites are highly fragmented, while others are not. Using a 5km buffer means that, potentially, a location within 5km of a project site could contain a higher Species Richness than anywhere within the project boundaries, and that higher richness value would be recorded for that project even though that value does not occur within the project boundaries. However, this circumstance is the same for each project, so the analysis of Species Richness is consistent for the project site and its 5km buffer.

Species Threat

Species Threat Abatement and Restoration - Threat Abatement

The STAR Metric integrates threatened species density, threat mitigation opportunities, and potential for restoration in a given region in two values; STARt for threat abatement, and STARr for restoration potential. STARt is discussed here, and STARr will be detailed in the Restoration Potential bin. First presented in the scientific literature (Mair et al., 2021), the STAR metric indexes threats to terrestrial biodiversity across the world in the form of global geospatial layers that quantify threatened species density (weighted by status per the IUCN Red List), the magnitude and severity of destructive human activity (per the IUCN Threats Classification Scheme), and restorable habitat as a proportion of the abundance of that habitat worldwide. The STARt value indicates how local threat abatement could contribute to avoiding species extinction, and every species in a given region is assigned its own score.

This metric is recommended by the SBTN for investors and corporations to indicate potential impacts on biodiversity when quantifying value chain footprints and biodiversity-positive actions (SBTN, 2024). In the context of carbon credit projects, the STAR metric indicates where biodiversity-positive projects can be leveraged to support biodiversity and where biodiversity-neutral or negative projects may contribute to the problem. This analysis will examine the STAR values (provided alongside Mair et al) at 50km resolution in the regions where the case study projects are sited, indicating the scale of impact a biodiversity-positive project could have on global biodiversity goals.

The STARt geospatial layer for reptiles, birds, and mammals was downloaded as a global 50km resolution raster in TIFF format from Mair et al. 2021. ArcGIS Pro was used to complete this analysis, and Microsoft Excel and Google Sheets were used to record results. The downloaded raster was opened in ArcGIS Pro and projected to WGS 1984 (EPSG 4326). Polygon shapefiles of the case study project boundaries were converted to points using the Feature to Point tool. Using the Extract Multivalues to Points tool, the STARt values of each pixel within the case study boundaries were calculated and tabulated in an attribute table attached to the shapefiles. If more than one STARt pixel was partly or fully within a project boundary, the values were averaged for the project. This attribute table was exported as an Excel table. The end results of the analysis were two values that represented the STARt values of the pixels or average of pixels where the case study project was located. These values can be compared to each other and to global minimums, maximums, and averages to make statements about the relative potential for abating threats and restoring habitat in the region.

The only publicly available dataset is at a resolution of 50km by 50km pixels, which is relatively coarse and imprecise when attempting to draw conclusions about projects that may be only hundreds of hectares in size. Higher resolution datasets are available for purchase from the provider, the Integrated Biodiversity Assessment Tool (IBAT), but this project is limited in its budget at this time. Given this limitation, the analysis must assess based on pixels that are larger than project footprints. It assumes that an average STARt value across the pixels intersecting with the project will be accurate without weighting given to the proportion of the project area within a given pixel. This assumption does not raise concerns as STARt values in proximity to each other generally do not vary significantly in value.

IUCN Red List

The International Union for the Conservation of Nature (IUCN) is the most comprehensive global database of the extinction risk of plant, animal, and fungus species (IUCN Red List, 2022). The database was established in 1964 and presently contains over 166,000 species on the Red List, including 43,000 species that are currently threatened with extinction (IUCN Red List, 2022). The Red List is used to guide policy and conservation decisions, shape scientific research, and inform the allocation of resources to vulnerable species and areas (IUCN Red List, 2022). Species are included on the Red List after scientists undergo a series of measurements on each species' threats, reproductive rates, population size, and geographic range (IUCN Red List, 2022). These measurements are then assessed against IUCN criteria to determine the species' extinction risk. The findings are then peer-reviewed and the species is assigned to one of nine levels of vulnerability: Not Evaluated, Data Deficient, Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild, and Extinct (IUCN Red List, 2022).

It is important to note the limitations of the IUCN Red List data. There are some concerns within the scientific community that the Red List has incomplete and biased coverage (Bachman et al., 2019). While comprehensive assessments have been conducted for birds, mammals, and amphibians, gaps remain for reptiles and fish, meaning only 68% of described vertebrate species have been evaluated (Bachman et al., 2019). Additionally, invertebrates, plants, and fungi remain largely under-assessed, with fewer than 3% of known species evaluated. As a result, the extinction risk of the majority of the world's species remains unassessed (Bachman et al., 2019). Nevertheless, this Group Project chose to include the IUCN Red List data to provide an additional layer of analysis for the species threat bin, in addition to STARt.

This analysis utilizes geospatial IUCN Red List data for reptile, mammal, bird, amphibian, and plant species, focusing only on species listed as Near Threatened, Vulnerable, Endangered, and Critically Endangered. Species shapefiles were sourced from the IUCN Red List of Threatened Species and BirdLife International (IUCN). These polygon shapefiles contain terrestrial presence data for amphibian, plant, mammal, reptile, and bird species and excludes marine, aquatic life, and fish species. In ArcGIS Pro, the Merge tool was used to combine multiple features within each project's shapefile into a single polygon feature. Next, a one-to-many Spatial Join was performed with the species polygons as the Join Features and the merged carbon credit project polygons as the Target Features with match option Intersect. The list of IUCN Red List species was exported from the attribute table of each spatially joined polygon into Excel. In Excel, the results were filtered for only species listed as Near Threatened, Vulnerable, Endangered, and Critically Endangered. Duplicate species names were removed so each species was only counted once. Finally, the quantity of species classified as Near Threatened, Vulnerable, Endangered, and Critically Endangered was summed for each project.

Rarity-Weighted Richness

RWR differs from traditional Species Richness by highlighting areas that support rare species. Rare species are defined here as those that have small geographic ranges (Albuquerque, 2016). This makes RWR useful for identifying areas critical for conserving endemic, or geographically restricted, species.

This metric was calculated downloading a raster in tiff format and summing the rarity scores of species within a given location using ArcGIS Pro (IUCN, 2022). A rarity score represents the proportion of a species' total range that occurs within that specific area. RWR is a key tool in conservation planning, helping to identify areas critical for biodiversity protection. In this analysis, the IUCN Red List RWR dataset (version 2024-2) is used to evaluate whether a carbon credit project is situated within a region that supports rare species, highlighting the region's importance for biodiversity conservation.

The dataset is focused on terrestrial areas. For each species, the RWR value for a pixel is the proportion of the species' range contained within that cell. This can be the area of the pixel divided by the area of the species' range, or, as in these analyses, 1 divided by the total number of cells overlapped by that species' range. These values are summed across all the species to give the relative importance of each pixel to the species found there. For species with different breeding and non-breeding ranges, where a pixel is contained in both ranges, the calculation is based on the smaller range, i.e. the season in which that area is more important.

RWR values for each species within a project site were summed to calculate the site’s overall RWR. The dataset was opened in ArcGIS Pro and projected to WGS 1984. A 5 km buffer, with dissolve type set to dissolve all output features into a single feature, was added around each site’s boundary to increase contiguity of the highly fragmented project shapes. Using this buffer means that a location within 5km of a project site could potentially contain a higher RWR than anywhere within the project boundaries. However, this circumstance is the same for each project, so the analysis of RWR is consistent for the project site and its 5km buffer. Fragmented polygons were merged in ArcGIS Pro and the Zonal Statistics tool was used to extract the maximum RWR value within the buffered site, providing a single numerical RWR score representing the site’s importance for species with small ranges.

Restoration Potential

Species Threat Abatement and Restoration - Restoration

As discussed above, the STAR metric incorporates present species threat levels, threats, and restoration opportunities on a regional level. The metric also outputs a STARr value, which quantifies the impact of restoration based on how much habitat is restorable and what proportion of that specific habitat exists worldwide. Like the STARt value, the STARr value indicates how local habitat restoration actions could contribute to global biodiversity conservation. Every species in a given region is assigned its own score for both values.

The STARr geospatial layer for reptiles, birds, and mammals was downloaded as a global 50km resolution raster in TIFF format from Mair et al. 2021. ArcGIS Pro was used to complete this analysis, and Microsoft Excel and Google Sheets were used to record results. The downloaded rasters were opened in ArcGIS Pro and projected to WGS 1984 (EPSG 4326). Polygon shapefiles of the case study project boundaries were converted to points using the Feature to Point tool. Using the Extract Multivalues to Points tool, the STARr values within the case study boundaries were calculated and tabulated in an attribute table attached to the shapefiles. If more than one STARr value was included within a project boundary, the values were averaged for the project. The end results of the analysis were two values that represented the STARr values of the pixels or average of pixels where the case study project was located. These values can be compared to each other and to global minimums, maximums, and averages to make statements about the relative potential for restoring habitat in the region. Like STARt, this analysis is limited by the coarse resolution (50km) of publicly available data.

Global Human Modification Index

The global HMI is a commonly used metric helpful when quantifying structural integrity of ecosystems and measuring how humans have altered the terrestrial landscape around the world, degrading ecosystems and impacting biodiversity in the process. This metric considers many factors, including the size of the area impacted, the intensity of modification, and the compounding of multiple stressors in a given location (Theobald et al. 2020). HMI integrates stressor data extrapolated from satellite imagery given a certain region and classifies them based on the Direct Threats Classification from Salafsky (Salafsky et al., 2008). Each classification of stressor (i.e., roads, agricultural, oil, and gas) uses a distinct methodology to calculate the *H* value of the activity. Those values are aggregated across a pixel to give a final *H* value for that area, given the nature, spatial extent, and intensity of the stressors recorded (Kennedy et al., 2019). In the context of this project's case studies, the HMI can indicate how fragmented and how impacted the surroundings of a given project footprint are. A highly impacted region may mean that the biodiversity impacts of a project have minimal impact on an ecosystem, whereas projects located in more intact areas have a higher potential to do harm or maintain ecosystem integrity.

To complete this analysis, a geospatial dataset in the form of a 1km by 1km resolution raster in TIFF format, created by Kennedy et al 2019, was sourced from NASA EarthData (Kennedy et al., 2019, NASA EarthData). The dataset was then processed in ArcGIS Pro. The raster data was projected to WGS 1984 (EPSG 4326). The values of HMI were calculated using the Zonal Statistics tool. The mean of HMI pixel values within each project boundary was generated and tabulated in an attribute table. This attribute table was exported as an Excel table. The end results of this analysis were the HMI values of the pixels, or average of pixels, where the case study project was located. These values can be compared to each other and to global minimums, maximums, and averages to make statements about the relative HMI in the region where the project is located.

This analysis assumes that the 1km resolution of the HMI layer will be accurate given that some case study projects are smaller than 1 km^2. This analysis also assumes that the mean of the HMI values within project boundaries accurately reflects the level of modification across the project area. This analysis was limited by the resolution of data. Additionally, the data is over 8 years old and does not capture the continued human modification that has occurred since then.

Proximity to Protected Areas

In today's world, protected areas contain much of Earth's remaining biodiversity and represent its best protection (McNeely, 1994). Conservationists and environmentalists work continually to create new protected areas and expand existing ones strategically, protecting land that will most benefit one or many species. When land cannot be protected or conserved, thoughtful land use practices may serve a similar purpose by supporting biodiversity on land around existing protected areas (Almeida Rocha & Peres, 2021). Special attention and creative strategies should be employed to conserve ecosystem function in these buffer zones. In the case of nature-based carbon credit projects, a project's proximity to an existing protected area or network of protected areas can determine how supportive or detrimental the project could be to biodiversity conservation goals. Parcels close to protected areas can act as buffers by effectively expanding or connecting habitat or contributing to habitat degradation by increasing edge effects and fragmenting existing habitat depending on the project design (Harvey et al., 2014).

The purpose of this analysis was to quantify the distance from each case study project to protected areas (PAs) to gauge the project's potential to act as contiguous habitat or function within a PA network. The IUCN World Database of Protected Areas (WDPA) dataset contains geospatial data on protected areas worldwide, as well as information on the level of protection in each area. IUCN categories I-IV generally afford a level of protection that excludes extractive economic activity (Schafer 2015), therefore this analysis will only include these categories. An edge-to-edge analysis will compare the distance between the nearest edges of the shapefiles, representing the distance an individual would travel before benefitting from the potential protections of the PA or carbon credit project. The results of this analysis will help determine whether or not case study projects are sited within short distances easily crossed by species in existing PA networks, giving insight into whether or not the area could contribute to habitat connectivity given biodiversity-positive project design. Projects in proximity to existing PAs without biodiversity-positive project design may contribute to habitat fragmentation and degradation rather than supporting a PA network (Almeida Rocha & Peres, 2021).

ArcGIS Pro was used to complete this analysis, and Microsoft Excel and Google Sheets were used to record results. Using the Select By Attribute tool, the WDPA dataset was limited to PA Classes I-IV, classifications that generally afford a level of protection that excludes most extractive uses. That selection was then limited to PAs greater than 100 hectares in size, also using the Select By Attribute tool, to represent PAs with significant amounts of viable habitat. The nearest PA was identified by performing a One-to-One Spatial Join by Closest within a 100km radius. The distance from the edge of the project to the PA boundary was calculated in this operation, and output into an attribute table, which was then exported to an Excel file. For each case study project, a distance to the nearest PA was generated, representing proximity to existing and protected habitat.

To calculate the z-score of this analysis, the distance accumulation tool was used to generate a raster of distances from the WDPA dataset of PAs, yielding a global dataset of how far away global locations are from the nearest IUCN category I-IV PA greater than 100 hectares. This dataset was clipped to terrestrial boundaries using an ESRI continents shapefile, and statistical results were generated using the zonal statistics as table tool. These statistics were then translated into z-scores using the methodology detailed above in Formula 1. As a secondary analysis, this raster was constrained geographically using the maximum latitiudes of a global geospatial dataset of nature-based carbon credit project shapefiles from Renoster (Karnik et al., 2024). The shapefile of the carbon credit project footprints was bound to its maximum latitudes using the Minimum Bounding Geometry Tool in ArcGIS, and the distance accumulation raster was clipped to the maximum latitudes of existing carbon credit projects. This excludes millions of hectares of land in the far north and south which do not generally support nature-based carbon credit projects and which do not contain PAs that fit the analytical criteria, thus skewing the mean and standard deviation of the global z-scores.

This analysis assumes that distinguishing between IUCN Categories I-IV and V-VI is a reasonable distinction to make, and is supported by the literature (Huang et al, 2024). This analysis also assumed that PAs greater than 100 hectares represent a volume of habitat that is likely to support plant and animal populations, whereas smaller PAs are less likely to do so. This analysis also assumes that the species that the PAs support generally have a range of 100km or less. This analysis was limited by inconsistent data on levels of protection for different PAs, and it is possible that PAs with certain IUCN categorizations may have less or more protections on the ground. Additionally, certain projects that may have existing IUCN classifications were not classified as such in the dataset. For each case study project, a distance to the nearest PA was generated, representing proximity to existing and protected habitat. In some cases, the analysis found that projects were in existing PAs, which raises an additionality problem.

Primary Project Attributes

Primary Use of Invasive Species

The objective of this analysis was to determine whether projects primarily use invasive species planting activities such as reforestation or agriculture. The data sources were project documents submitted to the project verifier, supplemented by external taxonomy and ecology sources to ascertain species' status. The methodology involved identifying species introduced to the region using project documents, followed by external research to determine species' native range and potential for invasive behavior. This process did not require specific tools or software. The analysis assumed that project documents were accurate and complete, with no other species introduced beyond those reported. The final output was a table listing project names and the introduced species, categorized as invasive or non-invasive.

The term "non-invasive species" encompasses both native species and non-native species that have the potential to contribute positively to biodiversity. According to the International Union for Conservation of Nature (IUCN) and the Convention on Biological Diversity (CBD), native species are those that exist within their natural range without human introduction or care. This definition does not specify a required time frame that the species must have been present in its range, so alternative definitions address this gap by proposing a timeline, such as species present since the Late Pleistocene or those that naturally (re)colonized during the Holocene (Crees, 2015).

Project developers must justify their species selection, so having a clear understanding of species impacts is essential (Crees, 2015). Defining non-invasive species is important because it allows project developers to make informed decisions on which species to plant or remove in the name of conservation and biodiversity (Crees, 2015).

Invasive species, the presence of which constitutes a potential biodiversity threat, is a species category that can be further delineated from non-native species. While all invasive species are non-native, not all non-native species become invasive. Invasive species aggressively establish themselves and cause environmental damage, harming biodiversity (EOPugetSound).

While the impact of invasive species is context-dependent, in many cases, an invasive species can dominate an ecosystem, creating a concentrated biomass of that species and resulting in overall lower biodiversity (Linders et al., 2019). However, similar to non-native non-invasives, certain invasive plant species, especially those classified as "ecosystem engineers," can significantly boost plant biomass and carbon storage in coastal environments such as salt marshes, mangroves, and seagrass beds (Davidson et al. 2018). For this reason, invasive species can sometimes be used in carbon credit projects to quickly sequester large amounts of carbon. However, using invasive species to store carbon can have negative biodiversity impacts; therefore, in this analysis, using invasive species to sequester carbon in carbon credit projects is characterized as not biodiversity-positive.

Polyculture vs. Monoculture

Projects were evaluated on their use of polyculture (multiple species) versus monoculture (single species). Polyculture enhances biodiversity and ecosystem resilience, while monoculture can degrade soil and reduce habitat diversity. Some projects integrate diverse plantings, but others rely on monocultures for forestry or agriculture, raising concerns about long-term ecological sustainability. In order to determine polyculture vs. monoculture status, project documents were reviewed and a determination was made, with polyculture representing best practices

Extractive vs. Non-extractive

This analysis examined whether projects incorporate extractive activities, such as forestry and agriculture, alongside conservation efforts. Extractive activities can generate economic benefits but may conflict with biodiversity goals if not managed sustainably. Non-extractive projects focus solely on habitat restoration and protection, minimizing human impact. While some projects balance extractive use with conservation, others prioritize biodiversity by avoiding resource extraction altogether, underscoring the trade-offs between economic viability and ecological integrity. In order to determine extractive vs. non-extractive status, project documents were reviewed and a determination was made, with non-extractive representing best practices

Nature's Contribution to People

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is a joint global effort motivated to influence policy formulation by evaluating biodiversity and ecosystems as they relate to humans. NCP is the most recent addition to the IPBES framework that builds on the concept of ecosystem services. By definition, NCP is all the positive and negative contributions of living nature to humanity's quality of life. Positive contributions include water purification, food provision, and flood control. Examples of negative impacts are disease and damage to human assets.

The NCP framework sorts nature's benefits into three categories: material contributions, regulating contributions, and non-material contributions. Material contributions are substances or material elements from nature that directly sustain a human's physical existence or assets. This typically includes substances that are physically consumed in the human experience, such as energy or material for clothing. Regulating contributions are objects that affect quality of life in an indirect way. For example, people enjoy being around beautiful plants yet indirectly benefit from the soil organisms needed to keep plants alive (Diaz et al., 2018). Non-material contributions explain the psychological effects that can bolster quality of life. Examples of non-material NCP include the educational and recreational benefits of ecosystems. **Figure 2** below illustrates benefits in each of these categories according to the NCP framework.

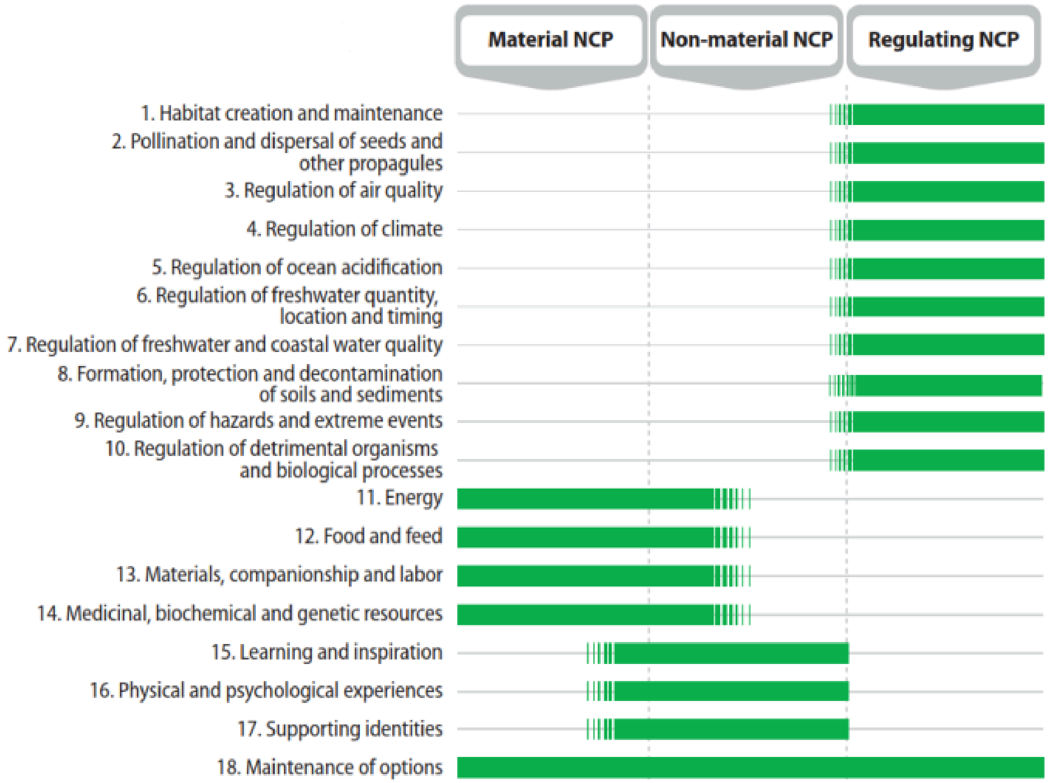

Figure 2. NCP categorization of different material and non-material benefits (Diaz et al., 2018).

While NCP has bolstered the considerations made by the ecosystem services framework by incorporating more social science and cultural components, the current NCP system still holds some limitations. The material, regulating, and non-material categories are not mutually exclusive, and many of the 18 named contributions in **Figure 2** may fit into more than one category (Diaz et al., 2018). Additionally, some local and Indigenous knowledge-holders describe food and pollinator-related contributions as human obligations to nature or reciprocal relationships with nature; these contributions do not fit well into NCP's categories (Diaz et al., 2018). Lastly, NCP inherently treats humans and nature as separate entities, which contrasts with the cultural beliefs of many groups worldwide.

In relation to this project, the NCP framework overall aligns well with the investigation of the community well-being aspect of our case studies. It should be noted that this Group Project is constrained in its ability to study many of the 18 contributions because of limitations in data availability. This project will focus on contributions 13, 15, 16, and 17 of the NCP framework to understand each carbon credit project's community and cultural implications. Namely, these contributions are (13) Materials, companionship, and labor; (15) Learning and inspiration; (16) Physical and psychological experiences; and (17) Supporting identities. Contribution 13 was chosen to evaluate the degree to which carbon credit projects support local economic livelihoods and provide opportunities for community employment. Contributions 15, 16, and 17 are included to develop a holistic view of each project's impacts on their surrounding communities; through these contributions, the analysis will provide context for the extent to which each project supports adjacent communities' ability to access green space, engage with the ecosystem for cultural purposes, and immerse themselves in educational opportunities related to the carbon credit project.

The objective of this analysis was to assess nature's contribution to people (NCP) within carbon credit projects, ensuring that these projects not only focus on carbon sequestration but also enhance human livelihoods and support human well-being. The analysis was conducted using the carbon credit project documents provided, with no additional data or external software tools employed. The methodology involved reviewing the project documentation by searching for keywords specific to each NCP category, including terms related to livelihood, materials, labor, education, well-being, community development, and sustainable development. These keywords helped pinpoint relevant information within the documents for each category of NCP. **Table 6** below depicts the exact keywords used to extract information. Information identified through keyword searches was compiled to evaluate the project's initiatives in promoting NCP. No underlying assumptions were made during the analysis, though a key limitation was the inconsistency in the depth and detail of project documents. Some projects provided comprehensive information on sustainable development and community well-being, while others lacked sufficient detail, which hindered a thorough comparison and assessment. As a result, the findings may not fully capture the scope of each project's potential to enhance human livelihood. The output of this qualitative analysis consists of a written summary of the findings, which assesses how each project considers NCP.

Table 6. List of keywords used to search the project documents for information related to each specific NCP category.

NCP Category	Keywords
Materials, companionship, and labor	*livelihood, pay, paid, economic, economy, labor, volunteer, involve, job, career, employ, income*
Learning and inspiration	*learn, inspire, inspiration, educate, education, educating, well-being; train*
Physical and psychological experiences	*community, development, health, well-being*
Supporting identities	*engage, women, social, sustainable development*

Additionality & Assurance

Additionality

Additionality in carbon credit projects generally refers to the degree that that emissions reductions or removals would not have occurred without the incentive provided by carbon credit revenues. A project is considered additional if it goes beyond business-as-usual practices and overcomes barriers that would otherwise prevent its implementation. This concept is crucial for maintaining the integrity and effectiveness of carbon offset projects, as it guarantees that the credits represent genuine environmental benefits.

While this is often analyzed with respect to carbon sequestration, it can also be considered with biodiversity implications. This means that if there are biodiversity benefits, they would not be occurring if it weren't for the project. This could be especially relevant for projects in the conservation and avoided deforestation space, since in order to prove additionality the project must prove that otherwise it would be deforested.

Case studies were analyzed in the following three categories: active restoration, presence of historic degradation, and previous non-protection, the presence of each being considered "best practices" in biodiversity additionality. Active restoration means a project involves active planting of carbon sequestering plants, versus preserving existing plants. To assess this, project document Presence of historic degradation determines whether the area was previously degraded, similar to project siting. Previous non-protection refers to an areas status as a non-protected or protected area, such as a national park. **Table 7** shows the presence of each category for each case study:

Table 7. Shows the presence of all the positive additionality characteristics for each case study.

Project name	Active Restoration?	Degraded Prior to Project Development?	Previously Unprotected?
Beed	Yes	Yes	Yes
Thompson River	No	No	Yes
Conhuas	Yes	No	No
ARR Horizonte	Yes	Yes	Yes
Bandai Hills	No	Yes	No

Verification Body

Verification plays a crucial role in ensuring the integrity and credibility of emissions reduction claims. Organizations such as Verra, Climate Action Reserve (CAR), and American Carbon Registry (ACR) serve as standard-setting bodies, establishing rigorous methodologies and criteria for project validation, monitoring, and credit issuance. These entities provide the framework within which carbon credit projects operate, defining the rules and requirements that must be met. Distinct from these organizations are third-party auditors, independent entities tasked with the actual verification process. These auditors, such as First Environment or SCS Global Services, conduct thorough assessments of project documentation, perform on-site visits, and validate emissions reduction claims against the standards set by the aforementioned organizations. This two-tiered system of standard-setters and independent verifiers aims to maintain transparency and reliability in the carbon credit market. From a biodiversity perspective, this verification process is particularly significant as standard setting bodies often do not include assessments of a project's impact on local ecosystems and wildlife.

Biodiversity Monitoring

Monitoring plans for biodiversity and ecosystem services build foundations for conservation efforts and enable scientific research efforts to inform future conservation work. Monitoring efforts, including using eDNA and acoustic sensors (Aide, 2024), have contributed to enhanced biodiversity management strategies and tend to form a collaborative, effective means of conservation applicable to carbon credit projects (Danielsen et al., 2005). Monitoring biodiversity in carbon credit projects also provides opportunities for community engagement and the generation of economic livelihoods when local community members are employed to conduct monitoring (Danielsen et al., 2005). Such local monitoring programs have proven credible and relevant, producing timely biodiversity conservation decisions on the local scale and often sparking a shift in the attitude of local communities to favor biodiversity-friendly resource management (Danielsen et al., 2005). Moreover, carbon credit projects that include monitoring schemes can bring about long-term monitoring of biodiversity datasets, which then provide scientific bases for setting conservation goals and developing conservation decisions (Willis et al., 2007).

To assess the scale at which biodiversity is being monitored in carbon credit projects, each carbon credit's project documentation was reviewed for the presence, absence, and/or quality of a biodiversity monitoring plan. Project documents were first analyzed for the presence of a plan for monitoring biodiversity. Keywords were first searched within the document: *monitor, plan, biodiversity, species, measure, record*. If the keyword search did not return any results for a biodiversity monitoring plan, then the project documents were read in full.

V. Results

The results of our analyses are described in the following tables and figures. Calculations for our case studies yielded a spread of metric and z-score values, indicating a varied span of local conditions across different ecosystem indicators in comparison to their global ranges.

Species Presence

Species Presence metrics represent the integrity of biodiversity in terms of the number of species currently existing in a region. The results of the Species Presence bin show relatively moderate values across global averages, but with significant variation between our values, indicating a range of species presence levels across the geography of our case studies.

Biodiversity Intactness Index

Figure 3 below represents the global map for the BII dataset, illustrating the spatial distribution of BII scores across different regions.

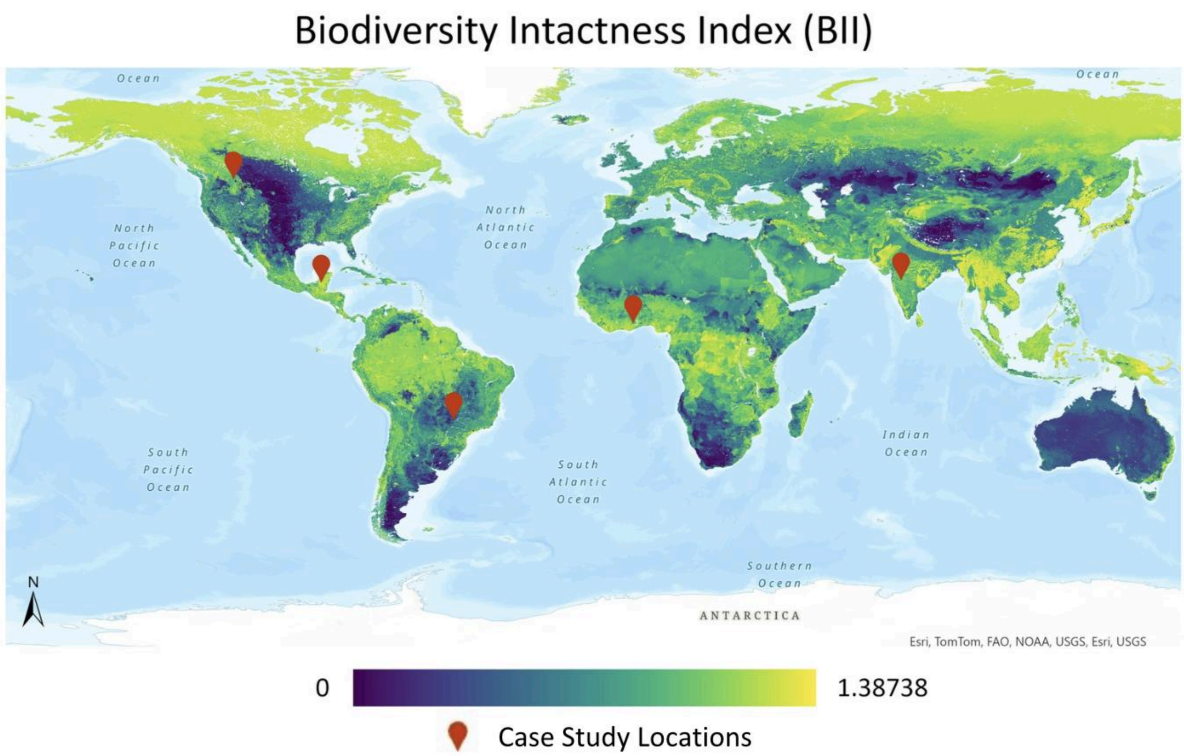

Figure 3. Map showing the global distribution of BII values. Darker colors have values closer to 0 while lighter colors have values closer to the global maximum of 1.38738.

The BII analysis results are shown in **Table 8**. As mentioned previously, BII assesses ecosystem health in terms of biodiversity by considering the number of species present (Species Richness) and the relative abundance of each species. This provides a more comprehensive measure of how closely the species composition and abundance resemble those of a pristine, undisturbed ecosystem. Furthermore, BII evaluates the health and integrity of biodiversity relative to a baseline of minimal human disturbance.

Table 8. Results of the BII analysis.

Project Name	BII	BII z-score
Beed	0.9113441379	0.0005164481
Thompson River	0.886168583	0.0002553147
Conhuas	1.016680067	0.001609045
Horizonte	0.6991558723	-0.001684474
Bandai Hills	0.973958641	0.001165917

As shown in **Table 9**, the BII dataset values ranged from 0.36 to 1.39, with a mean value of 0.86. Conhuas had the highest value (1.02), followed by Bandai Hills (0.97), Beed (0.91), Thompson River (0.89), and ARR Horizonte (0.70). The z-score results show that the projects are all clustered very close to zero, indicating minimal deviation from the mean.

Table 9. The global minimum, maximum, mean, and standard deviation of the BII dataset.

Global Values	BII
Min	0.361169
Max	1.38738
Mean	0.861554
Standard Deviation	0.134669

Species Richness

Figure 4 below represents the global map for the Species Richness dataset, illustrating the spatial distribution of Species Richness values across the world.

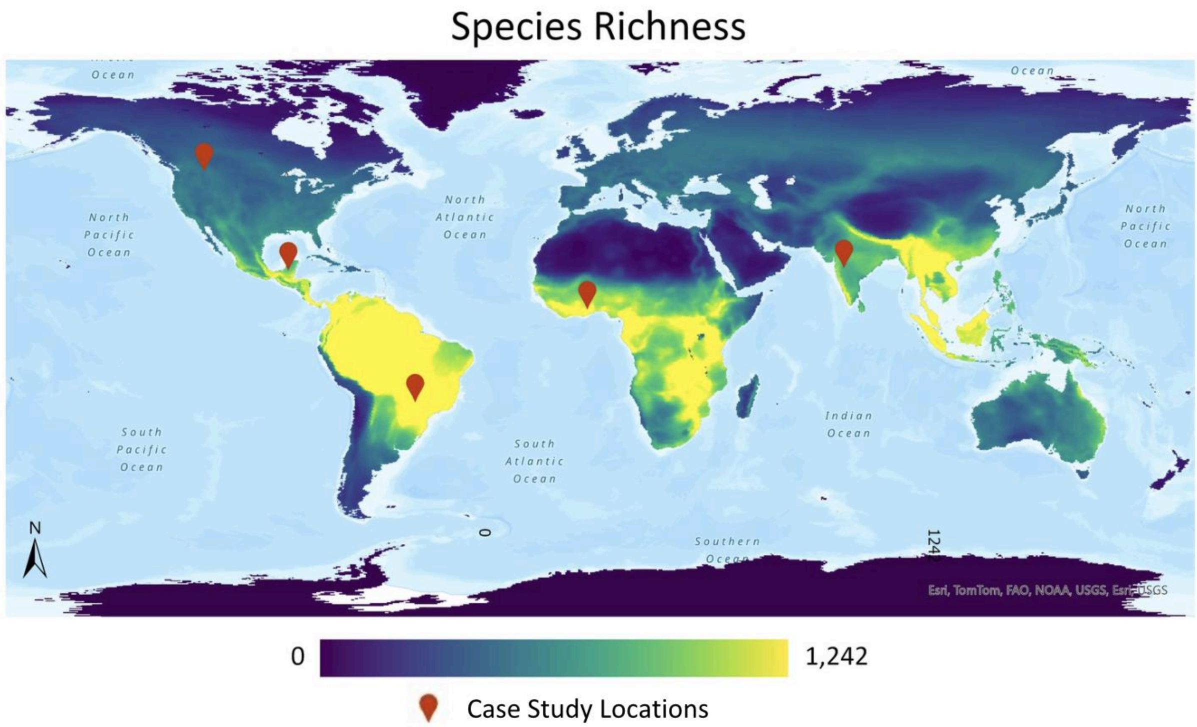

Figure 4. Map showing the global distribution of Species Richness values. Darker colors have values closer to 0 while lighter colors have values closer to the global maximum of 1,242.

The Species Richness, or number of unique species that could be present in each carbon credit project site, indicates the number of species that a carbon credit project that conserves biodiversity could protect. Species Richness values in the dataset ranged from 0 to 1,242, with a mean value of 199.30. Our results, shown in **Table 10,** indicate that ARR contains the most unique species (726), followed by Bandai Hills (685), Conhuas (453), Beed (407), and Thompson River (207). The z-scores for Species Richness show that ARR Horizonte and Bandai Hills have Species Richness values that are significantly higher than the mean value of the global dataset, both with z-scores greater than 5, which indicates that their Species Richness value is more than 5 standard deviations away from the mean. The other projects are also above the mean, with Beed and Conhuas scoring above 2 and Thompson River scoring close to 1. The global mean, maximum, minimum, and standard deviation can be seen in **Table 11.**

Table 10. Results of the Species Richness analysis.

Project Name	Species Richness	Species Richness z-score
Beed	407	2.154303
Thompson River	267	0.7021534
Conhuas	453	2.631438
Horizonte	726	5.46313
Bandai Hills	685	5.037857

Table 11. The global minimum, maximum, mean, and standard deviation of the Species Richness dataset.

Global Values	Species Richness
Min	0
Max	1242
Mean	199.306233
Standard Deviation	220.753952

Species Threat

Species Threat metrics are an indication of how vulnerable a region is to environmental degradation weighted by species richness. The results of the Species Threat bin show do not yield extreme results on the global scale, but do contain significant variation relative to each other, indicating that some regions are more threatened than others.

Species Threat Abatement

Figure 5 below represents the global map for the STARt dataset, illustrating the spatial distribution of STARt values across the world.

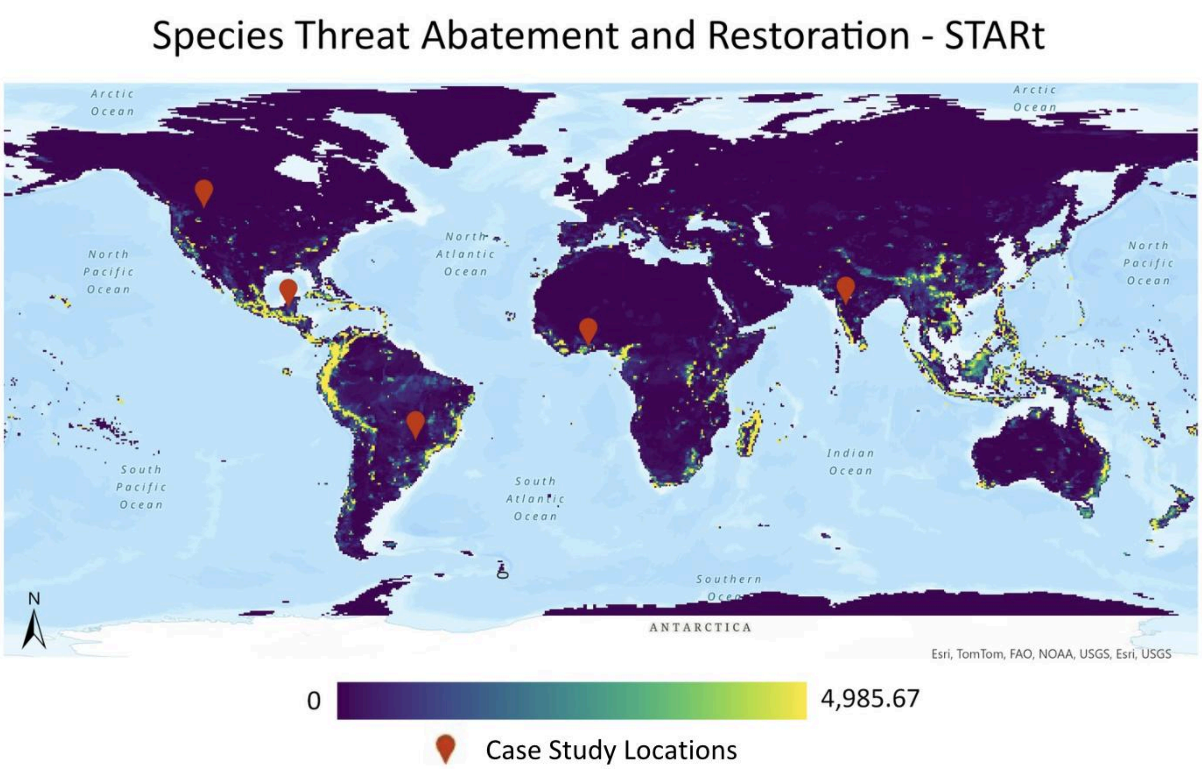

Figure 5. Map showing the global distribution of STARt values. Darker colors have values closer to 0 while lighter colors have values closer to the global maximum of 4,985.67.

Table 12 shows the results of the STAR analysis. As mentioned previously, the STAR Metric indicates the level of threat to biodiversity (STARt) in a given natural landscape.

Table 12. Results of the STARt metric analysis.

Project Name	STARt Value	STARt z-score
Beed	0.1040957	-0.1410786
Thompson River	0.3328257	-0.1387061
Conhuas	15.5814228	0.01945986
Horizonte	2.521899398	-0.116
Bandai Hills	6.1690103	-0.07817033

STARt values in the dataset ranged from 0 to 4985.7, with a mean of 13.7, with higher values corresponding to greater threat levels. The Beed and Thompson River projects have the lowest two values by a factor of ten, with both scores under 0.5. The ARR Horizonte project has a score of 2.5, while the Bandai Hills project has a value of 6.2. The Conhuas project had the highest score by a wide margin, with a value of 15.6, and was also the only project to score above the mean dataset value. The z-scores of these projects tell a similar story. For STARt, all the z-scores for all the projects were negative and clustered between -0.078 and -0.141, except for Conhuas, which had a z-score of 0.019. The global mean, maximum, minimum, and standard deviation are shown in **Table 13.**

Table 13. The global minimum, maximum, mean, and standard deviation of the STARt dataset.

Global Values	STARt
Min	0
Max	4985.673828
Mean	13.705318
Standard Deviation	96.408796

IUCN Red List

The abundance of species in a carbon credit project classified as Near Threatened, Vulnerable, Endangered, or Critically Endangered on the IUCN Red List can indicate how protecting at-risk species in a project location is important for conservation of at-risk biodiversity. Our results, shown in **Table 14**, indicate that the Bandai Hills project location contains the most at-risk species, 188 in total, followed by ARR Horizonte (71), Beed (50), Conhuas (40), and Thompson River (21).

Table 14. Results of the IUCN Red List analysis.

Project Name	IUCN Red List
Beed	50
Thompson River	21
Conhuas	40
Horizonte	71
Bandai Hills	118

Figure 6 compares the Species Richness and IUCN Red List results, revealing the number of species present in an area versus the number of those species that are classified as Near Threatened, Vulnerable, Endangered, or Critically Endangered on the IUCN Red List. The results show that 17.2% of Bandai Hills existing species are on the IUCN Red List, followed by Beed with 12.2%, then ARR Horizonte with 9.8%, Conhuas with 8.8% and finally Thompson River with 7.8% of its existing species on the IUCN Red List. Z-scores were not calculated for IUCN Red List values because the IUCN shapefiles for bird species are not categorized into threat level (we assigned threat levels to bird species outside of ArcGIS Pro for our raw-score IUCN analysis). Thus, we could not select only threatened species to rasterize our IUCN shapefile data to calculate global mean and standard deviation for z-score calculations. Instead, we focus here on raw-scores for IUCN (the number of unique threatened species present in each project area) and the percentage of unique species present in a project area that are listed as threatened.

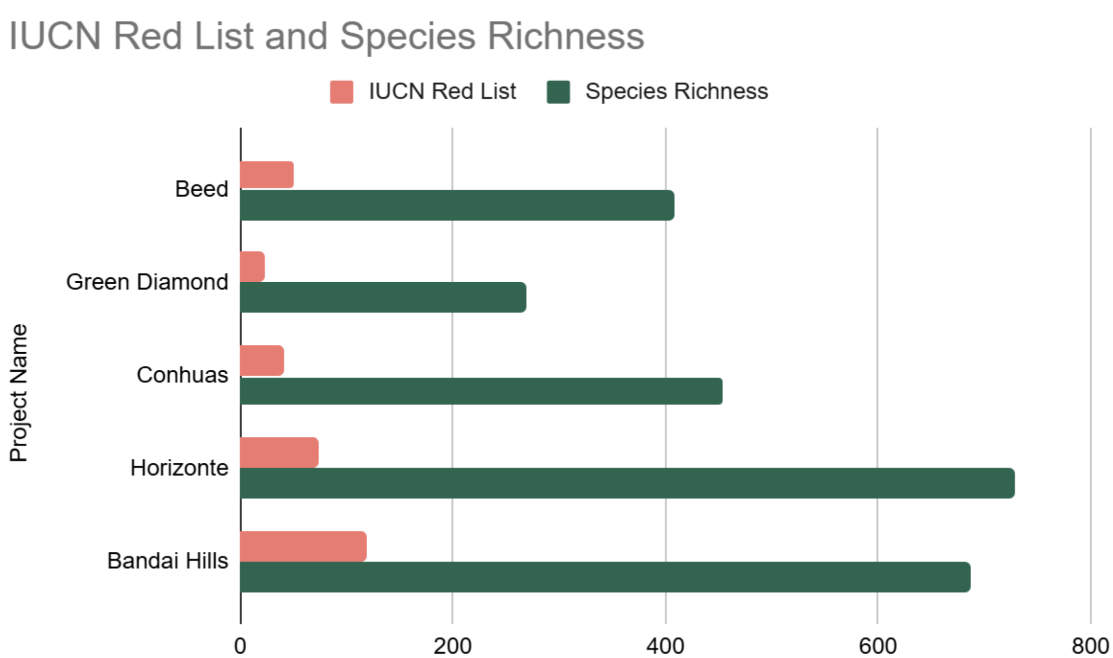

Figure 6. Bar chart showing the comparison between IUCN Red List values and Species Richness values for each case study. Pink represents IUCN Red List species while green represents Species Richness.

Rarity-Weighted Richness

Figure 7 below represents the global map for the RWR dataset, illustrating the spatial distribution of RWR scores across the world.

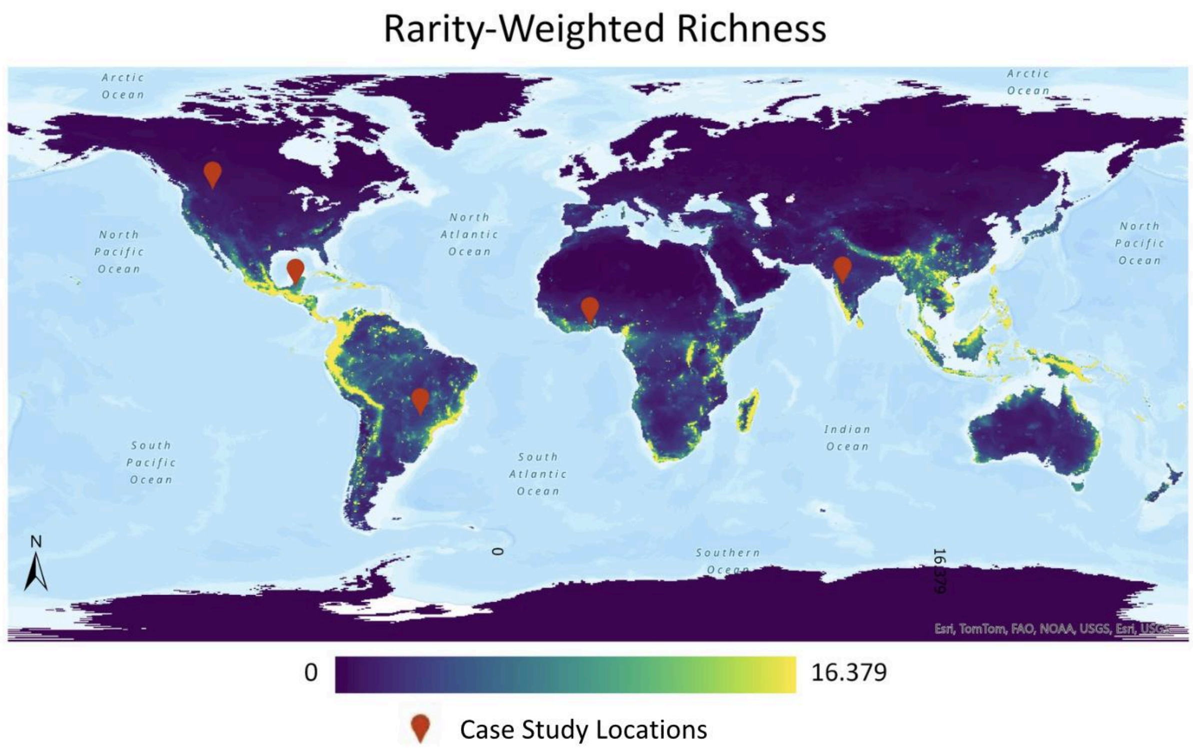

Figure 7. Map showing the global distribution of RWR values. Darker colors have values closer to 0 while lighter colors have values closer to the global maximum of 16.379.

RWR represents the number of species with small geographic ranges whose ranges overlap with each project site. The results for RWR are shown in **Table 15**. The project with the highest RWR was Bandai Hills (0.68), followed by Conhuas (0.44), ARR Horizonte (0.17), Beed (0.11), and Thompson River (0.06). The z-scores follow a similar trend, with all scores clustering close to zero, indicating minimal deviation from the mean. Beed and Thompson's RWR scores are slightly below the mean, while the remaining projects have RWR scores that are slightly above the mean. **Table 16** shows that the RWR global dataset values range from 0 to 16.37, with a mean value of 0.11.

Table 15. Results of the RWR analysis.

Project Name	RWR	RWR z-score
Beed	0.108545	-0.00003570214
Thompson River	0.0640214	-0.0004975231
Conhuas	0.435477	0.003355399
Horizonte	0.17126	0.000614809
Bandai Hills	0.676796	0.00585848

Table 16. The global minimum, maximum, mean, and standard deviation of the RWR dataset.

Global Values	RWR
Min	0
Max	16.378977
Mean	0.111987
Standard Deviation	0.394517

Restoration Potential

Restoration Potential metrics give insight into the extent to which ecosystem restoration actions could support species richness and ecosystem health. Our results show an imbalance in results in relation to eachother, with some projects located in significantly more advantageous locations than others in terms of restoration.

Species Abatement Threat Restoration

Figure 8 below represents the global map for the STARr dataset, illustrating the spatial distribution of STARr values across the world.

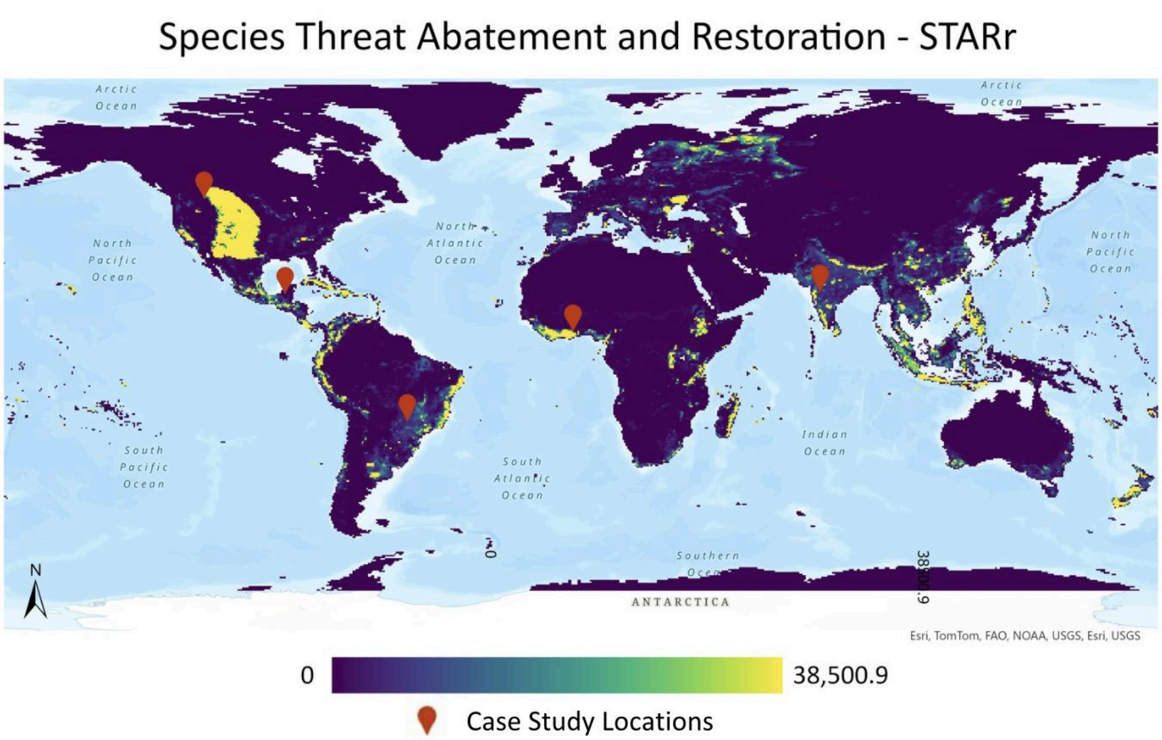

Figure 8. Map showing the global distribution of STARr values. Darker colors have values closer to 0 while lighter colors have values closer to the global maximum of 38,500.9.

Table 17 shows the results of the STAR analysis. As mentioned previously, the STAR Metric indicates the potential for biodiversity restoration (STARr) in a given natural landscape.

Table 17. Results of STAR metric analysis.

Project Name	STARr value	STARr z-score
Beed	3.4841983	-0.03944727
Thompson River	0.0153586	-0.0754278
Conhuas	0.2704663	-0.0727817
Horizonte	3.364540261	-0.04068842
Bandai Hills	50.4577217	0.4477855

The STARr values in the dataset ranged from 0 to 38,501, with a mean of 230, and higher values indicating higher restoration potential. The Thompson River project scored lowest by a margin of 0.02 at 0.015, while Conhuas also scored below 1 at 0.27. The ARR Horizonte and Beed projects scored similarly at 3.36 and 3.48, respectively, and Bandai Hills scored higher than all the others at 50.46. The z-scores reflected this pattern, with all projects having negative z-scores clustered between -0.039 and -0.075, except for Conhuas, which had a z-score of 0.44. **Table 18** shows that the STARr global dataset values range from 0 to 38500.93359, with a mean value of 7.287262.

Table 18. The global minimum, maximum, mean, and standard deviation of the STARr dataset.

Global Values	STARr
Min	0
Max	38500.93359
Mean	7.287262
Standard Deviation	230.76306

Global Human Modification

Figure 9 below represents the global map for the global HMI dataset, illustrating the spatial distribution of HMI scores across the world.

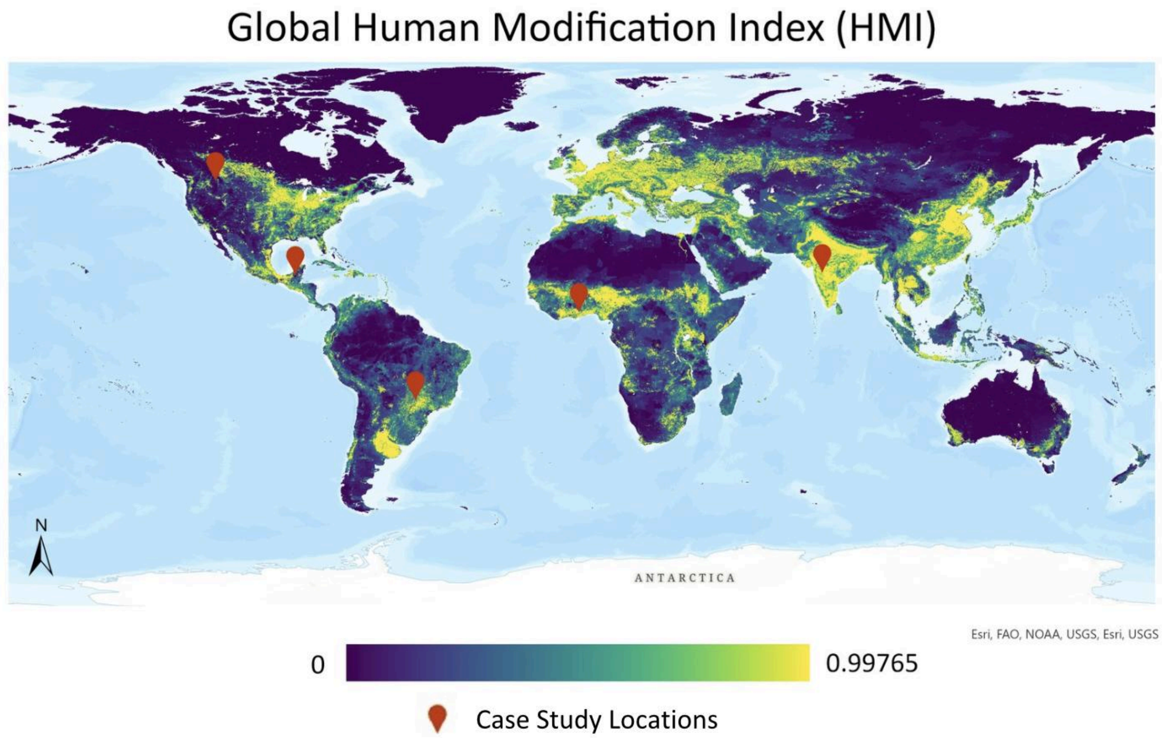

Figure 9. Map showing the global distribution of HMI values. Darker colors have values closer to 0 while lighter colors have values closer to the global maximum of 0.99765.

Table 19 shows the results of the global HMI analysis. As mentioned previously, the HMI provides a quantitative measure of the degree to which human activities have modified the natural landscape in a given location.

Table 19. Results of HMI metric.

Project Name	HMI	HMI z-score
Beed	0.524503	0.003508923
Thompson River	0.046223	-0.001452036
Conhuas	0.052135	-0.001390713
Horizonte	0.402071113	0.002238998
Bandai Hills	0.6692	0.005009792

HMI values in the dataset ranged from 0 to 0.99765, with a mean of 0.186212. The Thompson River and Conhuas projects have the lowest two values, with scores of 0.046 and 0.052, respectively. The ARR Horizonte project has a score of 0.402, while the Bandai Hills project has the highest score at 0.669. The Beed project falls between these extremes, with a score of 0.525. Only Bandai Hills and Beed scored above the mean dataset value.

The z-scores for these projects reflect similar trends. All projects have z-scores clustering close to zero, with Bandai Hills scoring the highest at 0.005009792 and Thompson River the lowest at -0.001452036. These z-scores indicate that the projects' HMI values are relatively close to the mean, with minor deviations.

Table 20 shows that the HMI global dataset values range from 0 to 0.99765, with a mean value of 0.186212.

Table 20. The global minimum, maximum, mean, and standard deviation of the HMI dataset.

Global Values	HMI
Min	0
Max	0.99765
Mean	0.186212
Standard Deviation	0.217642

Proximity to Protected Areas

Table 21 shows the results of the proximity to protected areas analysis. This metric indicates the distance, in kilometers, from a project's boundary to the edge of the nearest protected area.

Table 21. Results of proximity to protected areas.

Project Name	Proximity to PA (km)	Proximity to PA z-score (Global)	Proximity to PA z-score (Constrained by Latitude)
Beed	799.2513336	-0.7727116363	5.344553605
Thompson River	2.902612008	-1.01437764	-1.155819142
Conhuas	0	-1.015258489	-1.179512355
Horizonte	0.1666964047	-1.015207902	-1.178151659
Bandai Hills	0	-1.015258489	-1.179512355

Proximity values in the dataset ranged from 0 to 799.25 km, with Beed located the farthest from its nearest protected area. The Thompson River project is located much closer to its nearest protected area, with a distance of only 2.90 km. The ARR Horizonte project is the next closest, with the nearest protected area 0.17 km away. The Conhuas and Bandai Hills projects are both located within existing protected areas.

The z-scores of the case studies show some range away from the mean value in the global dataset, but overall reinforce the results of the initial analysis. Global z-scores are all negative, and thus indicate that all projects are below the global average distance from a PA. However, when constrained latitudinally, Beed scored well above zero at 6.5 while other projects stayed negative, meaning that this project was above the latitudinally constrained dataset mean, and further than average from a PA.

Table 22. The global minimum, maximum, mean, and standard deviation of the Proximity to PA dataset.

Global Values	Proximity to Protected Area
Min	0
Max	12119.363
Mean	3345.52559
Standard Deviation	3295.24513

Primary Project Attributes

Primary Project Attributes examine the features of a project's design that could influence its contributions to ecosystem health. Results indicate that some projects may support biodiversity more than others based on how they are designed.

Project Type and Activities

Table 23 shows the project type as described by Verra standardized project type. Additionally, the project activities as determined by the project documents were included. Projects were classified by their commercial status as extractive vs. non-extractive based on whether additional extractive activities took place aside from the generation of carbon credits. This includes agriculture, in the case of Beed, and timber operations, in the case of Thompson River. Project Type and Activities also includes polyculture vs. monoculture designation, which determines whether multiple species are primarily used in project operations. If a single species is the main species planted, then the project is determined to be a monoculture. If there are two or more primarily used species, then the project is considered a polyculture.

Table 23. The project types and project activities for each project.

Project name	Project Type	Project Activities
Beed	ALM - Verra	Extractive Polyculture
Thompson River	Forest Carbon - ACR	Extractive Polyculture
Conhuas	Forestry - CAR	Non-Extractive Polyculture
ARR Horizonte	ARR - Verra	Extractive Monoculture
Bandai Hills	ARR - Verra	Non-Extractive Polyculture

Primary Use of Invasive Species

Table 24 shows species-type results for each project site. All five projects involve restoring or conserving non-invasive species, which includes native species and non-native species that are not damaging to the ecosystem. Two of the projects, Beed and ARR Horizonte, included potentially invasive species. In the Beed project, these species were present in sustainable agriculture activities as tree crops that could become invasive, such as Gliricidia (*Gliricidia sepium*), Gulmohar (*Delonix regia*), and Rain tree (*Albizia saman*). The exact proportion of invasive to non-invasive species is unknown, but project documents indicate invasive species are a small portion of the total biomass in the project. In ARR Horizonte, the primary potentially invasive species is eucalyptus grown commercially for timber, which is a primary activity in the project. Eucalyptus comprises a majority of biomass grown in the project.

Table 24. Results of species type.

Project name	Non-invasive species	Invasive species
Beed	Yes	Yes
Thompson River	Yes	No
Conhuas	Yes	No
ARR Horizonte	Yes	Yes
Bandai Hills	Yes	No

Table 25 shows all variables for the project activities bin tallied up into a final score. This includes extractive vs. non-extractive and polyculture vs. monoculture as described in **Table 23** as well as presence of invasive species, as shown in **Table 25**. Scoring was given on a binary scale of 0 or 1, with 1 representing "yes" and 0 representing "no". The table was organized for 1 to represent what was shown to be biodiversity-supportive practices, according to the literature review. The scores were then tallied, to give an overall project activities score. Bandai Hills and Conhaus both received a perfect score of 3, while Beed and Thompson Hills received a score of 2 due to their extractive activities of agriculture and timber, respectively. ARR Horizonte, as an extractive monoculture with primarily invasive species, received a 0.

Table 25. Final scores for all the project activity variables.

Project Name	Primarily Polyculture	Primarily Non-Extractive	Primarily Uses Non-Invasive Species	Project Design Total Score
ARR Horizonte	0	0	0	0
Bandai Hills	1	1	1	3
Beed	1	0	1	2

Conhuas	1	1	1	3
Thompson River	1	0	1	2

Nature’s Contribution to People

Nature’s Contribution to People metrics give insight into how the projects interact with and support their local communities. The exhaustive results for the keyword analysis can be found in **Appendix C.** The following is a comprehensive description of what we identified in each project’s documentation.

Beed

Agriculture is the backbone of Beed District, with about 80% of the population relying on farming for their livelihood. Beed’s Watershed Management program, along with sustainable farming practices under the Sustainable Agriculture Land Management (SALM) initiative, aims to enhance multiple environmental assets for smallholder farmers in the watershed area, such as sustainable water management, improved carbon sequestration (both soil and tree carbon), and improved livelihoods. The overall goal of the project is to enhance the livelihoods of small-scale and marginalized farmers by restoring their degraded agricultural lands using water and soil carbon conservation techniques while adopting SALM practices for sustainable farming. The project is designed for smallholder farmers in three drought-prone villages—Bavi, Jamb, and Zapewadi—in Beed District, Maharashtra, an area facing severe groundwater scarcity.

Through generating carbon credits, the Beed project provides direct additional income to farmers through payments for environmental services, while also enhancing their resilience to climate variability and change. In support of this, the project has committed to integrating environmentally sustainable practices across the value chain and promoting carbon neutrality and water positivity as part of its ‘Good & Green by 2020’ initiative. Through this initiative, smallholder farmers can access the VCM and claim monetary support for their carbon credits.

India's sustainable development priorities emphasize accelerating economic growth, poverty alleviation, and environmental protection, which align with the project's goals. The Beed project also emphasizes community development, including improving market access for local products and promoting trade at both local and national levels. The lack of access to credit and markets in the region has traditionally hindered long-term investments in plantation activities, but the project aims to overcome these barriers by making SALM practices more economically viable, covering direct and indirect costs like planting, maintenance, training, and capacity building. The project is expected to achieve its objectives, resulting in improved soil conditions, water conservation, enhanced biodiversity, restored degraded areas, and increased food security and rural economic resilience. Other anticipated benefits include climate change adaptation, gender mainstreaming, improved nutrition, and community capacity building. The project also includes mechanisms for self-assessment by farmers, using commitment forms and group-level reporting to track progress.

Conhuas

The aim of the Conhuas project is to discourage negative land use change by providing communities with income generated from the sale of carbon credits. A key aspect of the project has been the active participation of the ejidos, traditional Mexican communal agricultural districts governed by participating families. This has included engaging the community in methodological training and direct employment to form brigades responsible for establishing baseline data for carbon collections. This participatory approach has empowered the ejido communities and ensured that locals play a vital role in the carbon sequestration process, while benefiting economically from the sale of carbon credits.

Thompson River

While Thompson River's forests are privately owned and managed, their benefits extend beyond monetary profits to the company itself, providing livelihoods for numerous rural communities and offering critical habitats for a wide variety of wildlife, fish, and plant species. In particular, increased grazing on their Columbia Basin Management Area (CBMA) forestlands plays a key role in their forest resiliency strategy and climate goals. Grazing helps reduce dry grass that can fuel wildfires, lowers brush levels, and improves soil water retention, all while benefiting local economies that depend on the health of both the forests and the region's livestock industry. Additionally, the project continues its voluntary participation in Montana's Fish, Wildlife & Parks (FWP) Block Management Program, which offers free public access for fishing and hunting, further contributing to the community and region's economic and environmental well-being. In the search through their project documents, there was no existing information about 'learning and inspiration' or 'supporting identities'.

ARR Horizonte

The ARR Horizonte project aims to further benefit these communities through specific social activities designed to enhance income, create employment, and promote sustainable practices to ensure year-round food availability. The project will also address potential risks and consult the local population regularly, ensuring no negative impacts have been reported. Nationally, the project aligns with Brazil's goal to reduce unemployment by 40% by 2030, particularly through initiatives such as the Inclusive Recycling and Nursery Seedlings projects, which aim to generate local jobs and ensure compliance with labor laws. Additionally, Suzano, the company behind the project, has developed a training procedure to equip the local workforce with the necessary skills for restoration, addressing the challenge of limited qualified labor in the region. The Nursery Seedlings project, focusing on native Cerrado species, will also provide training and resources to local families, fostering employment and income generation through the restoration of degraded areas. These initiatives, alongside biannual monitoring of income generation, are designed to help elevate local communities out of poverty and promote long-term socio-economic stability in the region.

The ARR Horizonte project is developed alongside three nearby communities: São Thomé, Ponte Velha, and Almanara. The São Thomé community is an agrarian reform settlement established by INCRA

(National Institute of Colonization and Agrarian Reform), where agricultural units are allocated to families of rural workers or small-scale agriculturists unable to afford land. These plots, which remain under INCRA's ownership until formal title issuance, are primarily used for family-based farming activities; dairy farming and fruit tree cultivation are the main sources of income. While some families are employed by Suzano's service providers in forestry, most are engaged in subsistence farming. Similarly, the nearby Ponte Velha community, which consists of properties ranging from 10 to 100 hectares, relies on dairy and beef cattle farming, with properties generally managed by fathers and children, with less involvement of women. In contrast, the Almanara community, composed mainly of elderly families, focuses on livestock and subsistence agriculture. According to the project documents, these communities, despite their proximity to forestry activities, have not experienced significant changes in their socio-economic structure due to the project.

Bandai Hills
Increased economic activity in the Bandai Hills project area is expected to significantly improve the living standards for communities through various avenues, including the creation of livelihood opportunities, the empowerment of women, and the promotion of sustainable development. The project has demonstrated positive net impacts on the social and economic well-being of these communities. These impacts are assessed through site visits by project developers that include interviews with smallholder farmers and community members to evaluate potential risks related to displacement, livelihoods, access to ecosystem services, and awareness of the project's benefits. Local stakeholder engagement is an integral part of the project, with the Ghana Forestry Commission, the Agogo Stool (landowners), fringe communities, and employees identified as key stakeholders. Communication with the Forestry Commission began in 2014, and in 2021, a series of meetings with community leaders and stakeholders was held to discuss project developments, although these villages have no direct rights to the land. The income from Verified Carbon Units (VCUs) will help overcome financial barriers and mitigate the long revenue timeline, while small-scale illegal subsistence farming within the degraded forest reserve is allowed to continue until harvests are completed. The project also plans to establish a Training Farm to promote permanent agriculture systems. Furthermore, the project focuses on empowering women, which leads to increased community spending on women's health and education, enhancing overall community welfare.

Additionality & Assurance

Additionality & Assurance metrics aim to gauge how additive a project is to biodiversity-supporting action in relation to historic and current counterfactuals. Our results show variation in these scores and that projects sited in sensitive regions and with biodiversity-supporting project design may not be the most additional.

Additionality
To evaluate additionality, we assessed three key factors: active restoration, presence of historic degradation, and whether the project area was previously non-protected. Each factor was scored on a

binary scale, where 1 indicates the presence of a biodiversity-supportive practice and 0 indicates its absence. The final additionality score was calculated by summing these values for each project.

Table 26 shows all variables for the project additionality bin tallied up into a final score. This includes active restoration, presence of historic degradation, and previous non-protection. Scoring was given on a binary scale of 0 or 1, with 1 representing “yes” and 0 representing “no”. The table was organized for 1 to represent what was shown to be biodiversity-supportive practices, according to the literature review. The scores were then tallied, to give an overall project activities score. Beed and ARR Horizonte both received a score of 3, while all other projects received a score of 1.

Table 26. Shows overall additionality for all project characteristics involving additionality

Project name	Active Restoration?	Degraded Prior to Project Development?	Previously Non-Protected?	Total
Beed	1	1	1	3
Thompson River	0	0	1	1
Conhuas	0	0	0	0
ARR Horizonte	1	1	1	3
Bandai Hills	1	1	0	2

Biodiversity Monitoring Plan

Table 27 shows which projects have biodiversity monitoring plans. Projects that contain a biodiversity monitoring plan in their project documents have the potential to verify and check the progress of their biodiversity conservation efforts. This analysis indicates that Conhuas contains a biodiversity monitoring plan, and the remaining four projects do not. This is not unexpected, as the inclusion of biodiversity monitoring plans in such projects is relatively rare (Kuhl et al., 2020). Conhuas’ biodiversity monitoring plan includes using revenue generated from the project to support the implementation of a territorial monitoring and management plan in collaboration with the ejido (an area of communal land used for agriculture in which community members have life estate rights rather than ownership rights to land). This plan ensures ongoing compliance with environmental and social safeguards throughout the project’s duration. As part of the ejido’s commitment to wildlife conservation, camera traps are strategically placed in various locations to monitor the diverse species in the jungle. These camera traps are deployed for 20 to 30 days in each area before being relocated, providing valuable data on the wildlife present. The monitoring covers a total of 24 species, including reptiles, amphibians, birds, and mammals, aiding in the protection and management of the forest ecosystem. The full exhaustive results for this analysis can be found in **Appendix D**.

Table 27. Biodiversity monitoring plans results.

Project name	Biodiversity monitoring plan
Beed	No
Thompson River	No
Conhuas	Yes
ARR Horizonte	No
Bandai Hills	No

VI. Discussion

The purpose of this Group Project is to assess the biodiversity implications of nature-based carbon credit projects by exploring which characteristics of project design and location provide potential for biodiversity benefits or risk biodiversity loss. The analysis assesses five carbon credit project case studies, with the aim of better understanding how different biodiversity-related characteristics manifest in real-world projects. This Group Project does not aim to compare and contrast these five case studies to declare a "best" project of the five, nor does it intend to make claims about any of these five projects in relation to the broader carbon market. Rather, this Group Project seeks to provide a quantitative and qualitative framework for carbon credit purchasers to understand which characteristics they may prioritize if they are seeking to support biodiversity through carbon sequestration.

Through this analysis, we identified two key categories to focus on to effectively assess the biodiversity implications of nature-based carbon credit projects. The first category focuses on the project's location, recognizing that the potential to support biodiversity is largely influenced by each project's surrounding ecosystem, existing species diversity, and regional conservation priorities. The second category considers project design, which encompasses factors such as land management practices, habitat restoration efforts, and long-term ecological monitoring. By evaluating projects through both of these lenses, carbon credit purchasers can gain a clearer understanding of the potential biodiversity impacts of carbon credits they are considering purchasing.

Assessing a carbon credit project's location involves analyzing the existing state of biodiversity in the area where the project is sited. High-biodiversity regions, such as tropical rainforests or wetlands, offer greater potential to support existing biodiversity compared to degraded or less ecologically diverse areas (World Health Organization, 2025). Additionally, location-based assessment considers factors like the presence of endangered species, connectivity to existing protected areas, and alignment with national or global conservation priorities. By prioritizing projects in ecologically critical locations, buyers can ensure that carbon credit projects are sited in areas where they have the potential to support higher levels of biodiversity.

The design of a nature-based carbon credit project plays a crucial role in determining its biodiversity impact. Project design components that are relevant to biodiversity include the selection of native versus non-native species for reforestation, the integration of agroforestry or sustainable land-use practices, and existing frameworks for ecosystem services. Effective project design also incorporates long-term biodiversity monitoring and adaptive management strategies to ensure continued positive outcomes for biodiversity. These design elements are typically outlined in project documentation, including management plans and monitoring reports. By considering project design characteristics, buyers can assess whether the project is using management practices that support biodiversity while also delivering carbon sequestration benefits.

While project location and project design serve as distinct criteria for assessing a nature-based carbon credit project's impact on biodiversity, they are inherently interconnected. A project's location establishes the ecological baseline of a carbon credit project, which determines how much biodiversity the surrounding environment can support, whether threatened species are present, and the broader conservation context. Then, project design directly influences how effectively this potential is realized. For example, a project situated in a high-biodiversity area may fail to deliver meaningful conservation outcomes if its design does not incorporate effective sustainable land management, habitat restoration, or species protection measures. Conversely, a well-designed project with strong biodiversity interventions may have limited impact if implemented in areas with historically low biodiversity. The interaction between these two factors highlights the need for a holistic approach to project evaluation, ensuring that biodiversity positive impacts are studied both at the project design and location levels. By considering both aspects collectively, buyers can make more informed decisions about which projects are best positioned to deliver meaningful, long-term biodiversity outcomes alongside carbon sequestration.

This investigation grouped metrics into location and project design categories to help buyers prioritize certain project locations and designs based on their biodiversity goals. In the Project Location category, metrics fall into three buyer priorities: conserving existing biodiversity (Species Presence), mitigating threats to biodiversity (Species Threat), and restoring biodiversity that has already been degraded (Restoration Potential). The analysis in each of these bins scores projects based on how critical the region is to achieving the goals of each buyer priority. These buyer priority bins reflect the complexity and tradeoffs embedded in the prioritization of project locations for biodiversity protection and restoration.

Results Interpretation

Species Presence

The species presence bin includes BII and Species Richness. Both of these metrics indicate the presence of existing species within the project region, demonstrating the amount of biodiversity that would benefit from conserving nature in the area. Buyers interested in supporting and protecting areas with high levels of existing biodiversity may choose to purchase carbon credits that score highly in this bin.

Species richness refers to the number of species present within a given geographic area. ARR Horizonte and Bandai Hills both have high positive z-scores around 5, indicating that their Species Richness is much higher than the global average. These projects are located in tropical rainforests, ecosystems known for their high biodiversity. Beed and Conhaus have z-scores around 2, still above the global average, indicating a high Species Richness. Thompson River, with the lowest z-score among the five projects at 0.7, has less Species Richness compared to the projects located in other areas, but remains above the global mean. As a temperate mixed-conifer forest, Thompson River's region generally supports a lower Species Richness than tropical rainforests, which aligns with expectations for this type of ecosystem.

BII can be used to quantify changes in ecosystem composition, providing a measure of Species Richness and abundance relative to the original undisturbed ecosystem. A higher BII value reflects a more intact and healthier ecosystem. According to the results, Conhaus has the highest BII score (1.016680067). Its value is greater than 1, suggesting biodiversity has increased in the area. Conhuas has a positive z-score close to 0 (0.001609045), indicating that the region where Conhuas is located hosts a more intact ecosystem than the global average location. Bandai Hills, Beed, and Thompson River show BII scores ranging from 0.88 to 0.97 and all have positive z-scores slightly above 0, indicating that these ecosystems are in good condition in terms of biodiversity compared to the ecosystem prior to degradation. In contrast, ARR Horizonte has a BII score of 0.69, suggesting that while the ecosystem remains relatively healthy, it has experienced some degradation. Its negative z-score (-0.001684474) further indicates that the ecosystem is below the global average for biodiversity intactness. ARR Horizonte is located in the Brazilian Amazon, a region known for its rich biodiversity. However, prior to the development of the carbon project, the site was historic pastureland degraded from overgrazing, which suggests significant ecosystem disruption.

Overall, a buyer looking to support existing biodiversity present in an area should consider purchasing carbon credits from projects that score highly in the species presence bin. Within the context of these five case studies, the two projects that score highest are ARR Horizonte and Bandai Hills. Therefore, a buyer whose top biodiversity priority is conserving existing biodiversity may choose to purchase carbon credits from a project located in a geographic area that scores highly in the species presence bin, such as ARR Horizonte or Bandai Hills.

Species Threat

The species threat bin includes the RWR, IUCN Red List, and STARt metrics. These metrics indicate the extent to which the species of a region are under threat, generally due to human development and land-use activities, or the importance of a project's location to threatened species. Carbon credit buyers with goals to protect endangered or certain charismatic, threatened species should consider purchasing credits from projects in this bin.

The STARt metric measures how threat abatement could mitigate the risk of species extinction. Higher scores indicate a region containing more threatened species and higher risk of destructive human activities based on development trends. A positive z-score indicates above-average species extinction risk compared to the global average, whereas negative z-scores indicate lower threats of species extinction and ecosystem degradation. Results show that Conhuas has the highest STARt score by a factor of 2.5x at 15.6, indicating the highest species extinction and ecosystem degradation risk out of the selected case studies. This result suggests that the region where Conhuas is located has a high proportion of threatened species and a specialized ecosystem, as STARt takes into account how rarely occurring the local ecosystem is on a global scale. Bandai Hills has the second-highest risk, then ARR Horizonte, Beed and Green Thompson River. The z-score results indicate that only Conhuas has above-average global species extinction risk out of the case studies, and not by much. All other projects have negative z-scores, indicating that the regions and ecosystems where case studies are located have somewhat healthy populations of local fauna, and ecosystems covering large areas. Beed and Thompson River have the lowest STARt z-scores, likely because the species present in these locations are generally not threatened and the ecosystem type is common. In some cases, this result can mean that the area no longer contains species that were previously threatened and have already gone extinct.

The IUCN Red List metric quantifies the number of threatened species in a region. Higher IUCN Red List counts indicate the presence of more species that are classified by the IUCN as being Near Threatened, Vulnerable, Endangered, or Critically Endangered. Positive z-scores indicate above-average counts of threatened species present in a project's region. The region where Bandai Hills is located contains by far the highest number of threatened species, which is not surprising given that the Bandai Hills region has a high Species Richness and is experiencing rapid human development and population growth (Richie et al 2023). The region where Thompson River is located contains the fewest threatened species, likely driven by the high proportion of protected and conserved land in the area and strict federal protections around threatened species (FAO, 2020). The other three projects are grouped somewhat closely in the middle of the range of case study z-scores.

The RWR metric is a quantification of the number of 'rare' species that are present in the region. A higher RWR score indicates that an area is home to a greater number of rare species, while a lower RWR score signals that fewer rare species are present in a project's area. A positive z-score indicates that an area has an above-average number of rare species, and a negative-score that an area has a below-average count of rare species. Bandai Hills scored highest within this metric, with Conhuas not far below. The regions where these projects are located have higher numbers of species with small geographic ranges, likely due to the fact that these ecosystems are both biodiverse and specialized, confining species' ranges with a variety of geographic factors. Beed, Thompson River, and ARR Horizonte all scored lower in this metric, indicating less specialized and more widespread ecosystems, even though ARR Horizonte and Beed have high regional Species Richness. The z-scores reflect these results, showing that Bandai Hills, Conhuas, and to a lesser extent, ARR Horizonte, have RWR scores above the global average. The other two projects contain RWR below the global average.

The results of the species threat bin are fairly consistent, indicating that the regions where the Conhuas and Bandai Hills are located, both tropical, biodiverse regions with fast-growing human populations face higher threats of ecosystem degradation and species loss (FAO, 2020). Buyers interested in addressing the more urgent drivers of biodiversity loss may consider purchasing carbon credits from projects in such regions.

Restoration Potential

The restoration potential bin includes the STARr, Proximity to PAs, and HMI metrics. These metrics reflect the degree to which ecosystem function in a region has been degraded by human activities and can be restored, potentially by biodiversity-positive carbon credit projects. Buyers that prioritize restoring degraded habitat or amending damages caused by commercial or extractive activities should consider purchasing credits from projects similar to those that score highly in this bin.

The STARr metric measures potential for restoration in terms of how restoring local ecosystems could contribute to global biodiversity goals by avoiding extinction and maintaining high global Species Richness, with higher scores indicating higher potential. A positive z-score indicates a region with above-average restoration potential compared to the global dataset. A negative z-score reflects below-average potential. By this metric, the Bandai Hills region scored highest by a wide margin, indicating that the region has been degraded but that restoration activities in this location have a high potential for conserving biodiversity. Beed and ARR Horizonte scored similarly, and next highest. These results indicate that these regions have a lower potential for restoration, though still some opportunity. In the case of Beed, this moderate potential for restoration likely has to do with this part of Southern India being largely agricultural and not very biodiverse. Restoration actions here may be isolated from larger ecosystems that could support ecosystem recovery by acting as source populations for returning species. ARR Horizonte may score lower for an entirely different reason, as its surrounding environment is largely intact, or that activities in the region have not yet harmed biodiversity to the extent that restoration will have a significant impact (FAO, 2020). The lowest two scoring project regions, Thompson River and Conhuas, may score that way as largely intact ecosystems without much restoration to be done. The z-scores reflect and reinforce these findings, with Bandai Hills having the only score above the mean of the entire dataset by a moderate margin (0.44). All other projects had z-scores below 0 with Beed and ARR Horizonte scoring slightly higher closer to the mean.

The proximity to PA metric assesses the project's distance from a protected area as a proxy for how a project may function as part of a wider network of protected habitat. A lower distance translates to a higher likelihood that the project could add contiguous or semi-contiguous habitat to existing habitat given biodiversity-positive project design. Results indicate that two of the case study projects, Conhuas and Bandai Hills, are already located within PAs. This project siting choice could indicate that the biodiversity benefits of a project are not additional beyond existing ecological protections, as discussed further in the Additionality section. Many PAs have been criticized for lackluster conservation practices even given their designations, and it is possible that a carbon credit project in a PA could provide stronger ecosystem protections than the PA designation does. For example, if the project design stipulates ecosystem restoration beyond the static protections of the PA, then the project may be additional from a biodiversity perspective. ARR Horizonte is located within less than a kilometer of the nearest PA, and Thompson River is located within 3km, suggesting that these projects, given biodiversity-positive design, could function as part of a larger PA network and improve habitat connectivity. It should be noted that ARR Horizonte is highly fragmented and is thus unlikely to provide a high-quality core habitat. Beed is not within 100km of a PA and is unlikely to interact with existing PAs as connective habitat. Z-scores emphasize these results, indicating that Bandai Hills, Conhuas, and Horizonte are closer to PAs than the average location within the global latitudinal range for nature-based carbon credit projects. Thompson River is slightly further from a PA than the average with a z-score near zero, and Beed is significantly further than average with a high z-score.

The HMI metric measures the extent of human-driven degradation in a project's location, with higher scores indicating higher levels of structural ecosystem degradation. A positive z-score indicates a region that has experienced human-driven structural ecosystem modification above the global average. In this metric, Bandai Hills scored highest, with Beed and ARR Horizonte not far behind. These scores indicate that these regions have experienced high degrees of human modification, which are consistent with wider socio-economic and demographic trends in these locations. Fast population growth and extractive industry may be drivers of this high degree of human modification of ecosystems in these regions. The regions where the Conhuas and Thompson River projects are located scored much lower, though these low levels of human modification may not remain static for Conhuas. Ecosystem degradation driven by timber and other extractive industries is generally in decline across most of Northwestern North America. This is not the case in the Yucatan region of Mexico, which is experiencing both population and economic growth, and is likely to experience further human modification in the future, as indicated by a high STARt score. Z-scores reflect these differences in results, showing that the regions where Bandai Hills, ARR Horizonte, and Beed are located have all experienced above-average levels of human modification.

The results of the restoration potential bin are somewhat mixed, but overall indicate that projects located in regions similar to those of Bandai Hills and ARR Horizonte have greater potential to support biodiversity through restorative actions. Conhuas has a lower restoration potential given the intact state of the ecosystem, but remains important to protect due to high species diversity. Thompson River and Beed are located in regions where the potential for restoration that supports biodiversity is low, but likely for different reasons, as Beed is located in an almost entirely agricultural region, and Thompson River is located in highly forested region. Buyers looking to prioritize restoration of degraded ecosystems through their carbon credit purchases should consider buying carbon credits from projects in biodiverse regions that have experienced moderate levels of human modification but have not been completely developed.

Primary Project Attributes

The primary project attributes analysis assessed the five case studies across three metrics: presence of monoculture, presence of invasive species, and presence of extractive activities. Once the scores were tallied up for each of the three attribute metrics, Bandai Hills and Conhuas scored 3 out of 3, Beed and Thompson River scored 2 out of 3, and ARR Horizonte scored 0 out of 3. Bandai Hills and Conhaus both represent biodiversity-positive based on the literature assessment, while Beed and Thompson River represent best practices with the exception of extractive activities besides generation of carbon credits. Beed and Thompson River employ agriculture and silviculture, respectively. One notable outlier was ARR Horizonte, with a score of 0 out of 3, as it is a monoculture commercial timber plantation which grows eucalyptus, an invasive species in its region.

Nature's Contributions to People

In the assessment of the five nature-based carbon credit project case studies, project documentation analyzed to determine whether these projects considered key elements of NCP in their design (IPBES, 2018). Specifically, four contributions, from the IPBES framework, were examined : (13) Materials, companionship, and labor; (15) Learning and inspiration; (16) Physical and psychological experiences; and (17) Supporting identities. As previously mentioned, Contribution 13 evaluates the degree to which carbon credit projects support local economic livelihoods and provide opportunities for community employment. Contributions 15, 16, and 17 provide context for the extent to which each project supports adjacent communities' ability to immerse themselves in educational opportunities related to the carbon credit project, access green space, and engage with the ecosystem for cultural purposes.

Through this analysis, it was found that four out of the five (ARR Horizonte, Bandai Hills, Beed, and Conhuas) projects included extensive information on how they plan to engage with local communities, outlining initiatives such as job creation, sustainable land-use practices, and programs for environmental education and cultural engagement. For instance, Beed has claimed that they provide direct additional income to farmers through their environmental service. In addition, ARR Horizonte aligns with Brazil's goal to reduce unemployment by 40% by 2030, through initiatives such as the Inclusive Recycling and Nursery Seedlings projects, which aim to generate local jobs and ensure compliance with labor laws. On the other hand, Thompson River lacked significant documentation on community involvement; it is therefore unclear how, or if, the project intends to support adjacent communities in the above ways.

It is important to note that this assessment is solely based on what is presented in project documentation, and cannot verify the extent to which these initiatives are implemented in practice. Additionally, it is not the intention to speak on behalf of the communities impacted by these projects, as their lived experiences and perspectives are essential in evaluating the true social and cultural benefits of these initiatives. This discrepancy highlights the importance of transparent reporting and intentional community integration to ensure that carbon credit initiatives deliver both environmental and social benefits.

Biodiversity Monitoring Plan

For this analysis, the project documentation of each of the five case studies was analyzed to determine the extent to which there is a robust biodiversity monitoring plan in place for the project. Conhuas was the only project out of the five that included any management plans describing methods to monitor wildlife in the area. The other four projects included monitoring plans exclusively for carbon sequestration rather than for the project's impact on biodiversity. Our results suggest that Conhuas is the only project of our case studies that has the explicit intention to measure its impact on biodiversity. However, it is possible that these four projects are conducting biodiversity monitoring of some kind that is not listed in their project documentation.

Additionality

Our results show that Beed and ARR Horizonte received the highest additionality scores of 3, meaning they incorporate all three biodiversity-supportive practices. These projects engage in active restoration, were established on previously degraded land, and were not under prior protection, indicating strong additionality in their conservation impact.

Bandai Hills received a score of 2, meeting two of the three criteria but lacking prior non-protection status. Thompson River received a score of 1, indicating that it meets only one of the additionality criteria. Meanwhile, Conhuas received a score of 0, suggesting that it does not demonstrate additionality based on these assessed factors.

These findings suggest that additionality varies across projects and that even those designed with biodiversity in mind may not always score highly under this metric. This reinforces the importance of considering multiple dimensions—including baseline conditions and counterfactuals—when evaluating a project's true conservation impact.

Concluding Remarks

The lack of a standardized framework for evaluating the impacts of carbon credit projects on biodiversity complicates efforts to ensure that carbon credit projects deliver meaningful ecological benefits. While some third-party carbon credit organizations have begun developing biodiversity standards, there is no clear consensus on best practices, making it challenging for buyers to assess whether a project actually supports biodiversity. This analysis aims to bridge this gap by providing a structured approach to evaluating the potential of nature-based carbon credit projects to support biodiversity, which will directly inform the development of a buyer decision-support tool. This tool is designed to help buyers navigate the complexities of biodiversity assessment by offering clear criteria based on project location and design. By synthesizing analysis of project documentation and external ecological datasets into a standardized evaluation framework, the tool will enable buyers to make more informed decisions, ensuring that their carbon credit investments align with both their climate and biodiversity goals. Ultimately, this approach seeks to promote the purchase of carbon credits that integrate biodiversity conservation as a core component of carbon sequestration efforts.

Recommendations for Buyers

Corporate purchasers of nature-based carbon credits are increasingly scrutinizing projects for both carbon sequestration and biodiversity co-benefits, as evidenced by the price premium for Sustainable Development Goals-certified projects (Procton, 2024). Many of the metrics used in our analysis are used by reporting frameworks and guidance like TNFD, SBTN, GRI, and others so that corporations looking to report on their operations can discuss how these projects compare to operational impacts. While some companies may initially be drawn to projects such as ARR Horizonte due to its large scale or cheap cost per credit, our biodiversity assessment reveals potential biodiversity risks stemming from eucalyptus monoculture conversion in the Cerrado. Therefore, corporations seeking to credibly support biodiversity are prioritizing projects strategically located in high-biodiversity regions or those designed with specific biodiversity-positive practices. As emphasized in this assessment, multiple factors within project location and design play into a project's ability to support biodiversity.

Project design and location significantly influence biodiversity outcomes. Projects located in high-biodiversity regions, such as the Conhuas project, or adjacent to protected areas can offer the conservation of existing high levels of biodiversity or threatened biodiversity. Furthermore, a well-designed project may incorporate native species, agroforestry practices, and long-term biodiversity monitoring, all of which may contribute to improved habitat quality and species diversity. In contrast, projects focused solely on maximizing carbon sequestration through non-native monocultures may yield limited biodiversity benefits, as previously discussed regarding the ARR Horizonte project.

Ultimately, the most effective approach for corporations seeking to invest in biodiversity-positive carbon credits involves evaluating both project design and location. As this Group Project is focused on providing an evaluation framework, it is important to note that a corporation should prioritize projects that have biodiversity considerations incorporated into their development. By carefully considering these factors, corporations can make informed decisions that support genuine emissions reductions while simultaneously promoting biodiversity conservation.

Limitations

While the methods used in this investigation are literature-based and reproducible, analysis was limited in its scope, accuracy, and precision in several ways. One of the biggest sources of uncertainty is the fact that the project documentation that much of this analysis is based on is subjective, and written by the project developer. Because of the limited oversight and minimal verification of some of these projects, one of the biggest shortcomings of the VCM, there is no way to confirm that the project design outlined in the project documents is being implemented as described. While verification bodies provide some oversight and monitoring around carbon sequestration outcomes, the extent to which practices affecting biodiversity are being implemented is hard to verify, and some projects undergo more evaluation than others.

The accuracy of many of the geospatial analyses performed was limited by the resolution of the data available. Most of the datasets used were generated at a global scale, with data inputs focused on regional, macro-scale trends. In some cases, finer-resolution data was available, but the investigation was limited by the cost of the data or the computing power or time required to process the data. While these datasets are impressive compilations that are accurate on a regional scale, they likely fail to capture the nuances of the landscape at the scale of a carbon credit project, which may be less than a square kilometer. This investigation was careful to draw conclusions at the resolution allowed by the dataset, and often was not able to identify trends that are occurring on a parcel scale.

This study was also limited in the complexity of the analyses performed given group size, group knowledge, and overall Group Project timeline. Several other analyses quantifying more complex metrics of biodiversity were considered and not completed due to such limitations. Metrics such as habitat connectivity for sensitive species, habitat fragmentation, project footprint land cover change, and more were considered, attempted, and discarded before the final metrics list was agreed upon. A more comprehensive, longer-term study, especially one focused on fewer species, regions, or project types, may have the capacity to go more in depth into complex but relevant metrics listed above.

Finally, the scope of this Group Project was limited to five nature-based carbon credit case studies. Resourcing and time constraints meant that additional projects could not be considered, and the small sample size is a limitation of the analysis. Nevertheless, the results of this analysis will be used to inform the prototype of a carbon credit buyer decision-support tool. Eventually, the framework of analysis used to assess these five case studies could be applied to the entire carbon market. A larger sample size would enable buyers to more effectively rank and compare the biodiversity implications of projects within the context of the global carbon market, allowing buyers to make more informed decisions when purchasing carbon credits with biodiversity co-benefits.

VII. Conclusions

This project explored the intersection of nature-based carbon credit projects and biodiversity. The development of a framework to assess the potential for carbon credit projects to support biodiversity highlighted which characteristics of carbon credit projects provide potential for biodiversity benefits or risk biodiversity loss. The implementation of this framework to evaluate five case study projects provided insight into how these characteristics manifest in a selection of different carbon credit projects globally. The results of this research are not exhaustive and reveal specific insights for only a small sample (n=5) of the larger VCM, however, the research process uncovered recurring biodiversity themes within carbon projects. These insights lay the groundwork for a structured tool to help carbon credit buyers assess biodiversity co-benefits more effectively.

First, this analysis determined that there are two key categories at play in determining the biodiversity impacts of a carbon credit project: project location and project design. Understanding the difference between these two qualifiers allows buyers to prioritize different aspects of a project's potential to support biodiversity and highlights the importance of considering both features when purchasing a carbon credit. Projects located in areas with high levels of existing biodiversity inherently lend themselves to have a high potential to support existing biodiversity. However, a project simply being located in a biodiverse area is not enough to ensure that biodiversity is being supported in practice. For example, ARR Horizonte scored highly across all project location metrics, indicating that its location in the Brazilian Amazon is conducive to supporting biodiversity. Nevertheless, ARR Horizonte's project design primarily consists of an invasive monoculture eucalyptus plantation, which significantly undermines its biodiversity benefits. This example highlights why buyers must consider both project location and design characteristics to ensure that a carbon credit they purchase is supportive of biodiversity.

Second, this analysis explored key themes within project location and project design, which consider different components of existing biodiversity and allow for nuanced distinctions between project design elements. There is no "one size fits all" recommendation for biodiversity, and each project has a unique potential impact. To help buyers assess this impact, six key themes, or "bins," were identified: Species Presence, Species Threat, Restoration Potential, Primary Project Attributes, Nature's Contributions to People, and Additionality & Assurance.

In practice, one project might have a high potential for restoration, indicating that the area has been severely degraded; targeted restoration, perhaps through a carbon project, could significantly improve biodiversity in the area. Another project may rank very high in species presence, indicating that it contains high levels of existing biodiversity, so buyers could prioritize conserving a biodiversity hotspot through its carbon credits. While these example projects differ in their current state (one degraded and one not), both offer pathways to support biodiversity. Distinguishing between projects in this way allows buyers to evaluate carbon credits through their company's biodiversity priorities, ultimately selecting credits that align with their specific biodiversity goals.

Lastly, this analysis will inform the development of a buyer decision-support tool designed to translate the findings of this Group Project into a user-friendly format. This tool will help buyers identify their biodiversity priorities and filter carbon projects to find those that align with their goals. While the scope of this project does not allow for a tool that covers the entire VCM, our prototype aims to demonstrate the potential for a broader system that assesses biodiversity impacts and clearly relays this information to potential buyers. Ultimately, this tool could make it easier for buyers to understand the nuances of biodiversity co-benefits within carbon credit projects, allowing them to make more informed and strategic purchasing decisions.

VIII. References

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X. Appendices

A. Supplementary Metrics

The following section encompasses all the materials and documentation for the discarded metrics.

Mean Species Abundance
MSA is a measure of local terrestrial biodiversity intactness that calculates a value based on the abundance of original species in an ecosystem under a given threat regime compared to the abundance of species in a pristine environment (Alkemade et al.,2009; Schipper et al.,2019). The metric is expressed as a value between 0 and 1, where a 1 indicates that all original species are present, and a 0 indicates none of them are. The MSA weights every hectare equally and does not weight especially biodiverse land any differently, unlike similar metrics, including the Biodiversity Intactness Index. Unlike STAR, individual species do not have MSA values. MSA refers to the total species assemblage in an ecosystem. MSA indicates how much an ecosystem has lost species, generally due to human drivers. This metric is the basis for the GLOBIO model, which aims to assess how biodiversity is changing worldwide in order to support policy. The model has informed proceedings at the Convention for Biological Diversity and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service (IPBES). The Taskforce for Nature-related Disclosures (TNFD) recommends the MSA as a useful indicator when assessing ecosystem condition and extent (TNFD, 2023). In the context of carbon projects, MSA can be used as a proxy for ecosystem intactness when considering the locale where the project is sited and whether that project could improve or decrease an MSA score. This analysis will examine the MSA values associated with the case study project locations to determine each ecosystem's intactness and how each project may affect that intactness.

Ecosystem Integrity Index

Ecosystem integrity is a widely recognized concept in ecology, referring to the ability of an ecosystem to support and maintain its biodiversity and ecological processes (Leo & Levin, 1997). It reflects the overall health of ecosystems, encompassing their structural, functional, and compositional elements. These three components, structure, function, and composition, are fundamental to defining and measuring ecosystem integrity (Hansen et al., 2021). While numerous frameworks for assessing ecosystem integrity exist, one of the key challenges is developing a standardized method that can be applied across different ecosystems and at global scales. The EII represents one of the most promising approaches to overcoming this challenge by aggregating spatially explicit indicators of these three components.

The concept of an ecosystem integrity index has been refined over time, incorporating data from various sources, including Earth Observations (EO) and in-situ measurements. Such indices aim to provide a quantitative assessment of ecosystem health, offering insights into how ecosystems respond to natural and anthropogenic pressures. Notably, Hansen et al. (2021) propose a framework that integrates these three critical components (structure, function, and composition) into a composite index for evaluating global ecosystem integrity.

The EII integrates multiple Essential Biodiversity Variables (EBVs) that represent the three core components of ecosystem integrity: structure, function, and composition. Each component captures a different aspect of ecosystem health.

Structure: The structural component of ecosystem integrity relates to ecosystems' spatial configuration and fragmentation, including habitat connectivity. The **HMI** is one commonly used EBV to quantify structural integrity and measure how humans have altered the terrestrial landscape around the world. This metric considers many factors, including the size of the area impacted, the intensity of modification, and the compounding of multiple stressors in a given location (Theobald et al.,2020). It integrates stressor data extrapolated from satellite imagery and probability given a certain region and classifies them based on the Direct Threats Classification from Salafsky et al. Each classification of stressor (i.e., roads, agricultural, oil, and gas) uses a distinct methodology to calculate the *H* value of the activity. Those values are aggregated across a pixel to give a final *H* value for that area, given the nature, spatial extent, and intensity of the stressors recorded (Kennedy et al., 2019). In the context of this project’s case studies, the HMI can indicate how fragmented and how impacted the surroundings of a given project footprint are. A highly impacted region may mean that the biodiversity impacts of a project have minimal impact on an ecosystem, whereas projects located in more intact areas have a higher potential to do harm or maintain ecosystem integrity.

Function: Ecosystem function refers to the processes that maintain ecosystem stability, such as nutrient cycling, carbon storage, and primary productivity. The **NPP** indicator, which reflects the amount of energy plants capture through photosynthesis, is commonly used to quantify ecosystem function (Running & Zhao, 2019). High NPP values indicate productive ecosystems that are capable of sustaining ecological processes like nutrient cycling and energy flow. NPP is a well-documented metric of ecosystem function and a helpful indicator of the presence or absence of conditions that support biodiversity (Hill et al., 2020).

Composition: The composition component captures the biodiversity within an ecosystem, including species diversity and abundance. The **BII** dataset, measuring species present in a given location, was produced by the Projecting Responses of Ecological Diversity in Changing Terrestrial Systems (PREDICTS) project. It can be used to quantify changes in ecosystem composition, providing a measure of Species Richness and abundance relative to undisturbed ecosystems similar to the MSA (Newbold et al., 2016). The dataset was created by inputting the results of ecological studies on species presence and abundance worldwide, including 54,000 species of animals, plants, and fungi, into models that reflect the extent to which human activities have altered species communities. The output was then combined with data on human pressures and their intensity, yielding an output that indicates how those human pressures correlate to species loss (Natural History Museum, Biodiversity Intactness Index). The result was aggregated into a publicly available global geospatial layer.

These three components are integrated into the EII to provide a comprehensive assessment of ecosystem integrity. The key challenge in developing such an index is harmonizing diverse data sources, such as remote sensing data, field-based observations, and ecological models, into a cohesive framework. In the context of carbon credit projects, the EII provides a location-specific value that reflects the overall integrity of the ecosystem, offering insights into its potential sensitivity or resilience.

Target End State

The target end state of a project (e.g., native forest, agricultural land, plantation forest, etc.) is set by project developers before development for some carbon credit projects and is included in the published project documents. Target end states are decided based on the individual developer's unique goals for the land, including agricultural intentions, ecosystem restoration plans, and other objectives. The target end state determines the type of ecosystem–and thus the amount and type of biodiversity– that will be developed on the project site. Natural and native forests tend to support greater biodiversity than mixed-species plantation forests (Brockerhoff 2008; Calvino-Cancela 2012; Stephens 2007), which in turn hold enhanced biodiversity compared with monoculture plantation forests (Cheng & Wang, 2019). Additionally, plantation forests may harbor greater biodiversity than traditional agricultural land (Stephens, 2007). Afforestation of agricultural land that was once naturally forested can also support biodiversity by increasing the area of suitable habitat and mitigating edge and fragmentation effects in the target end state of the project (Brockerhoff, 2008). Furthermore, native forest target end states tend to support more rare species than other forest types and foster increased seed dispersal by vertebrates (Calvino-Cancela 2012).

When designing a carbon project, following the recommended best practices from the "Establishing the Native Reference Ecosystem" guidance for ecosystem restoration projects is a best practice. Native reference ecosystems are ecosystems that are the targets of conservation and restoration activities (e.g., boreal forest, freshwater marsh, tropical savanna). They are generally the ecosystems that would be present at or near the project site if degradation or conversion had not occurred, adjusted as necessary to accommodate changes or predicted changes in biotic or environmental conditions (e.g., from climate change). Native reference ecosystems inform the development of reference models, which are used to measure progress in restoring biodiversity and other ecosystem attributes from the baseline condition. The target for agroforestry and other agricultural projects is not the native reference ecosystem itself. Still, the goal is to incorporate components of the reference model into the site as appropriate. These components could include native trees and shrubs incorporated into agroforestry projects, hedgerows in agricultural landscapes, restored wetlands along drainage ways, or the restoration of native habitat patches for wildlife (Bartholomew & Mosyaftiana et al., 2024).

Table A1 below depicts the results found from project documentation for target end state.

Table A1. The results for target end state.

Project name	TARGET END STATE
Beed	The agricultural land of small-holder farmers will be converted into sustainably managed agricultural land (using SALM-- nutrient management, soil and water conservation, carbon sequestration, etc.) by those farmers. "About 40%-80% of the land are adopted by SALM activities during the first 2 years and the entire area will be covered for the implementation during the third year. The project is undertaken small scale farmers in 3341.7Ha land area with total of 1116 farm holdings across in three watersheds." "The project integrates sustainable agricultural land management practices aiming at soil carbon enhancement, since agriculture is the main source of income for the farmers involved in the project."
Thompson River (Green Diamond)	Continued sequestration and reduced harvest from 80,851 acres of forest. "The OPO intends to increase carbon stocks in the Project Area, compared to the baseline, by decreasing harvest levels relative to the (legally and financially feasible) harvest levels that predominated prior to project commencement."
Conhuas	Restoration and Conservation of native forest to "develop a project together with the aim of, number one, increasing the ecosystem services that this community provides to the world; but number two, and perhaps more importantly, doing it in a way that benefits the community first and foremost." Focus on ecosystem services.
ARR Horizonte	Eucalyptus plantation. Non-native, invasive(?) plantation forest.
Bandai Hills	Bamboo forest. Non-native (invasive?) plantation forest. (source: https://www.gardenia.net/plant/dendrocalamus-giganteus). Additionally, native forest restoration will be conducted in the areas where bamboo will not be planted. "The project represents the project proponent's proven integrated method of planting, where individual bamboo clumps are inter planted with remaining standing trees, patches of native vegetation and remnant small areas of forest, thereby maximizing biodiversity and overall ecosystem health." "Historical GIS mapping shows that without intervention the lands within the project boundary will transition into a grassland of nonnative, invasive grasses with no chance of reforestation occurring without human intervention."

Assisted Regeneration

The techniques for the restoration of forest ecosystems vary across a wide spectrum of approaches. On one side of the spectrum is passive natural regeneration, and the other side is active seed planting. Assisted regeneration lands in the middle of these approaches as a combination of the two. By definition, it is the combination of active planting and passive regeneration that relies on human intervention and knowledge to preserve and protect forests. Human intervention assists in the recovery of natural vegetation and trees, eliminating barriers to the growth of natural regeneration by applying knowledge of the land and ancestral traditions (Chazdon et. al, 2021).

Assisted regeneration is believed to be critical to advancing global climate and biodiversity targets. Based on the World Resources Institute (2022), it is estimated that assisted regeneration costs less than a third of active tree planting. In addition, in terms of biodiversity benefits, assisted regeneration is the best approach to mimic the habitat of wildlife and native plants within the area. This is especially true in areas where human presence is inevitable, i.e., areas with cattle grazing and agriculture. Assisted regeneration allows for the protection of protected areas with fencing to support the regrowth of native species.

Natural Regeneration

Natural regeneration is the recovery and restoration of ecosystems without human intervention (Chazdon, 2017). Given the correct conditions (adequate seed production, successful germination, and seedling growth), natural regeneration is the most ecological and biodiversity-positive approach to large-scale forest regeneration (UC Davis, 2007). The benefits of this approach include the enhancement and conservation of local biodiversity, genetic diversity, and climate resilience (Chazdon & Guariguata, 2016). Natural regeneration allows for the forest or other ecosystems to independently adapt to local conditions, which is beneficial for long-term success. While it is often thought that active tree planting will generate enhanced community and ecosystem services in comparison to natural regeneration methods, studies have found that natural regeneration can match or exceed the benefits of tree planting (Bechara et al., 2016; Shoo et al., 2015).

Despite the abundant net positive benefits of natural regeneration on a recovering ecosystem, barriers exist to its implementation, especially on a larger scale. It has been observed that the trajectories of natural regeneration can vary greatly, even among plots located within the same region and containing similar previous land uses (Chazdon et al. 2007, Feldpausch et al. 2007, Mesquita et al. 2015, Norden et al. 2015, Arroyo-Rodriguez et al. 2016). Thus, natural regeneration does not prove favorable for reforestation projects that need to be predictable, orderly, or generate results in a timely manner. Producing and sustaining a long-lasting forest ecosystem takes multiple generations and will not reap many economic benefits for project developers. In addition, natural regeneration forests have the potential to seem ineffective and an improper use of land by the local community (Zahawi et al. 2015). In review, natural regeneration is proven to be the most biodiversity-positive forest restoration approach; however, the process also proves to be lengthy, unpredictable, and economically less viable.

Habitat Fragmentation

Similarly to its proximity to protected areas, the project’s shape, size, and contiguity may determine how it supports or degrades biodiversity (Wilson et al., 2015). Nature-based carbon credit projects have the potential to support biodiversity by providing habitat, among other functions. This potential is lessened if the project is fragmented by non-habitat land use like agricultural, commercial, residential, or industrial development, many of which can qualify for carbon accreditation through existing methodologies. When habitat is fragmented into patches, habitat-degrading edge effects increase, leading to less high-quality habitat. The term edge effect refers to disturbances and impacts (e.g. increased noise, loss of shade, polluted runoff) along the boundary of a patch of habitat that often has negative impacts on the rest of the habitat and the species that inhabit it (Wilson et al., 2015). Edge effects can decrease the area of high-quality habitat, as disturbances adjacent to the habitat patch in question can change or eliminate ecosystem functions that a species may depend on. It is worth noting that these edge effects can at times create new habitat for different species adapted to a changed regime. When high-quality core habitat decreases as a result of disturbance, populations decline due to increased competition for resources and other effects of high population density like disease and susceptibility to natural disasters (Haddad et al., 2015). Furthermore, when habitat patches are isolated from each other, populations become genetically isolated, which has ramifications for a population's susceptibility to stochastic events (Haddad et al., 2015). Effective mesh size (Jaeger, 2000) is a widely used and straightforward metric that can help calculate the likelihood that two points within a given project boundary are connected by habitat.

B. Model Builder Code

This section will show the model builder processes used for all GIS analysis conducted in this project.

Species Richness

Figure B1 below is the process that was done in GIS for Species Richness.

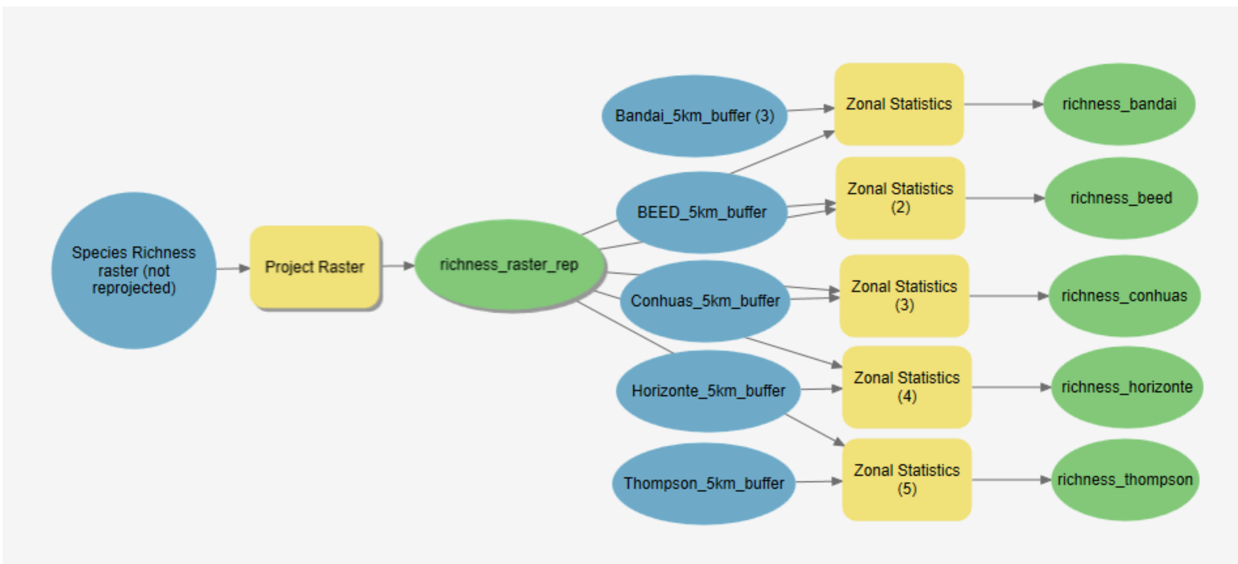

Figure B1. Model builder for Species Richness.

BII

Figure B2 below is the process that was done in GIS for BII.

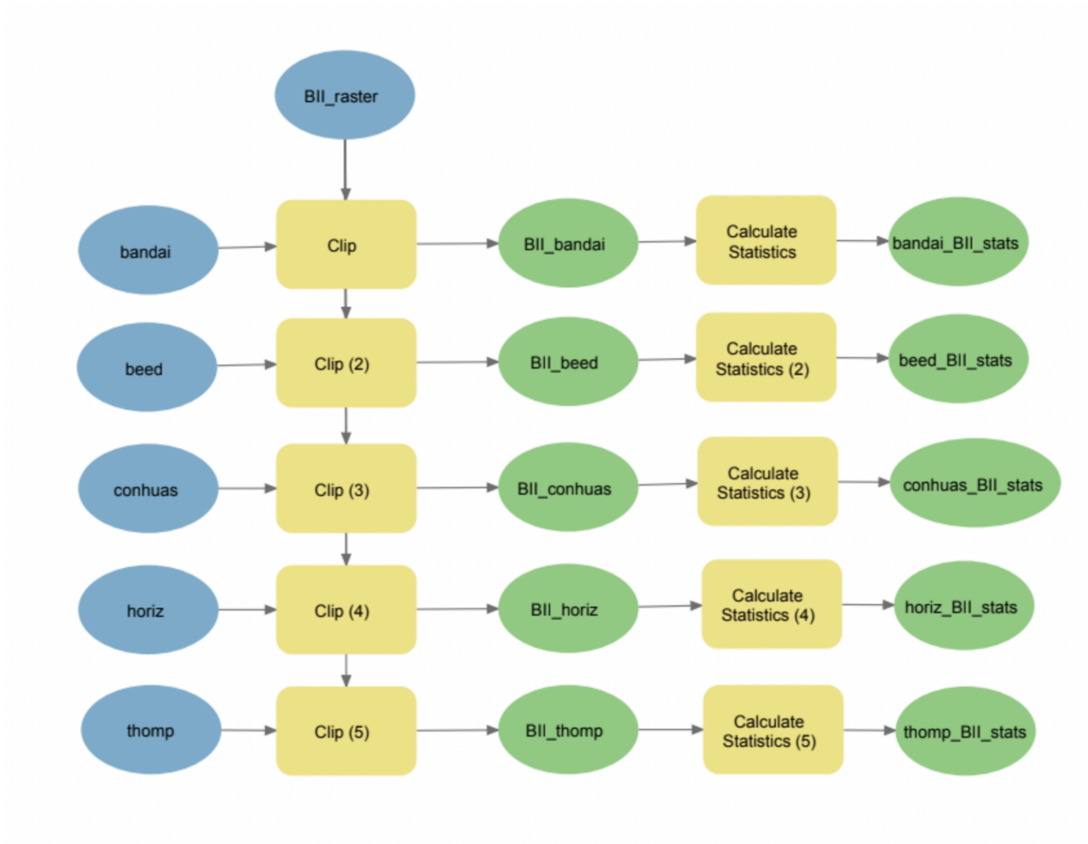

Figure B2. Model builder for BII.

IUCN Red List

Figure B3 below is the process that was done in GIS for IUCN.

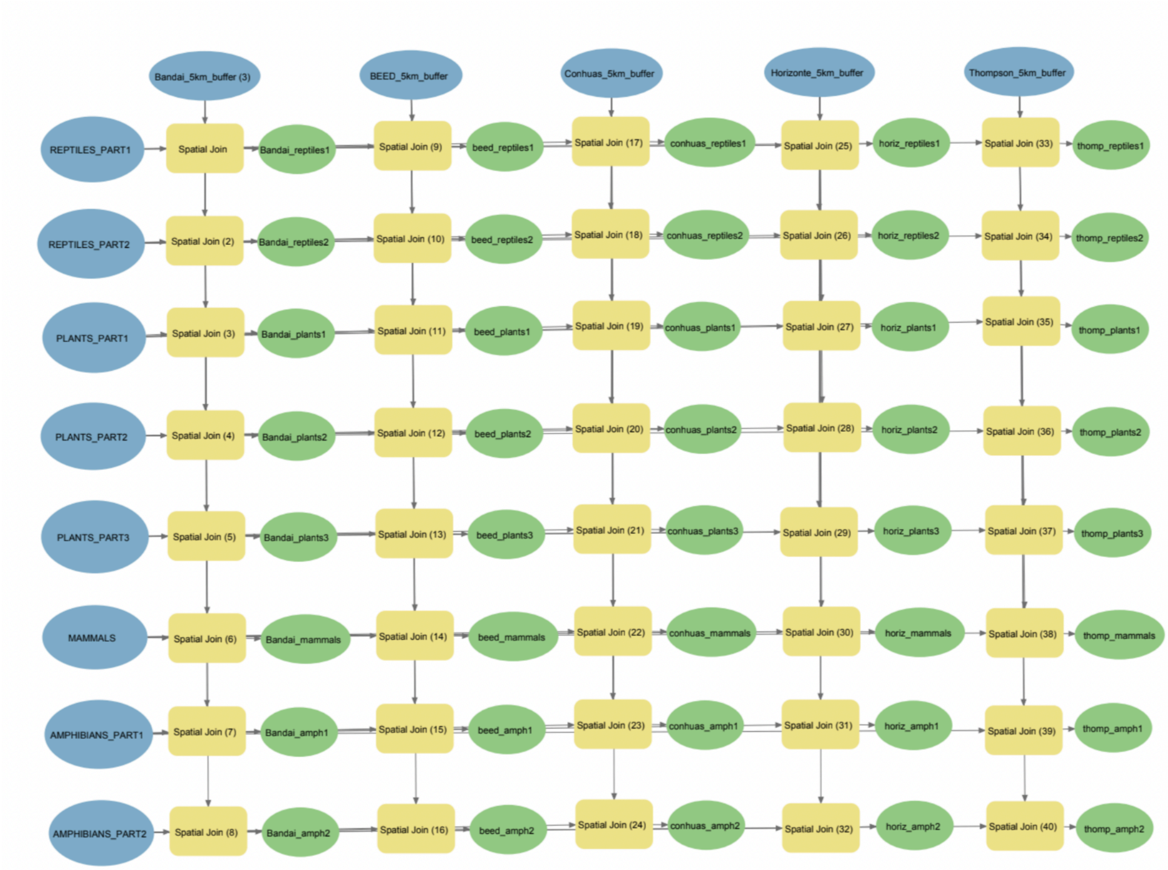

Figure B3. Model builder for IUCN.

RWR

Figure B4 below is the process that was done in GIS for RWR.

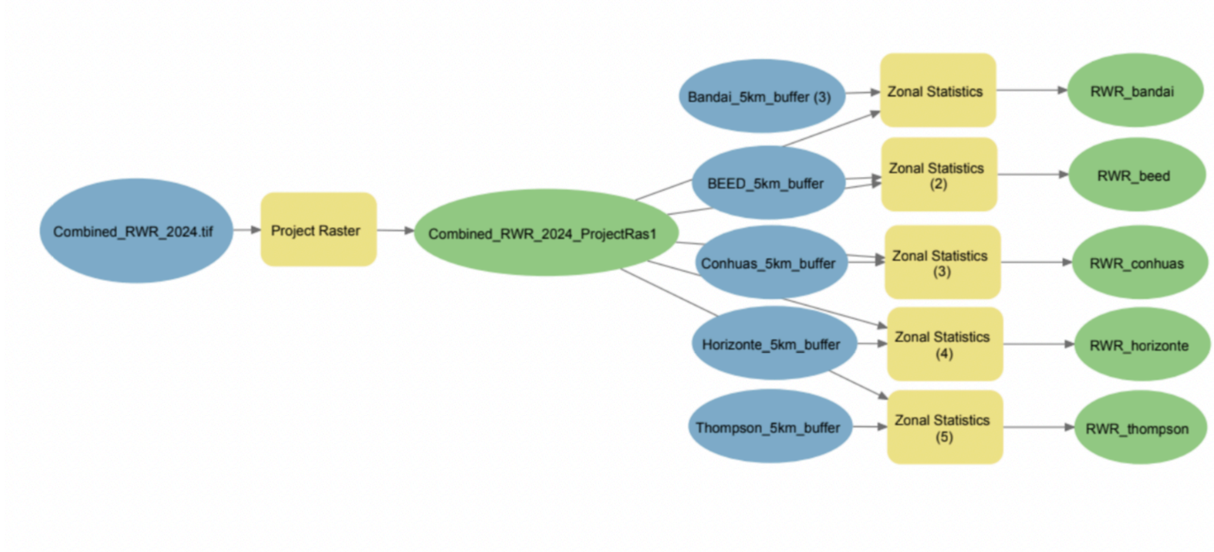

Figure B4. Model builder for RWR.

STAR

Figure B5 below is the process that was done in GIS for STAR.

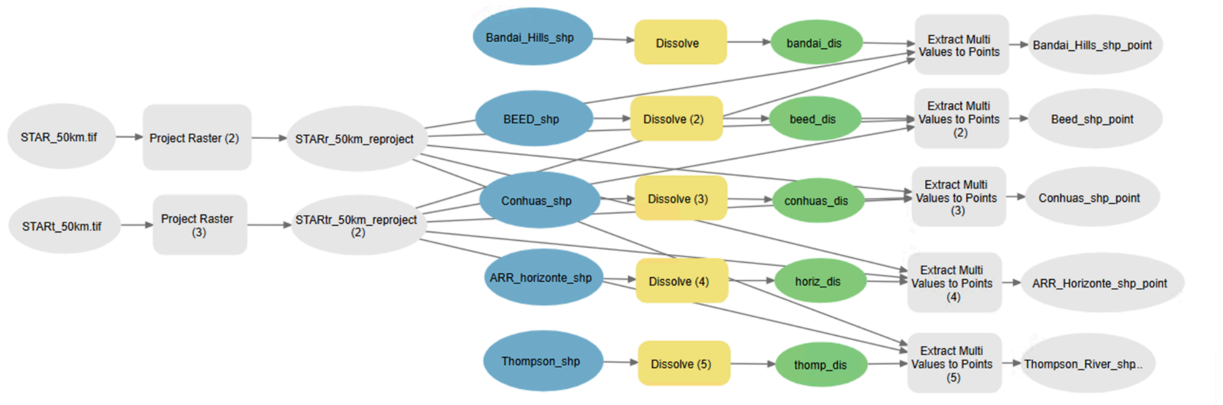

Figure B5. Model builder for STAR

Proximity to Protected Areas

Figure B6 below is the process that was done in GIS for Proximity to Protected Areas.

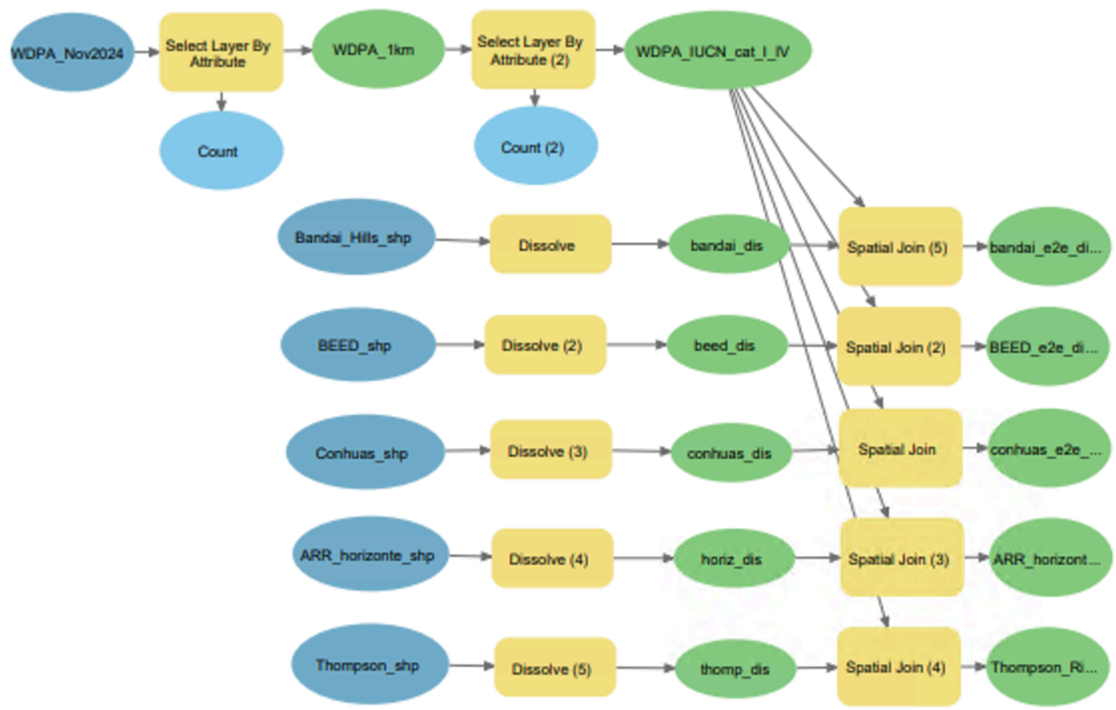

Figure B6. Model builder for Proximity to PA

HMI

Figure B7 below is the process that was done in GIS for HMI.

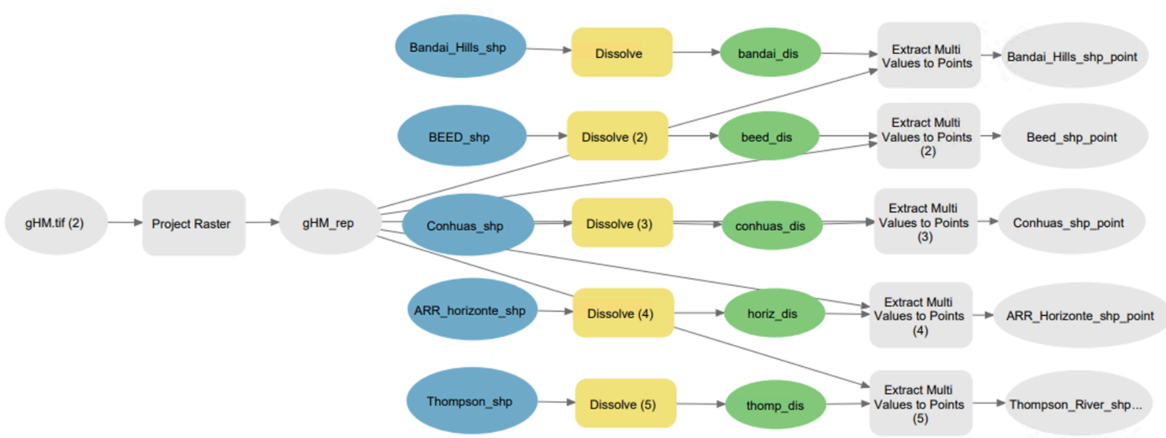

Figure B7. Model builder for HMI

C. *Nature's Contribution to People Exhaustive Results*

The exhaustive results for Nature's Contribution to People can be viewed here.

D. *Biodiversity Monitoring Plan Comprehensive Results*

Table D1 below is the full results from the biodiversity monitoring plan project documentation search.

Table D1. Biodiversity monitoring plan results.

Project name	BIODIVERSITY MONITORING
Beed	**No, there is not a biodiversity monitoring plan. However, the following parameters are known/monitored that could contribute to an understanding of project biodiversity/used to build a biodiversity monitoring plan:** **Data and parameters available at validation** (relating to biodiversity): area under agroforestry tree planting; density of tree species j; biomass expansion factor for conversion of stem biomass to above-ground tree biomass for species j; reference SOC stock corresponding to the reference condition in native lands; relative stock change factor for baseline land-use in stratum I of the areas of land; Relative stock change factor for baseline management regime in stratum I of the areas of land; Soil organic carbon density, to a depth of 30 cm, at equilibrium for cropland with management practice, mc; **Data and parameters monitored:** (relating to biodiversity): The diameter at breast height (1.3 m from the ground) of Afforestation plantation; The diameter at breast height (1.3 m from the ground) of Agro-horticulture plantation in SALM Sample plots; Height of tree planted; Area under agroforestry tree planting; Soil organic carbon density, to a depth of 30 cm, at equilibrium for cropland with management practice, mc;
Thompson River	**Currently, there is no biodiversity monitoring plan in place. Based on the project documents made available, it does not seem like there is a motive to build a plan**.
Conhuas	**Yes, there is a biodiversity monitoring plan. The following describes the measures put in place to monitor biodiversity:** "These revenues will also allow us to implement a territorial monitoring and management plan together with the ejidos to ensure the compliance with environmental and social safeguards throughout the life of the project." "The ejido is committed to the conservation and protection of wildlife. Camera traps are strategically placed in different areas, in order to to know the different species that the jungle of the ejido houses. The camera traps take from 20 to 30 days in each area and they are placed in another place, which is a tool that helps us for monitoring

	wildlife within the forest area of the ejido.”
ARR Horizonte	**No, there is not currently a monitoring plan specific to biodiversity in place; however, this project does contain parameters that could contribute to an understanding of project biodiversity.** Moreover, to keep track of the benefit brought by this activity, Suzano also monitors and register local fauna apparitions, which will be available at the monitoring events.
Bandai Hills	**No, there is not a biodiversity monitoring plan. However, the following parameters are known/monitored that could contribute to an understanding of project biodiversity/used to build a biodiversity monitoring plan:** “In addition, the PP included the monitoring of pre-existing trees to document the impact by the bamboo plantation. Monitoring will occur as part of the carbon monitoring process within the dedicated Permanent Sample Plots.” Monitoring Plan “The monitoring plan presented in the PD complies with the requirement of the applied methodology. The assessment team checked all parameters presented in the monitoring plan against the requirements of the VCS standard and the methodology. For the monitoring of carbon stock changes under the VCS the requirements and parameter list as per methodology were followed. Relevant parameters available at validation are listed in the PD and are considered valid by the audit team as all values are derived either from IPCC sources, or other well-regarded published literature. As described in the PD, site specific allometric equations were developed for the ex-ante calculation of above ground biomass of Dendrocalamus asper and Bambusa textilis. Details are provided under section 3.3.6 in this report. No errors or misrepresentations were detected in the review of these data and based on review of the calculations of the project proponent, no values are missing. All relevant parameters that need to be monitored for verification are listed in the PD as required by the methodology.”