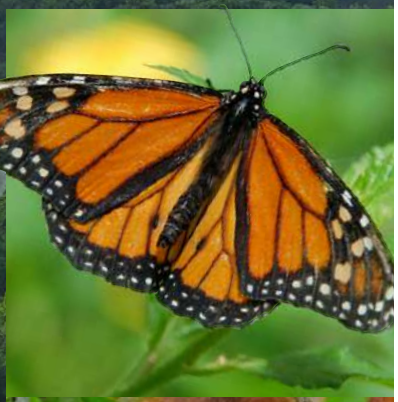
ADM CAPITAL FOUNDATION









Accounting for Biodiversity

Working Paper:

Towards measuring and valuing the biodiversity impacts of financial investments

Over the past sixteen years, ADM Capital Foundation has engaged in research, policy action, and thought leadership on issues relating to nature, climate, and sustainability across Asia. Established by the partners of ADM Capital in 2006, the Foundation has played a key role in supporting the firm's investment activities and Environmental Social Governance (ESG) integration, most recently through its Finance for Nature programme.

ADM Capital is a private credit firm that has been lending across Asia since 1998, initially starting with distressed assets. At present, the firm manages USD2.5 billion across Asia Pacific and Europe, with sustainability and ESG themes playing an integral part of investment decisions. Beyond Asia Private Credit, the firm manages the private equity Cibus Funds out of London. These series of funds focus on sustainable food, agriculture, and agricultural technology.

While sustainability has been a factor in ADM Capital investment decisions for many years, the funds have not had a clear strategy with regard to biodiversity except in terms of excluding investments that represent bad practice in this regard. Increasingly, particularly through ADM Capital's new Asia Climate-Smart Landscape Fund (ACLF), investment team members are looking to invest in companies that embrace good practices relative to biodiversity. We believe the value of these companies' impact is yet to be priced in.

Through its Finance for Nature programme, the ADM Capital Foundation looks to promote new strategies to execute on biodiversity objectives that can be adopted not just by its parent funds, but also by others. We are constantly looking for new methods and approaches that are both feasible and impactful, including the considerations put forth in this paper. We welcome any questions, feedback, dialogue directed to info@admcf.org.

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Foreword

Three decades of rapid economic growth across Asia and associated fossil fuel-based energy consumption has resulted in excessive resource use, pollution, and biodiversity loss, among other challenges. In 2015, the Asian Development Bank predicted that the ASEAN region's greenhouse gas (GHG) emissions from energy consumption will increase by 300% by 2050.[1]

To adhere to the Paris Agreement's limitation of global temperature rise to 1.5 degrees, however, the region must achieve net-zero emissions by 2065 relative to its 2010 baseline.[2] Furthermore, 40% of Asia's land area is projected to experience biome shifts that threaten biodiversity, human health, and food production. These are associated with a 40% risk of substantial decline in grain yield.[3]

As the climate and biodiversity crises of the 21st century become increasingly material to all industries and sectors, finance broadly has turned attention towards natural capital and its influences and dependencies on investment activities. Increasingly, capital is flowing towards investments that prioritise positive outcomes for biodiversity, or at the very least do not actively contribute to its degradation.

This shift has led to a broad range of guidance and frameworks geared towards valuing and measuring biodiversity impacts, risks, and opportunities within the context of sustainable finance. However, we see comparatively few examples of applying such frameworks to real-world portfolios or investment projects. ADM Capital's two decades of engagement with SMEs across Asia, the last ten years of which were executed through a sustainability lens, has provided the perfect opportunity to trial, develop, and implement analytical tools to consider the biodiversity impacts of investments and manage related risks.

ADM Capital's new **Asia Climate-Smart Landscapes Fund** (ACLF) offers an outstanding opportunity to apply the early stages of this framework. The fund is geographically focused in Indonesia, which contains the world's third largest tropical rainforest along with globally significant biodiversity hotspots. Indonesia is also the fourth largest GHG emitter, with an estimated 60 percent of those emissions originating from land use change from forest to agriculture. The impacts on biodiversity are dramatic: Indonesia has the highest number of threatened mammal and bird species in the world, with many more continuing to decline.

As the finance industry awaits the emergence of a clear and universal standard by which to evaluate biodiversity impact, ADM Capital Foundation has embarked on its own effort to proactively integrate nature positive themes alongside the development of ACLF. The framework showcased in this working paper documents the ongoing considerations being taken as we collectively develop an approach to biodiversity accounting for investments.

Lisa Genasci
Managing Director, Sustainable Finance
ADM Capital

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Executive Summary

The need for biodiversity accounting

Global biodiversity is declining rapidly as a result of human activities and climate change. Without peaking global greenhouse gas emissions before 2025, the world risks crossing irreversible thresholds that could trigger permanent losses in biodiversity and the human systems that rely on them.[5] Impacts range from resource scarcity and lack of food security to public health risks, all of which have the potential to disrupt global supply chains and economic systems. Consequently, businesses and investors face growing operational and market risks.

In light of this, guidance on assessing biodiversity risks and impacts has begun to emerge at the nexus between climate, nature, and finance. This space, however, remains relatively fragmented and without standardised metrics or approaches. There is an urgent need for practical examples of how to quantitatively assess the impacts of investments on biodiversity, the risks that biodiversity loss poses to investments, and subsequently to develop nature positive investment strategies: a process that we refer to as **biodiversity accounting**.

Developing and documenting the process

This working paper seeks to close this gap by providing examples of a process towards developing a scientifically robust and practical framework to measure biodiversity impacts and manage nature-related risks. The framework is being developed with a Private Credit application in mind, focusing on investments with a defined location where biodiversity impacts are to be measured. Our aim is to share insights, challenges, and resources that financial stakeholders can apply to inform their own biodiversity approaches. This paper also serves to inform readers on the fundamental concepts of biodiversity, its materiality, and the range of guidance, metrics, and initiatives that are emerging.

Acknowledging that much of the high-level guidance lacks real-world examples of implementation, we provide such an application to exhibit how these metrics are being used for the ongoing development of ADM Capital's **Asia Climate-Smart Landscapes Fund** (ACLF). ACLF is the first in a series of funds under a new climate vertical within the firm. The Fund looks to offers medium-term senior secured lending to SMEs in Indonesia that are engaged in sustainable agriculture, agroforestry, and aquaculture while integrating climate, livelihood, land use and gender equity targets.

Through this real-world application, we showcase a variety of analytical tools and metrics that assess biodiversity under three key pillars: habitats, species, and human activities. Our approach seeks to address the need for globally comparable metrics that can be applied to any investment location, whilst also applying locally-specific and granular data to gain a deeper understanding. Two levels of analysis were employed in our framework:

Level 1: high-level snapshot of biodiversity that applies the same metrics to all projects

Level 2: detailed accounting and monitoring of biodiversity that applies metrics specific to the context of each project, selected and shaped by insights from the Level 1 analysis

Level 1 Analysis

The IUCN's Integrated Biodiversity Assessment Tool (IBAT) platform was identified as a practical and user-friendly way to generate baseline insights about the biodiversity characteristics of an investment project. IBAT was used to calculate:

a) Species Threat Abatement and Restoration (STAR) metrics, which characterise species extinction threats; and

b) IFC Performance Standard 6 (PS6) metrics, which describe the key biodiversity areas, protected areas, and endangered species that lie within the vicinity of the project site.

The Level 1 analysis is quick to execute without a need for technical expertise, and its results can be compared for all projects regardless of geography or investment type – so long as they possess a physically-defined project site. These analytical insights also shape the development of project management strategies that align with the IFC PS6 and Mitigation Hierarchy principles, particularly the first stage, Avoidance.

Level 2 Analysis

This analysis builds upon the Level 1 analysis with a suite of metrics and indicators that provide a deeper dive into the drivers impacting biodiversity on a local and landscape level. The tools, software, and analyses that are performed at this stage will differ from project to project depending on:

- the availability of local data;
- the way in which the investment affects the surrounding ecosystem; and
- the project's specific biodiversity goals.

Achieving the level of depth to account for biodiversity at the project level requires companies to devote resources to collecting site-based data through established methodologies, such as the High Conservation Value and High Carbon Stock (HCV-HCS) approach, and working with geospatial data. These capabilities can be enabled through partnerships with local NGOs, academic institutions, or emerging biodiversity tech start-ups, as well as through accessing pools of grant/blended capital that target this sort of support.

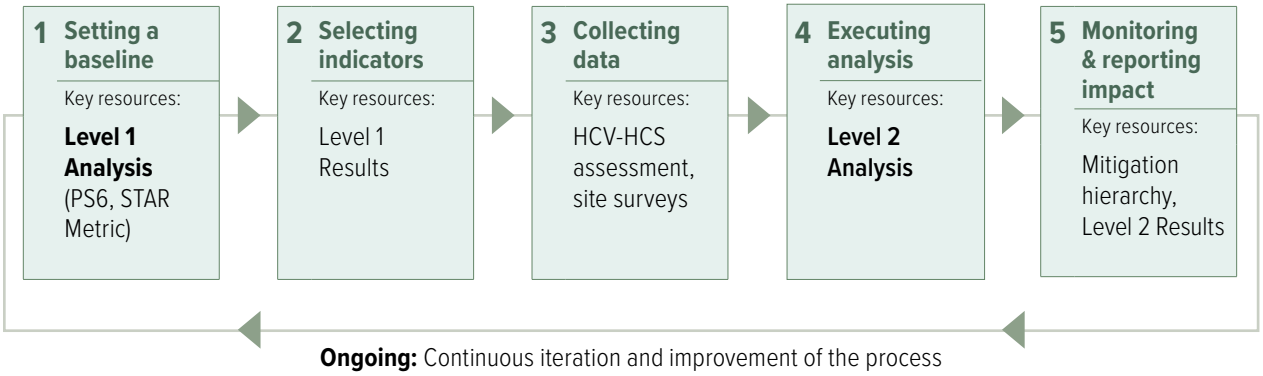
Real-world Application

The real-world application presented in this report applies both the Level 1 and Level 2 analyses to serve as a foundation for the ongoing biodiversity accounting process for ACLF. This application demonstrates how the framework can be used to approach biodiversity in investment projects that are still in the pipeline development stage.

Without the availability of data collected on site at this early stage, the ACLF biodiversity accounting process relied on the creative use of global datasets and geospatial analyses (e.g., spatial analysis of historical forest cover changes) to quantify biodiversity impacts. The Level 1 analysis provided an initial high-level overview of a project's underlying biodiversity context at the early stage of pipeline development, where such detailed data was still lacking.

The Level 2 analysis was particularly useful for producing insights to inform the development of key biodiversity management strategies to prioritise during the execution of each project. As these investments mature, they will require the collection of data on-site, through the HCV-HCS approach and others, to set the foundation for future biodiversity monitoring and impact measurement.

Framework development process



Key Recommendations

Our initial framework development and trialling process yields three key recommendations for those seeking to develop their own biodiversity and natural capital accounting strategies:

a) Develop and improve site-base data collection capabilities;

b) Integrate geospatial modelling tools with in-house workflows; and

c) Support and contribute to cross-sectoral dialogues that facilitate the alignment of standards, taxonomy, and frameworks.

Looking forward, we will continue to develop our biodiversity accounting framework in conjunction with the launch and implementation of ACLF. With this initial phase of the framework, the next stages of development will detail the process of measuring tangible changes through the suite of indicators established. In particular, we hope these measurements will translate to quantifying the biodiversity impacts achieved through ACLF.

The approach outlined here is currently only focused on terrestrial ecosystems. Nevertheless, there will also be ongoing development to expand the suite of metrics and techniques to also evaluate and account for freshwater and marine biodiversity impacts. As we continue to document our journey towards enabling a nature positive future, we look forward to engaging closely with other financial sector stakeholders to accelerate positive change.

1. Introduction

What is accounting for biodiversity?

The concept of **biodiversity accounting** arises from the need to understand the impacts that a company's investments and operations have on natural ecosystems and their functioning, as well as the relevant risks that biodiversity impacts pose to investments.

As companies move towards more sustainable operational and investment models that aim to produce positive impacts on nature and reduce negative impacts, it is critical to measure, monitor, and validate the progress made towards these goals. This accounting process extends beyond traditional environmental impact assessments (such as those carried out for land development projects) in that it seeks to evaluate and monitor the positive or negative impacts that financial investments, including their value chains, have on biodiversity.

The measurement of **biodiversity impact** requires a systematic and quantitative approach that can be practically implemented at regular intervals. For the purposes of this working paper, the process of biodiversity accounting takes stock of the baseline state of the ecosystem, sets a framework for monitoring future impacts or progress, and identifies priority actions that projects can address in their management strategies to maximise benefits for biodiversity.

Who is this working paper for?

In this working paper, our initial approach to quantifying and valuing biodiversity impacts is documented using the sustainable land use and climate-focused impact fund of ADM Capital Asia Private Credit as a real-world application. By being as transparent as possible about the data sources employed, analytical process developed, and challenges encountered at the onset of this journey, we hope that this paper can provide other industry practitioners with practical insights to kickstart, guide, or inform their own biodiversity accounting process.

This working paper aims to:

- Inform financial industry stakeholders who wish to undertake or develop their own biodiversity accounting process, specifically for investments that have a defined location at which biodiversity impacts are to be measured;
- Serve as an educational resource to increase industry-wide literacy on biodiversity-related themes related to investments and the range of science-based metrics and data available on the market; and
- Facilitate the exchange of knowledge with technical practitioners who are experienced with the quantitative aspects of biodiversity, with the hope of sparking discussion on our endeavour to creatively operationalise existing metrics and tools to guide industry stakeholders.

How to use this report

Learn about biodiversity, how it is valued, and its relevance to investments	**CHAPTER 2** Biodiversity Fundamentals
Gain an overview of various standards, metrics, and initiatives currently available to evaluate biodiversity in financial contexts	**CHAPTER 3** Biodiversity Tools & Resources
Understand ADMCF's approach to biodiversity accounting and the methodologies we have developed	**CHAPTER 4** Developing a Biodiversity Accounting Process
Follow a detailed example of how our framework has been applied to inform the biodiversity accountability and management strategies of an early-stage investment fund	**CHAPTER 5** Real-world Application: ACLF
Read our recommendations and plans for future work	**CHAPTER 6** Looking Forward

2. Biodiversity Fundamentals

What is biodiversity?

Across terrestrial, marine, and freshwater ecosystems alike, biodiversity underpins the health and wellbeing of human and natural systems. Defined as the variability among living organisms – including diversity within species, between species, and of ecosystems – that exist within a given area,[6] biodiversity is one of many ways of describing the state of an ecosystem and its functioning.

Biodiversity upholds the multitude of **ecosystem services** that benefit humans. These services fall into three main categories:[7]

1. Provisioning services: raw materials and natural resources such as food, water, timber, and fibre
2. Regulating and maintaining services: the regulation of climate, water, and nutrient cycles
3. Cultural services: the recreational or experiential value of ecosystems

The resilience, quality, and effectiveness of ecosystem services, which serve as a foundation for human health, livelihoods, and economic development, are ultimately upheld through the biodiversity and health of natural ecosystems. Biodiversity also plays an important role in mitigating climate change, with crucial linkages to the carbon cycle (Box 1).

Box 1: Biodiversity, carbon, and climate change: How are they connected?

Biodiversity, carbon, and the climate are all closely interlinked and serve crucial roles in Earth's overarching natural systems. Healthy ecosystems play an important role in storing and regulating carbon emissions. Soils, oceans, and vegetation, including forests, are the world's most significant carbon sinks, storing more carbon than they release and keeping the carbon cycle in balance when maintained in their undisturbed state.

Biodiversity serves as a key regulator that upholds the health and carbon storage abilities of natural ecosystems. In most cases, ecosystems that have higher species diversity and abundance can sequester more carbon due to increased resilience of the carbon stocks and higher ecosystem productivity.[8] This makes the maintenance of biodiversity crucial to addressing and mitigating the climate crisis.

Stated by Sveinung Rotevatn, Norway's climate and environment minister: "It's clear that we cannot solve the global biodiversity and climate crises in isolation – we either solve both or we solve neither."[9]

As humans extract and burn long-term carbon stores (i.e., fossil fuels) for energy, an increasing amount of carbon is released back into the atmosphere to contribute to the greenhouse warming effect. This phenomenon has led to an accelerated rate of warming.

The changing climate is negatively impacting human populations and biodiversity alike by altering habitats, the availability of water, and prevalence of extreme climatic events such as floods or fires. Moreover, the direct destruction of natural habitats for urbanisation and resource extraction has also contributed to the loss of biodiversity, which has further exacerbated climate change and weakened our ability to mitigate it.

In this way, the functioning of ecosystems, preservation of nature, and mitigation of climate change are tied together through mutually dependent relationships. With this in mind, financial institutions should consider climate change and biodiversity in tandem as they develop strategies and targets relating to sustainability and ESG themes.

> *"Ecosystem services underpin nearly all global economic activities and further provide invaluable cultural and regulatory benefits, the ability to sequester carbon among them. Biodiversity measures how well those benefits are protected from disturbances – that is, how resilient those services are. In a world already witnessing biodiversity loss and negative feedbacks between climate change and nature's health, continued understanding and protection of biodiversity is imperative for all our future goals."*
>
> **Oliver Miltenberger**
> Founder and Principal
> The Conservation Exchange (July 2022)

Biodiversity loss

Over the past several decades, the impacts of climate change, resource exploitation, pollution, and other human activities have degraded biodiversity at an increasingly rapid rate. Already, three quarters of the land surface has been significantly altered and half of coral reef cover has been lost since the 1870s.[10]

Despite repeated international policy commitments aimed at slowing or halting the rate of species loss, biodiversity continues to decay at an alarming rate. It is estimated that global populations of vertebrate species (i.e., mammals, birds, fish, amphibians, and reptiles) have reduced by 69% between 1970 and 2018 (Figure 1), and the average abundance of native species in terrestrial biomes has fallen by at least 20%.[11] Over the same period of time, species declines have been particularly severe in tropical regions, namely Southeast Asia and the Amazon.

Asia, home to the largest number of **biodiversity hotspots** in the world, has seen a sharp loss of biodiversity over the last several decades due to unsustainable agriculture, logging, mining, and urban development.[12] Deforestation rates in Southeast Asia are among the highest globally, with intense harvesting and illegal overexploitation driving the decline of critical species and habitats.[13]

The value of biodiversity

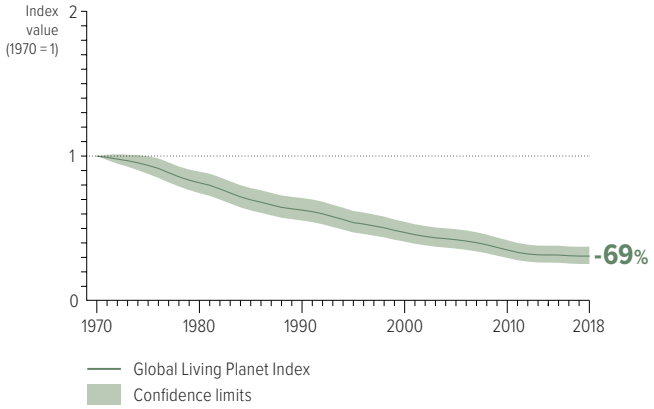
The dependence of financial markets, supply chains, and investments on natural ecosystems and biodiversity are anything but nominal. A study by the World Economic Forum estimated that USD44 trillion of economic value generation – 52% of the world's GDP – is moderately or highly dependent on well-functioning ecosystems and therefore on their biodiversity.[14]

With financial regulatory bodies like the EU's European Supervisory Authorities requiring the disclosure of **principal adverse impacts** (PAI)[15], including those relating to biodiversity, it is imperative that financial institutions act swiftly to integrate biodiversity considerations with existing risk management and investment decision-making processes.

Figure 1

Between 1970 and 2016, the average abundance of vertebrate species declined by 69% as measured by the global Living Planet Index

Source: Almond et al. 2022



Such institutions need to consider the impacts of nature on their investments and the risks they pose to operations, as well as the positive impacts that they can have on biodiversity. A landmark study conducted by the University of Cambridge shows that the economic benefits of conserving nature and biodiversity now outweighs the potential profits generated from intensive human land use (e.g., from agriculture or logging).[16]

These net benefits involve greenhouse gas regulation, flood protection, and many other ecosystem services, showing that there is value in not just avoiding adverse impacts, but actively contributing positively to the restoration and conservation of nature (Box 2). The fundamental transformations required to address the nature crisis are furthermore estimated to create USD10.1 trillion in annual business opportunities by 2030, highlighting the win-win pathway that a nature positive future holds.[17]

The appetite for a voluntary biodiversity credit market

Regulated biodiversity offsets have been in place for several decades as a policy-driven mechanism to compensate for losses of biodiversity incurred by development projects. As with other types of offsets, such as carbon, the ability to compensate for environmental damage through monetary means would only be available in circumstances when negative impacts are unavoidable and all other steps of the mitigation hierarchy have been exhausted.[19]

In recent years, however, the potential for a **voluntary biodiversity credit market** has gained traction through growing demand from entities who wish to actively finance positive biodiversity impacts without a distinct need to offset unavoidable impacts. This comes as a growing number of institutions and corporates seek to develop nature positive strategies alongside their net zero commitments.

If implemented effectively, particularly by taking into account lessons from the adjacent carbon credits arena, the voluntary biodiversity credit market has been predicted by some industry experts to exceed the size of voluntary carbon markets.[20] These credit mechanisms have been identified as one of the key available tools to address the USD598–824 billion annual spending gap estimated for biodiversity conservation.[21]

However, several key challenges stand in the way. For instance, there is still a lack of clarity on the kinds of metrics that can be used to assure the appropriate baseline measurement, implementation, verification, and monitoring of biodiversity credits. The development of such markets – whether they are voluntary or regulatory – will also involve the careful consideration of the pricing mechanisms implemented to assure positive and productive outcomes of biodiversity credits.

"To achieve real, positive outcomes for nature, the emerging biodiversity credits market will need verifiable, science-based methods and metrics that evidence on-the-ground results to buyers and financiers – enabling buyers to purchase with confidence and directing financing to where it drives tangible, additional benefits.

It will also need to be structured such that financing reaches those who are delivering for nature on the ground. The carbon offset market has taught us much about what happens in the absence of robust measurement, reporting, and verification (MRV), metrics, accounting, and equitable distribution of financial incentives."

Zoe Balmforth
Co-founder
Pivotal Future (August 2022)

A related concept is that of **biodiversity insetting**, which targets activities directly within a company's value chain where nature-based solutions or conservation efforts can be integrated for measurable reduction in climate impact – as opposed to investing in external projects that serve as offsets.[22] For instance, a company that is involved in commodity-production landscapes may implement sustainable agroforestry practices or conservation strategies for nearby ecosystems. These activities would directly produce benefits to nature while also enhancing yield and the resilience of supply chains to climate change impacts.

Regardless of offsetting or insetting, however, a clear understanding of the metrics and standards used to measure baselines and monitor progress are paramount. At the moment, there still lacks a single unit to define biodiversity credits and no clear platform has emerged to trade such credits. On a broader level, there are still questions pertaining to scale for widespread uptake: how can pipelines be developed – and accurately measured – to deliver high quality projects at the scale required from both public and private markets?

A paradigm shift for businesses

With more than half of the world's economic output highly or moderately dependent on nature, it is in the interest of companies, investors, and lenders to turn their attention towards biodiversity.[23] The relationship between businesses and nature is one of tightly-linked interdependence, where the wellbeing of one system hinges on the actions of another. Just as biodiversity is impacted by investment activities across value and supply chains, this degradation of ecosystems ultimately increases operational risks and economic losses to financial institutions.[24]

As a result, business and finance sectors are being galvanised to become drivers of positive change. Some have begun to use biodiversity as a screening criterion for environmentally-themed equity funds, while others are developing blue and green bonds to fund projects that benefit species conservation, habitat restoration, or other nature-based solutions (Box 2).[25]

Increasingly, financial institutions are being called upon to set targets towards **net zero** carbon emissions as well as **nature positive** impacts.[26] Biodiversity-related investments are also becoming recognised by regulatory bodies: the EU's taxonomy for sustainable activities, for instance, establishes 'the protection and restoration of biodiversity and ecosystems' as one of the six environmental themes that determine the environmental sustainability of an investment.[27]

"Investing in nature brings a tremendous range of benefits to people; together these benefits are known as nature-based solutions. However, as with all investments, it is prudent to ensure that the returns are measured in a verifiable, robust and scientifically anchored fashion. Positive impacts on biodiversity require particular attention as biodiversity has generally been thought of as difficult to encapsulate in metrics that can be used by investors.

IUCN's Nature Positive approach, which utilises immense datasets assembled under IUCN standards, begins to address this problem. Initiatives like these open up substantial opportunities for investors to generate nature-based solutions for climate and biodiversity – a market with immense potential in global biodiversity hotspots such as Southeast Asia."

Frank Hawkins
Policy Advisor
IUCN (August 2022)

Box 2: Nature-based solutions

Much of the important action needed to stem biodiversity loss, climate change, and other environmental concerns can be unlocked through changes in human consumption habits or the conservation of nature.

Nature-based solutions refer to activities that involve the protection, sustainable management, and restoration of ecosystems. Such actions have been defined by the UN to "address social, economic, and environmental challenges effectively and adaptively."[28]

It was estimated in 2019 that a USD1.8 trillion investment in climate adaptation from 2020 to 2030 could yield USD7.1 trillion in net benefits.[29] Nature-based solutions are a key component of these climate adaptation strategies, particularly because their outcomes can benefit local communities and regional economies in addition to biodiversity.

For example, the restoration of tropical mangrove forests provides the primary benefit of restoring local biodiversity within the coastal ecosystem. Beyond this, there are additional positive externalities provided to surrounding coastal communities, such as protection from storm surges and natural filtration of pollutants. With careful management and monitoring of fishery populations residing within the mangrove ecosystems, local residents can also benefit from additional value streams generated.

When executed and monitored effectively, nature-based solutions thus provide a valuable and economically viable opportunity to stem biodiversity loss and mitigate climate change. Assuring that positive biodiversity outcomes can be quantitatively validated has therefore never been a more pressing priority as an unprecedented amount of capital flows towards nature-based solutions.

The Mitigation Hierarchy: The journey towards a nature positive future for businesses and financial institutions is guided by tools such as the mitigation hierarchy, a framework for managing risks and impacts to biodiversity and ecosystem services.[30] The hierarchy describes a sequence of actions that companies should take to anticipate and avoid negative biodiversity impacts in their development projects, supply chains, or investments (Figure 2). The hierarchy is as follows:

1. **Avoidance:** avoiding the creation of impacts from the outset through site selection, design, or scheduling.
   Example – selecting a site that does not encroach on critical biodiversity habitats

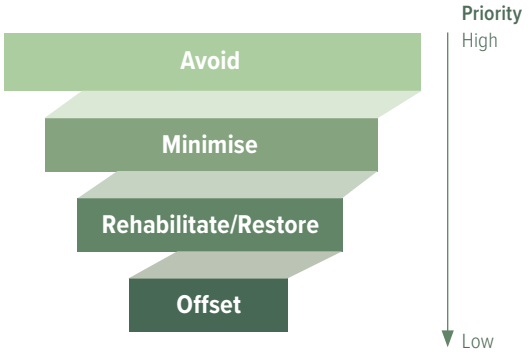
2. **Minimisation:** reducing the duration, intensity, or extent of the impacts that cannot be completely avoided.
   Example – building wildlife corridors to connect habitats that the site interrupts

3. **Rehabilitation/restoration:** improving ecosystems that have been degraded following exposure to impacts that could not be avoided or minimised.
   Example – replanting trees to stabilise bare soil in degraded land areas

4. **Offset:** compensating for any residual, adverse impacts only after the full implementation of the prior three steps of the mitigation hierarchy.
   Example – 'restoration offsets' that rehabilitate degraded habitat, or 'averted loss offsets', which aim to reduce or stop biodiversity loss in intact areas

Figure 2

Sequential steps of the mitigation hierarchy to limit negative impacts on biodiversity



While there are systems in place that financial institutions can implement to measure the progress made towards contributing positively to biodiversity in their investment projects – such as the IFC Performance Standards, Environmental Social Action Plans, and site-based data collection process, – there is not yet a consensus on a comprehensive, universal approach. This presents a key challenge in a space that requires further development of standardised yet practical assessment approaches.

The need for practical methodologies to assess impacts

The first step towards making meaningful positive change for nature and biodiversity is to quantitatively assess the impacts of existing business activities – beyond the traditional environmental impact assessments that are carried out for land development purposes. The biodiversity accounting process would instead serve as a starting point from which to monitor changes, as well as set targets for actions addressing mitigation, restoration, or conservation.

Institutions must have a clear understanding of not just the nature-related risks or opportunities that biodiversity loss poses to them, but also the impact that their activities have on biodiversity. Doing so presents a challenge: methodologies for quantifying biodiversity-related insights must be scientifically and analytically robust, while also maintaining practicality and cost-effectiveness to business and financial stakeholders.

The need for practical methodologies is particularly significant as institutions are increasingly called upon by investors and regulators to report on their impacts, potential risks, and strategies related to climate change and nature (Box 3). Without a way to benchmark or measure progress in these areas, however, industries will be unable to truly drive positive change for their investments and the planet.

Box 3: Nature-related risk disclosure and the need for metrics

There has increasingly been a regulatory push for financial institutions to understand and disclose risks related to not just climate change, but also biodiversity.

The EU, for instance, is currently proposing a Corporate Sustainability Reporting Directive that would require over 50,000 companies to disclose their impacts and dependencies on climate, air, land, water and biodiversity using PAI indicators.[31] Furthermore, their **Sustainable Finance Disclosure Regulation** (SFDR), published in 2019, outlines measures specifically for financial entities that relate to ESG-related disclosure obligations, including those relating to PAIs on the environment.[32] It has further been bolstered by the 2020 Taxonomy Regulation that introduces concepts surrounding 'environmentally sustainable economic activities.[33]

One emerging initiative to provide guidance for financial institutions on such disclosures is the **Taskforce for Nature-related Financial Disclosures** (TNFD). Aligning closely with the disclosure recommendations from the Taskforce on Climate-related Financial Disclosures (TCFD), which were released in 2017, the TNFD's framework contributes complementary nature-related risk identification and management strategies. Its first beta version of its risk management and opportunity disclosure framework was published in March 2022, with the final recommendations set to be released in September 2023.[34]

"The TNFD is addressing data and metrics slightly differently to the TCFD. Whereas the TCFD worked on the basis that building the metrics will allow the data to follow, the TNFD has separated data and metrics into two different working groups – Data & Analytics and Metrics & Targets. As the framework develops, the Data & Analytics working group will continue to work more closely with the Metrics & Targets group to show what data can be used to populate the metrics being adopted."

James d'Ath
Technical Lead for Data and Analytics
TNFD (July 2022)

The coming years may see the integration of nature-related disclosures with financial regulations in the same way that climate disclosures have. Many jurisdictions have begun implementing regulations and mandates for climate-related financial disclosure, from the US and EU to Hong Kong and Singapore.[35] Additionally, voluntary industry initiatives, such as the Principles for Responsible Investment (PRI), have also made climate reporting with TCFD-based indicators mandatory for their signatories.[36]

Comparatively, the TNFD and related guidance are in the early phases of development. There still lacks a consensus on standardised metrics that organisations can use to assess nature-related risks. A key challenge lies in the complexity of ecosystem dynamics and biodiversity, which cannot be encapsulated within a singular metric. This is unlike carbon emissions, which are uniformly measured in units of CO_2 equivalents (CO_2e).

There is much room for the development and standardisation of specific metrics to support the disclosure of nature-related risks and opportunities. Many platforms that can be used to measure nature through the lens of biodiversity are not yet directly integrated with complementary tools relating to carbon or other sustainability elements. For example, scenario analysis tools used for climate-related risks disclosure do not yet include references to nature-related risks. This poses logistical difficulties to users who must also consider holistic ESG themes. In addition, emerging tools are largely inaccessible to non-technical users and limit access for industry stakeholders who do not possess specific geospatial or ecological expertise.

"Ultimately, models are only as good as their data and relevance, but collecting spatially-explicit information for the entire value chain of companies will be both challenging and time-consuming for companies. The challenges at hand, whilst numerous, are not insurmountable and I fully expect to see significant developments in the nature-related data landscape over the next 12 months or so."

James d'Ath
Technical Lead for Data and Analytics
TNFD (July 2022)

Challenges for biodiversity measurement

At present, there is still a lack of clarity or standardisation on biodiversity and natural capital-related assessment methodologies tailored for the financial sector. Traditional biodiversity surveys that have been employed by ecologists are often technically complex and expensive, producing results on timelines that are unsuitable for the rapid pace of financial decision-making. Challenges include:

Multiplicity of indicators: Biodiversity cannot be measured by a single indicator because it is influenced by an amalgamation of many ecological factors. The diversity of species itself is difficult to estimate, even in a small area, given the sheer number of populations that may need to be surveyed – ranging from plants and insects to mammals, birds, and reptiles. There is also considerable variation in metrics that quantify the different facets of species diversity, such as those that count the number of species present in an area (e.g., species richness) while others calculate weighted values based on the relative abundance of each species (e.g., Shannon's diversity index).

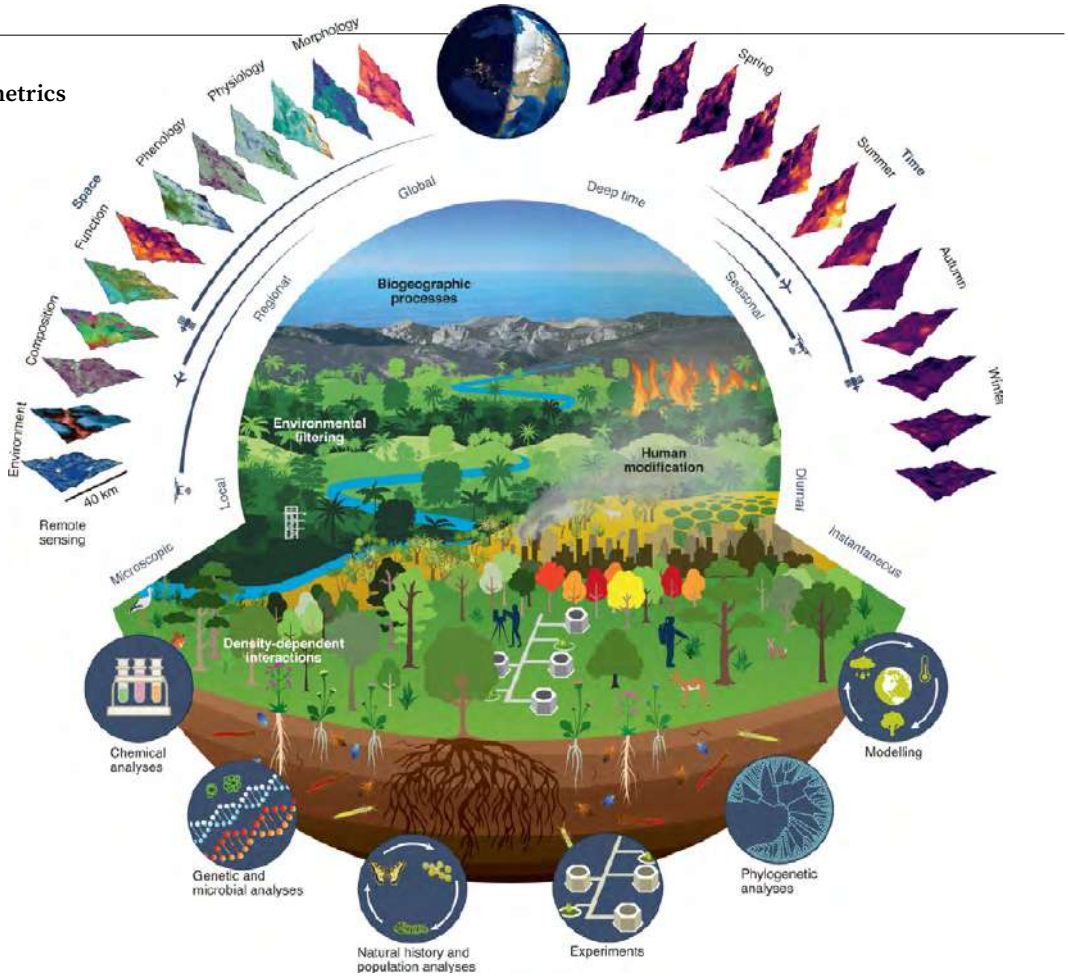
Tracking trends and changes: Biodiversity is also not easily captured at a specific point in time. To gain a full picture, it is important to also track the trends and changes in populations, habitat condition, and human pressures through time. This is especially important if investors expect projects to have impact outcomes that are tied to conservation or ecosystem restoration, as these targets can only be confirmed through consistent monitoring over time. Datasets can be biased towards a specific location or time period, and therefore may not be suitable for all use-cases.

Identifying suitable proxies: In place of directly measuring species diversity, scientists often employ other indicators that may partially serve as proxies for diversity that reflect the state of the ecosystem, intactness of the natural landscape, or influence of anthropogenic impacts on the area (Figure 3).[37]

Figure 3

Range of tools, methods, and metrics for measuring biodiversity

Source: Cavender-Bares et al. (2022)



These can range from being remotely detected by satellites or captured directly through instruments operated on-site. Scientific research shows that when applied well, proxy metrics are 'a vital part of an applied ecologist's toolkit and are frequently used to link science with management and policy, often combined together in various ways to build a holistic understanding of the factors influencing biodiversity.'[38]

Given the complexities that surround biodiversity measurement, as well as the broad range of ecosystems that each hold specific considerations and caveats, measuring and monitoring biodiversity continues to be a challenge for the finance sector given the constraints and considerations under which the sector operates. Despite these challenges, new innovations with technology, as well as the operationalisation of existing scientific approaches, are rapidly paving the way for solutions addressing this gap (Box 4).

With these developments, challenges, and considerations in mind, our report provides detailed documentation on the applications of quantitative techniques for biodiversity accounting and nature positive themed investments.

Box 4: Biodiversity assessment and innovation in technology

As the demand for biodiversity assessment and monitoring tools grows, new and old technologies have emerged in cross-discipline contexts for this application. Increasingly, companies and start-ups have made use of existing technologies from academic research disciplines and creatively applied them for direct and practical uses within specific sectors – such as for insurance, financial services, and real estate.

One such technology is **remote sensing**, which is broadly defined as the remote collection of data (e.g., with satellites, drones, or other) to model environmental conditions. The geospatial data and resulting analytical processes derived from remote sensing have been identified by many as a promising ESG and biodiversity monitoring tool.[39] Data collected from satellites are advantageous in that they can be analysed in near-real time, are scalable across industries and geographies, and are increasingly being applied to deliver environmental and biodiversity-related insights from the asset level to the broader corporate level.[40]

Other areas of biodiversity-related innovation lie in the application of environmental DNA (eDNA), drone-based sensors (e.g., LiDAR) and acoustic monitoring techniques to monitor biodiversity. Again, while these methods have traditionally been applied at site-specific levels for academic research or environmental surveys, new start-ups[41] have scaled and bridged these technologies to corporate clients seeking to incorporate nature or biodiversity considerations into their operations.

Woven into the tools and services offered by many of these start-ups are elements of modern technological innovation, such as artificial intelligence and machine learning algorithms.[42] When combined with existing analytical pipelines, the application of these data science techniques can improve processing times, analytical precision, and expand the scale of study beyond what is typically achievable through traditional surveying methods.

"Satellites provide the most powerful and transparent data source in the fight against climate change. Earth Blox puts satellite data into the hands of ESG experts, removing the need for remote sensing scientists or specialist consultants, so organisations can transition to net-zero, monitor their environmental impacts, and achieve biodiversity and sustainability goals faster and more efficiently."

Sam Fleming
Co-Founder
Earth Blox (July 2022)

3. Biodiversity Tools & Resources

At present, there is a rapidly growing body of resources available for institutions seeking to embark on their biodiversity accounting journeys. These range from high-level guidance and standards on assessment criteria to specific metrics and methodologies that can be used to execute these approaches. An increasing number of initiatives and alliances have also taken shape, aimed at convening industry stakeholders and facilitating knowledge sharing between academic, government, and corporate sectors.

With the biodiversity and finance interface being relatively new and evolving, taking stock of the landscape may be overwhelming to those entering the space from a traditional finance background. Provided in this chapter is an overview of various frameworks, alliances, initiatives, and guidance surrounding work related to biodiversity in the broader finance sector. While the list is not exhaustive, it showcases the range of work that is currently being done to assess nature-related risks and impacts and may serve as a useful starting point.[43]

Guidelines & Standards

IFC: Environmental and Social Performance Standards (2006)	The IFC Performance Standards (PS) on Environmental and Social Sustainability define the responsibilities of corporations for managing environmental and social risks. The importance of conserving biodiversity, maintaining ecosystem services, and sustainably managing natural resources is specifically addressed in PS6: Biodiversity Conservation and Sustainable Management of Natural Resources. Under the requirements of PS6, clients are expected to systematically identify any direct and indirect project-related impacts on biodiversity and manage these risks through a mitigation hierarchy. These guidelines apply to projects that: a) are located in modified, natural, and critical habitats; b) potentially impact or are dependent on ecosystem services over which the client has direct management control or significant influence; or c) include the production of living natural resources (e.g., agriculture, fisheries, forestry).
Science-Based Targets for Nature: Initial guidance for business (2020)	As part of the broader Science Based Targets Network (SBTN) facilitated by the Global Commons Alliance, the science-based targets for nature expanded upon existing climate-focused targets to also address goals related to nature. The guidance includes a five-step process to set such targets, from a materiality and impacts assessment to disclosure and monitoring of action plans. By 2025, the SBTN aims to have widespread adoption of science-based targets for nature by both the public and private sector.
Taskforce on Nature-related Financial Disclosures (2021)	The TNFD was launched in 2021 to develop a risk management and disclosure framework for organisations to report and address nature-related risks in alignment with the TCFD. The first beta version of the framework was released in March 2022, describing the LEAP approach for assessing nature-related financial risks: Locate, Evaluate, Assess, and Prepare. Following an 18-month consultation process with market participants, the final framework will be released in late 2023.
UNEP-FI & UNEP-WCMC: Guidance for Biodiversity Target-setting (2021)	Designed for signatories of the Principles for Responsible Banking (PRB), the Guidance for Biodiversity Target-setting outlines practical steps towards setting portfolio-wide biodiversity targets. The Guidance offers example targets and KPIs, an inventory of suggested tools, and case studies on how these steps have been applied by financial institutions in specific sectors or focal areas.
IUCN: Guidelines for planning and monitoring corporate biodiversity performance (2021)	Produced by the IUCN's Business and Biodiversity Programme, these guidelines provide an approach for developing a corporate-level biodiversity strategic plan. They are broad in scope so as to be applied by any company, sector, or operational scale to set measurable goals and objectives and establish a set of indicators to measure biodiversity performance. The Annexes of this guidance contain a comprehensive list of other relevant standards, tools, and guidelines for corporate biodiversity planning and monitoring.

Methodologies & Metrics

Species Threat Abatement and Restoration Metric (STAR) – Integrated Biodiversity Assessment Tool (IBAT) Alliance	The STAR Metric quantifies the potential positive contributions to biodiversity that are made through actions to reduce species extinction risk. Utilising globally standardised data from the IUCN Red List of Threatened Species, the analysis estimates STAR scores across a given area of interest. It also provides a breakdown of threat types underpinning the site's STAR score, allowing for the prioritisation of actions that are most suitable to reduce species extinction risk. See more about the IBAT Alliance in Chapter 4.
Global Biodiversity Model for Policy Support (GLOBIO) – PBL Netherlands Environmental Assessment Agency	The GLOBIO model provides a framework to quantify the impacts of six types of human pressures on biodiversity, calculating a 'Global Biodiversity Score'. Using the mean species abundance (MSA) indicator as a proxy for biodiversity, the model also includes scenario modelling options for socio-economic development pathways, options to assess ecosystem service values, and covers both terrestrial and freshwater ecosystems.
Biodiversity Footprint for Financial Institutions (BFFI) – ASN Bank	Combining both a quantitative footprint calculation and a qualitative analysis of sector-specific considerations, the BFFI measures the footprint in number of hectares in which biodiversity is lost. The impacts of portfolio activities on biodiversity are calculated through a combination of lifecycle assessment data, portfolio company information, and environmental impact indicators. The model has been applied by the Netherlands Enterprise Agency in 2021 to evaluate the biodiversity impact of loans and investments of various Dutch financial institutions.
Exploring Natural Capital Opport unities, Risks and Exposure (ENCORE) – Natural Capital Finance Alliance & UNEP-WCMC	The ENCORE tool guides financial institutions in understanding natural capital risks through an ecosystem services framework. Initially developed from a risk management perspective, additional modules have been developed to specifically address the positive or negative influences that portfolios may have on biodiversity. The tool is tailored to 167 economic sub-industries, all of which depend on a different combination of ecosystem services for production processes.
Nature and Biodiversity Benchmark – World Benchmarking Alliance	In 2022 and 2023, 1000 companies across 22 industries are being assessed for their impacts on nature and biodiversity to develop strategies towards No Net Loss (NNL) or Biodiversity Net Gain (BNG), goals that sit underneath the broader Nature Positive approach. Their methodology, released in April 2022, underwent an initial public consultation process with input from ~100 companies, including financial institutions. Each company will be assessed under 18 social indicators and 25 nature indicators, including aspects of land use change, direct resource exploitation, pollution, and climate change.
High Conservation Value (HCV) Approach – Forest Stewardship Council, HCV Network	The HCV approach was initially developed by the Forest Stewardship council in 1999 to maintain and enhance six environmental and social values in production landscapes: species diversity (HCV 1), landscape-level ecosystems (HCV 2), rare ecosystems/habitats (HCV 3), critical ecosystem services (HCV 4), community livelihood needs (HCV 5), and cultural values (HCV 6). Now managed by the HCV Network, the evaluation methodology is used by a wide range of certification schemes for sustainable production. HCV assessments involve desk-based research that applies satellite imagery analysis, site visits, and stakeholder consultation with local communities. The HCV approach overlaps closely with the High Carbon Stock (HCS) approach, which was further developed to distinguish forest areas for protection from degraded land that could be restored. The two assessments are often carried out in conjunction (HCV-HCS Assessment) to holistically identify areas where commodity production, conservation, and community lands should be most appropriately and responsibly allocated.

Initiatives & Alliances

Science Based Targets Network (SBTN)	As part of the Global Commons Alliance, the SBTN is a partnership of over 65 private and public organisations. It aims to develop methods and resources to guide companies in developing science-based targets for nature and climate-related action aligned with the Sustainable Development Goals (SDGs).
Natural Capital Finance Alliance (NCFA)	The NCFA is a finance-led initiative dedicated to integrating natural capital considerations into financial products, as well as improving nature-related risk accounting, disclosure, and reporting. Its Secretariat is led by the UNEP Finance Initiative and Global Canopy, who support the Alliance in developing tools and methodologies such as ENCORE.
European Union Business @ Biodiversity Platform (EU B@B)	The B@B platform operates at an EU level, providing a forum for dialogue and policy interface on integrating natural capital and biodiversity considerations in business practices and delivering the objectives of the EU Biodiversity Strategy to 2030. Its three functional workstreams consist of Methods (developing practical guidance and tools), Pioneers (facilitating corporate collaboration), and Mainstreaming (promoting biodiversity-focused business decision-making across Europe).
Finance for Biodiversity Pledge	The Finance for Biodiversity Pledge was launched in 2020. Financial institutions who sign the pledge commit to protecting and restoring biodiversity through their financial activities through knowledge sharing, engagement with companies, assessing their impacts, setting targets, and reporting on these criteria by 2025. Its accompanying Finance for Biodiversity Foundation, formed in 2021, hosts four working groups on engagement with companies, impact assessment, public policy advocacy, and target setting (as of October 2022).
Partnership for Biodiversity Accounting Financials (PBAF)	As a sister-initiative of the Partnership for Carbon Accounting Financial (PCAF), the PBAF aims to develop a standard by which financial institutions can assess and disclose impacts and dependencies on biodiversity. It is closely aligned with other initiatives such as the TNFD and Finance for Biodiversity Pledge and is supported by the Dutch government. In June 2022, the PBAF launched its first standard describing requirements and recommendations for financial institutions to carry out a biodiversity footprint assessment.
Network for Greening the Financial System (NGFS)	Launched at the Paris 'One Planet Summit' in 2017, the NGFS serves as a platform for central banks to share best practices, contribute to the development of environment and climate risk management in the financial sector, and mobilise mainstream finance to support the transition toward a sustainable economy. Amongst its various work streams is the task force for 'biodiversity loss and nature-related risks', which acts as an incubator for the consideration of nature-related risks across the Network.
Finance for Biodiversity Initiative (F4B)	The F4B initiative aims to increase the materiality of biodiversity in financial decision-making and align global finance with the conservation and restoration of nature. Established in 2019, the initiative produces research on interdisciplinary strategic areas such as nature markets, public finance, strategic liabilities, and citizen engagement.

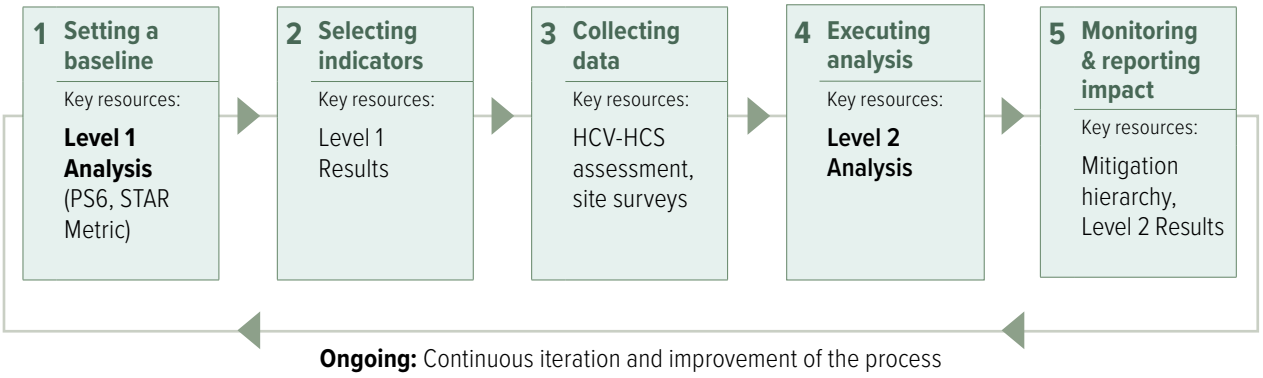
4. Developing a Biodiversity Accounting Process

There is no one-size-fits-all framework that can be used to account for biodiversity. Rather, the process is shaped by a wide range of parameters that characterise the nature and structure of each investment. These include the investment tenor, type of activity associated with the investment, existence of site-based monitoring infrastructure, desired impact or management outcomes, surrounding socioeconomic and environmental context, and many other considerations. The metrics used to track progress in a restorative forestry project, for instance, would be different from those used for a coastal fish farming project.

Given these complexities, the development of a biodiversity accounting framework is a continually evolving process that shifts as new data, tools, and guidance becomes available. Figure 4 highlights the steps we took to develop a practical and science-based approach to biodiversity for investment projects, including two analytical phases (Level 1 and 2) that are described in greater detail below.

Figure 4

Biodiversity accounting framework development process



The framework provides the necessary flexibility that enables metrics to be tailored to the context of each investment, while also being executed under a standardised and systematic analytical approach that shares the same baselining process.

The analytical components that shape the framework in its current form consist of two stages: Level 1) a broad-level baseline on a globally comparable scale, and Level 2) an in-depth analysis specific to the local context and the investment project's impact goals. Each of these analytical approaches are applied to a real-world example in Chapters 5.

Level 1 | High-level snapshot of biodiversity

- Uses secondary (existing) datasets
- Quick execution time (less than one day)
- High-level baseline
- Datasets are global
- Comparable across sites
- Analysis is run at the beginning of the project
- No technical expertise required

Level 2 | Detailed accounting and monitoring of biodiversity

- Uses primary (new) and secondary (existing) datasets
- Longer execution time (several weeks)
- In-depth insights and monitoring
- Datasets are global or local
- Not always comparable across sites
- Analysis is conducted throughout the life of the project
- Requires some technical expertise

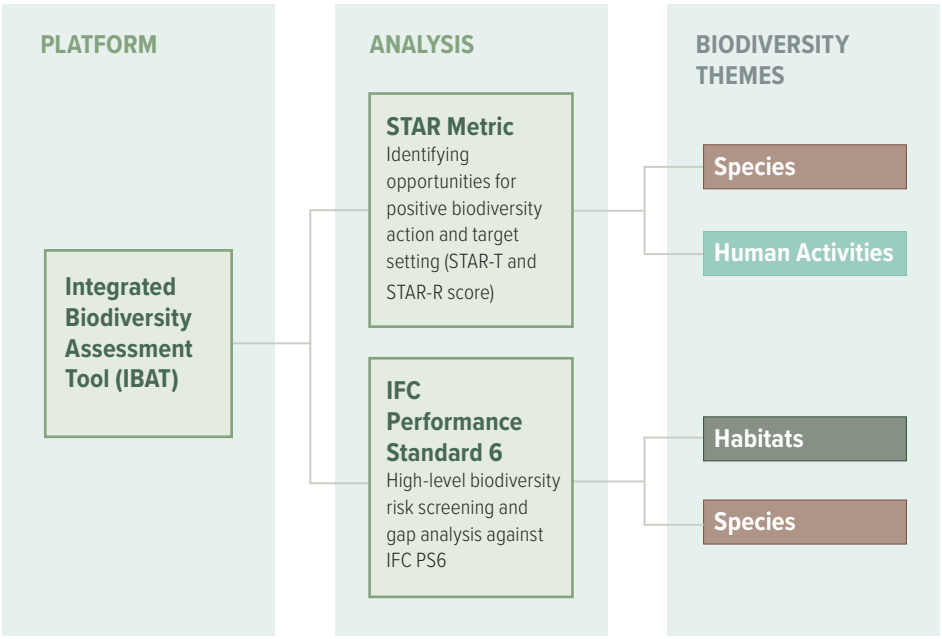
Level 1: Broad baseline

The goal of the Level 1 analysis is to establish a broad understanding of the factors influencing biodiversity at the site(s) of interest. The site of interest is defined as the physical location(s) of the investment project at which biodiversity impacts are to be measured, such as the location of tree plantations in an agroforestry project. The analysis is intended to be executed quickly, allowing for results to be produced expediently to inform time-sensitive decisions. There are no skill or software requirements for this level, meaning that a wide range of staff or project members could perform this analysis.

Provided below is a detailed description of the platforms and tools used for our Level 1 baseline assessments (Figure 5). In general, the analysis allows for rapid comparison between multiple sites without any geographic restrictions, as it uses datasets that are global in scope. The trade-off for this flexibility, however, is a lack of specificity in the analytical outputs and derived insights, which is further addressed in the Level 2 analysis.

Figure 5

Overview of Level 1 workflow



Platform: Integrated Biodiversity Assessment Tool

Rapid and high-level biodiversity assessment

Cost	Analysis Time	Skill level	Software	Data Scope	Resolution	Input Data
Basic tools free, paid subscription for expanded capabilities	< 1 day	Basic	Web browser	Global	Mid to low	Site location*

* Ideally, the user should have a spatial data file (e.g., shapefile) that defines the geographic, coordinate-linked features of the project area on a map. If this is unavailable, however, users can manually draw the project area boundaries directly onto a map in the browser.

The **Integrated Biodiversity Assessment Tool** (IBAT) is an Alliance between BirdLife International, the United Nations Environment Programme – World Conservation Monitoring Centre, the International Union for Conservation of Nature (IUCN) and Conservation International.

Its online platform serves as a biodiversity data provider, licensing commercial access to global biodiversity datasets and derived data layers. It provides access to biodiversity maps, data, and site-specific reports that allows users to gain site-specific insights on biodiversity risk and opportunities.

IBAT currently supports 13,000 users across over 150 companies around the world to perform biodiversity assessments and screen the risk of impacting biodiversity across their portfolios or operations.

Reports that can be generated through the platform include a Proximity Analysis, IFC & World Bank PS6/ESS6 Report on Critical Habitat, Freshwater Report, Multi-site Analysis, and STAR Report. These reports rely on three main global datasets defining endangered species, protected areas, and key biodiversity areas respectively (Box 5). An example of the basic statistics that can be drawn from each are shown in Table 1, which provides a biodiversity profile for Indonesia.

Table 1

PS6 Report statistics for Indonesia, generated from the IBAT Platform

Area (km^2)	**1,904,569**
Key Biodiversity Areas	**494**
Protected Areas	**733**
IUCN Red List Species (critically endangered or endangered)	**812**

Box 5: IBAT Databases

IUCN Red List of Threatened Species

A public database developed by the IUCN that classifies species into one of seven Red List Categories to represent its level of extinction threat (ranging from Least Concern to Extinct). The profile of each species also contains information about its geographic range, population size, habitats, threats, and priority actions for conservation. The Red List is considered to be the world's most comprehensive inventory of the conservation status of wildlife species and currently has over 142,000 species logged in the database.[44]

World Database on Protected Areas

A global database of marine and terrestrial protected areas, defined by the Convention on Biological Diversity as: "a geographically defined area, which is designated or regulated and managed to achieve specific conservation objectives". Jointly managed by the IUCN and the UN Environment Programme, it the database provides downloadable geospatial information that details the boundary and characteristics of each protected area. The database is the largest assembly of data documenting the world's protected areas, with over 270,000 recorded protected areas.[45]

World Database on Key Biodiversity Areas

A global database that identifies the locations of Key Biodiversity Areas (KBA), which are defined as sites that "contribute significantly to the global persistence of biodiversity". Sites are identified based on five different criteria: threatened biodiversity, geographically restricted biodiversity, ecological integrity, biological processes, and irreplaceability. The database is run by the KBA partnership, which is jointly led by 13 conservation organisations and has identified over 16,000 KBAs.[46]

"The Integrated Biodiversity Assessment Tool provides access to globally authoritative biodiversity datasets, and enables investors to take the first steps in understanding how their investments may affect critical biodiversity."

Ed Ellis
IBAT Manager
IBAT Secretariat (July 2022)

The IBAT platform aims to offer financial institutions the opportunity to rapidly screen investments or portfolios of asset locations in relation to three of the world's most authoritative biodiversity datasets. This allows organisations to identify and avoid potential biodiversity risks and easily derive statistics for annual sustainability reporting, the SFDR, or to follow the TNFD LEAP process.

To execute our Level 1 analysis, the IBAT platform was selected for several reasons:

- The databases used by the platform are among the most reputable, comprehensive, and scientifically robust global databases for biodiversity
- It serves as a unified platform where users can generate reports that assess aspects of biodiversity risk and impact according to various industry standards or regulations
- It is free for certain users[47] and is used on a web browser that does not require any technical expertise.

The broad baseline established for each site in the Level 1 analysis, paints a picture of three key themes that influence biodiversity: species, habitats, and human activities.

The IBAT portal was used to calculate two different biodiversity report types that provide the most relevant insights on these themes for a project location in terrestrial ecosystems: the STAR report and IFC Performance Standard 6 (PS6) report.

The **STAR Metric** was chosen because it is one of the only indicators that measures contributions that investments can make to reducing species' extinction risk – and is therefore highly applicable to the goals of the Level 1 analysis.

The **PS6 Report** was chosen because its metrics model the importance of the site's surrounding habitat for biodiversity. Furthermore, since the IFC's Performance Standards are one of the international benchmarks by which companies manage environmental and social risks, the measurement of biodiversity in accordance with its standards aligns our framework to existing standards.

Species Threat Abatement and Restoration Metric
species human activities
The STAR Metric quantifies the potential contributions that activities related to biodiversity conservation (i.e., threat abatement and restoration) can have towards reducing species extinction risk. The scores are derived from data on the distribution, threats, and extinction risks for species on the IUCN Red List of Threatened Species, as well as the documented habitat ranges of each species. Scores are calculated for each 5km grid across all terrestrial ecosystems, allowing for sites to be compared globally with this metric.

The STAR Metric calculates two scores: the STAR-T (threat abatement) and STAR-R (restoration) score. Both represent the estimated potential to reduce species extinction risk through threat abatement, but through different means: by managing and conserving intact habitats where the species still occurs (STAR-T) or by restoring degraded habitats where the species once existed but no longer occurs (STAR-R). Calculating these scores also produces insights to inform actions under the mitigation hierarchy: STAR-T scores inform the 'minimise' stage, whereas STAR-R scores address the 'rehabilitate/restore' stage. More information on how the STAR scores are calculated is available in Appendix I.

IFC Performance Standard 6 Report
habitats species
The PS6 outlines international best practice to protect biodiversity, maintain ecosystem services, and promote the sustainable management of living natural resources. It requires companies to consider the direct and indirect project-related impacts on biodiversity, as well as their value.

The PS6 report generated by the IBAT platform provides a summary of the IUCN Red List species, protected areas (defined by the World Database on Protected Areas), and KBAs that lie within 1km, 10km, and 50km of the project site. These three metrics contribute to the baseline biodiversity snapshot by highlighting the types of ecologically significant

or vulnerable habitats and species included within and around project sites. Identifying these areas are also critical for informing the 'avoidance' stage of the mitigation hierarchy.

The application of these two IBAT analyses provides a valuable overview of the factors influencing biodiversity at a site, as well as potential management strategies that can be prioritised to produce nature positive outcomes. Following the Level 1 analysis, general conclusions can be drawn about the potential impact outcomes or targets of the project, as well as the types of indicators needed to monitor these goals. Most importantly, the insights derived from Level 1 in our framework are critical for determining the types of analyses undertaken in Level 2 – a deep dive analysis that is tailored to the specific considerations of each project.

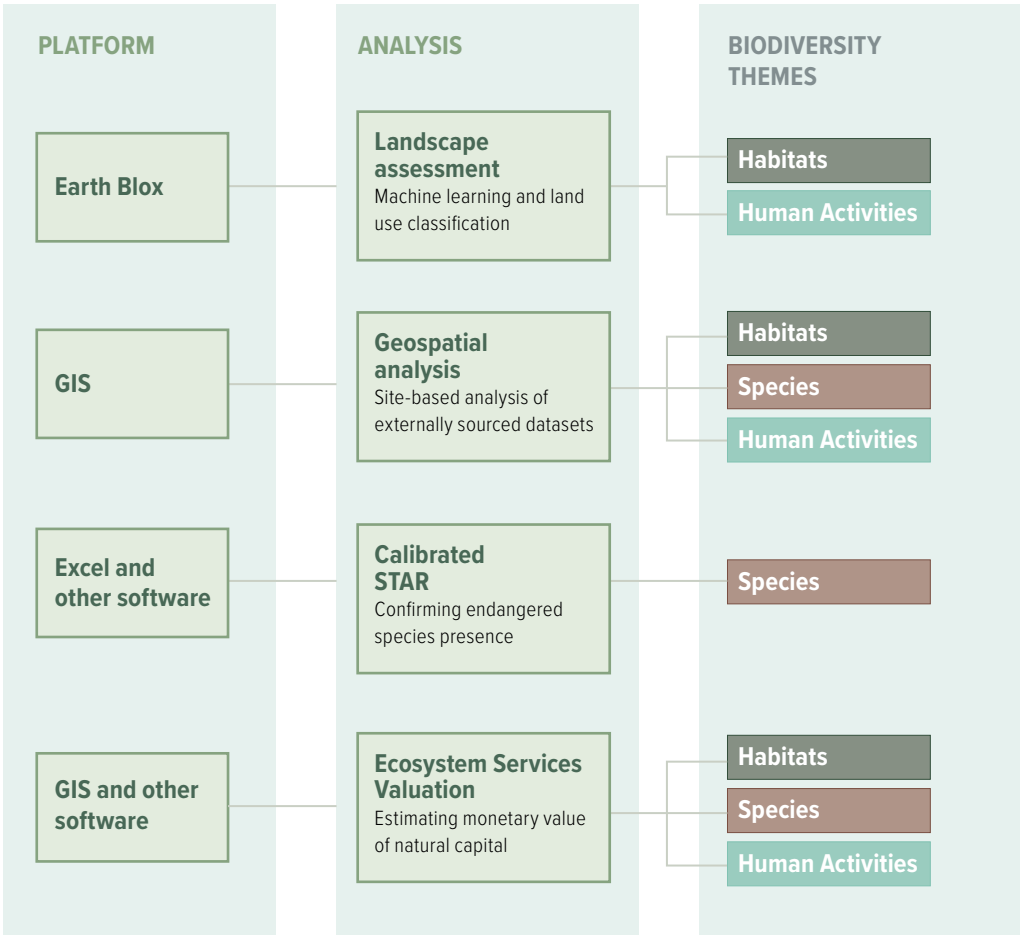
Level 2: Detailed accounting

The Level 2 stage of our framework aims to provide a continuous basis for in-depth monitoring of biodiversity throughout the lifetime of a project, as well as utilise more in-depth and accurate assessment approaches (Figure 6). It allows for the flexibility for any additional analyses to be performed on an ad-hoc basis for any projectsite, based on considerations surrounding the investment goals, data availability, and applicability.

In order to model the site's biodiversity parameters at a more granular level, the analyses employed may utilise datasets that are only local or regional in scope, rather than global. This also allows for the consideration of specific data or indicators that may only be relevant to the project site or region – as well as the impact targets of each investment

Figure 6

Overview of Level 2 workflow



project –and therefore cannot be compared globally. For instance, a sustainable agroforestry project in Indonesia tracks the movement of elephants on-site with relation to nearby agricultural areas and villages to better mitigate occurrences of human-wildlife conflict. This is an example of a highly specific dataset that not all projects would have available, yet are crucial to quantifying the biodiversity impact of a project.

To maximise the accuracy and validity of the analyses performed, Level 2 analyses also require the collection of data on-site. These data may be used to verify the insights drawn from the Level 1 baseline study or serve as input data for more sophisticated analyses that are used for this stage (e.g., training data for a machine learning algorithm).

As discussed prior, the collection of site-based data is not necessarily restricted to manual field surveys (Box 4). Increasingly, various imagery sensors, acoustic monitoring instruments, and other technology can be used to collect data while optimising time and cost. Regardless of the method employed, the ground truthing process is a critical step in our biodiversity monitoring and risk management process, as it ensures that the insights drawn from global datasets are representative of fine-scale changes that take place at a site level.

With ACLF still being in the development stage, not all of these analyses have yet been applied. Rather, the descriptions of the Level 2 tools and platforms provided below demonstrate the diverse set of in-depth analyses for that can be applied for different investment use-cases.

Earth Blox

Habitat and landscape assessment with ground truthing

habitats | human activities

Cost	Analysis Time	Skill level	Software	Data Scope	Resolution	Input Data
Paid subscription	Several minutes to days (depending on analysis chosen and input data required)	Basic	Web browser	Local or global (depending on the dataset)	Mid to high	Site location*, additional algorithm training data (optional)

* Ideally, the user should have a spatial data file (e.g., shapefile) that defines the project area on a map. If this is unavailable, however, users can manually draw the project area boundaries directly onto a map in the browser.

Founded in 2019, Earth Blox is a coding-free platform that allows users to analyse and process satellite data in near-real time, such as classifying land use, calculating change in habitat types, or visualising spatial changes in environmental conditions. The platform draws directly from Google Earth Engine, which houses one of the largest libraries of open-source earth observation available for environmental monitoring.

Depending on the subscription type, users can access built-in analyses from an existing library of workflows, create their own workflows using the modular drag-and-drop interface, or develop bespoke analyses with the Earth Blox development team. Our framework has applied all three of these use options for different projects, described in Chapter 5 and Appendix II.

Geographic Information System (GIS)

Geospatial data processing

habitats species human activities

Cost	Analysis Time	Skill level	Software	Data Scope	Resolution	Input Data
Free or paid	Several days to weeks	Technical training required	QGIS (free), ArcGIS (paid), ESRI, or others	Local or global (depending on the dataset)	Mid to high	Site location, datasets for analysis (all sourced independently by user)

* Ideally, the user should have a spatial data file (e.g., shapefile) that defines the project area on a map. If this is unavailable, however, users can manually draw the project area boundaries directly onto a map in the browser.

GIS platforms are software that are specifically designed to process geospatial data such as maps, remotely sensed data layers, and coordinate-based information (Figure 7). Much like Excel can be used to process numerical data in spreadsheets, GIS platforms are used to analyse geospatial data with a wide variety of tools, customisation options, and output forms.

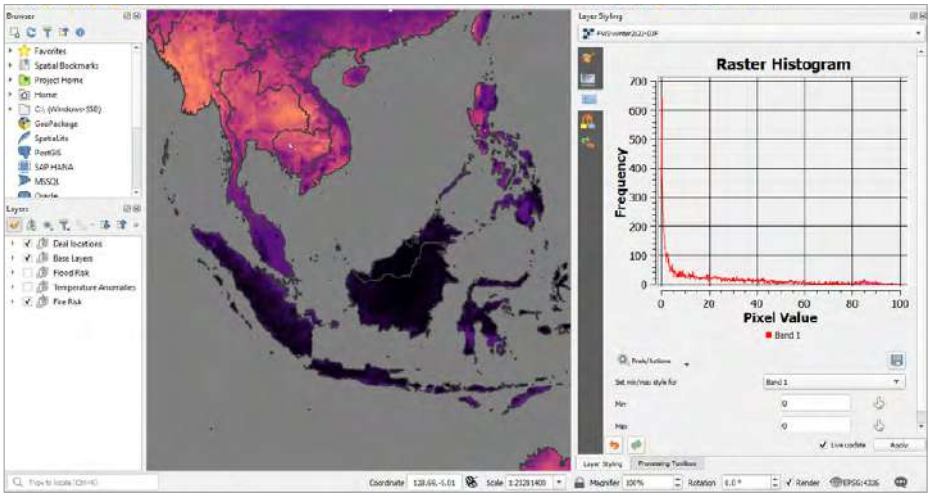
Like any other software or data processing programme, GIS requires a certain level of technical expertise to manipulate geospatial data, conjure new ideas for analytical pathways, and produce publication-grade map outputs. Therefore, companies who wish to gain the agency in performing their own geospatial analyses that GIS provides (but are not yet offered by platforms like Earth Blox) should consider integrating this skillset within their team's capabilities.

The use of GIS has been highly relevant in all stages of our framework. At the most basic level, GIS is valuable for preparing geospatial data prior to uploading site location layers onto platforms such as IBAT or Earth Blox (e.g., extracting or editing polygons[48] that defines a site, converting data formats).

For the ACLF application presented in Chapter 5, we have analysed geospatial datasets beyond the global databases described in Level 1. This includes data provided by governments or NGOs, such as maps classifying land use types within a specific area. These are highly useful for biodiversity analyses, but are not otherwise available on commercial platforms and therefore need to be analysed using GIS software.

Figure 7

Sample GIS interface (QGIS v3.22.2)



We also use GIS to analyse global datasets within the confines of our site of interest and extract values that summarise the environmental conditions only at that site. The most straightforward way to analyse these layers and derive relevant insights is directly through the processing tools offered on GIS. These layers can also be manipulated using coding languages such as R or Python, but would nevertheless warrant a level of technical expertise beyond that of most corporate stakeholders.

Additional platforms and analyses

Depending on the indicators deemed relevant for the Level 2 analysis made for each project, a variety of methods may be used that are more niche in their application or not yet fully operational at scales comparable to the Level 1 analysis.

The nascent nature of biodiversity accounting for investment contexts ultimately requires the trial and error of various approaches – all of which takes time, continuous iteration, and collaboration. When possible, we have therefore sought to take our accounting framework a step further by testing novel approaches grounded in ecological or resource economics theory for the purposes of this new, industry-grounded application.

While these analyses are not guaranteed to be permanent fixtures in our framework, we believe that it is equally important to continue testing, developing, and refining creative approaches. **Examples of some of these analyses, which are trialled in Appendix II, are provided below.**

Ecosystem Services Valuation

Monetary value assessment

habitats species human activities

Cost	Analysis Time	Skill level	Software	Data Scope	Resolution	Input Data
Free or paid	Several days to weeks	Environmental economics knowledge and technical training required	GIS, Excel, or other specific software (e.g., InVEST)	Local or global (depending on dataset)	Mid to high (depending on dataset)	Site location, economic values for ecosystem services (all sourced independently by user)

For many financial stakeholders, assigning monetary value to biodiversity and natural capital are key to evaluating the impact of investments and relative value of interventions. While some ethical considerations and underlying theory on this topic are still debated, one such way of placing a price on nature is through **ecosystem services valuation**. First used to estimate the global worth of ecosystem services in 1997[49], this valuation process was developed to better inform resource allocation decisions and raise awareness on the importance of ecosystems and biodiversity to policymakers. Today, a wide variety of economic models have been used to value ecosystem services – categorised into provisioning, maintaining, regulating, and cultural services – and the willingness of individuals to pay for them.

An ecosystem services valuation method known as **benefit transfer** is the most basic method that can be applied under circumstances when extensive economic modelling or site-specific data collection cannot be performed. This approach applies the economic value estimates from one location to a similar site in another location.[50] For instance, if a user seeks to quantify the value of the oil palm produced within their study area in Sumatra, they could apply the values generated from an existing ecosystem service study in a similar ecosystem (i.e., another oil palm site within Sumatra).

The benefit transfer valuation method is widely used for broad-scale scoping assessments of costs and benefits associated with the natural capital present at the site. However, it is limited in that it relies on an assumption that the chosen reference site is an accurate proxy for the study site, or that such a proxy exists. For our purposes, assigning value to the ecosystem services of our project sites serves as a way to identify additional revenue streams that can be created through management for positive biodiversity outcomes, as well as strengthen the business case for nature positive actions.

Calibrated STAR Score

Species assessment

species

Cost	Analysis Time	Skill level	Software	Data Scope	Resolution	Input Data
Beta testing (see IBAT tool)	Several days to weeks	Basic	Web browser (once tool is launched by IBAT)	Local	Depends on input data	Site location*, species presence or absence at site

* Ideally, the user should have a spatial data file (e.g., shapefile) that defines the project area on a map. If this is unavailable, however, users can manually draw the project area boundaries directly onto a map in the browser when this analysis becomes integrated with the IBAT platform in the future.

The STAR score applied in the Level 1 analysis currently represents an **Estimated STAR** score. The presence of the species in the specified site is modelled by data from the IUCN Red List rather than on-site field surveys. In this sense, the STAR score is still an 'estimate' that requires additional validation to ensure that the species listed are truly present within the site.

In order to move towards a **Calibrated STAR** score, the IBAT Alliance is trialling a validation process that combines insights from local species experts and on-site field surveys to confirm or deny the presence of the listed species within the site. This process gives rise to a verified version of the STAR score that more accurately represents the ecosystem's current state, also serving as a baseline from which measurable targets can be set to manage threats to biodiversity.

While this metric is still in the beta stage of development by the IBAT Alliance, there is ongoing work to formalise the process of moving from an Estimated to a Calibrated STAR score.

The importance of partnerships

The formation of partnerships between investment projects and local NGOs, academic institutions, or research institutions is critical to access data and knowledge that may otherwise not be possible to collect first-hand. Some sites, for instance, may be adjacent to or overlap areas where ecological monitoring projects have been conducted by academic institutions, government researchers, or NGOs. These stakeholders may be willing to form partnerships that yield data to support deeper analysis on the changes in species or habitat composition through time.

Producing a targeted and accurate evaluation of biodiversity impacts often requires the input of local and site-specific data. At present, these data are largely collected through surveys that rely on knowledge or participation from members of local communities, which can be facilitated through collaboration with NGOs or research institutions. These partnerships are instrumental in gaining access to knowledge relative to performing regular surveys to monitor a site or extensively take stock of environmental parameters.

Local academic institutions are also valuable partners in identifying existing studies that have been conducted in the area, and may be open to developing ongoing ecological studies or suggest external institutions that may do so. In geographies where there are language barriers or cultural sensitivities, these local partners are crucial in navigating public data repositories or liaising language translation. Informed by the insights derived from biodiversity impact assessments, these partners play an equally valuable role in facilitating engagement with local communities to ensure that their perspectives are used to inform project management strategies.

"When investing in diverse cultural and conservation landscapes in the emerging markets in particular, it is often challenging for investors to build adequate data sources or local knowledge to manage risk effectively and recognise transition opportunities. Increasingly, regulation and public scrutiny means greater accountability and transparency in terms of potential adverse impacts in a transaction.

Managing partnerships, whether with NGOs, local academic or research institutions or even with local government, can provide another dimension to a transaction, significantly mitigating risk at multiple levels. This is particularly true in the agriculture sector where there are significant biodiversity and climate risks to be managed."

Lisa Genasci
Managing Director, Sustainable Finance
ADM Capital (August 2022)

The following chapter demonstrates the application our analytical framework to the ACLF pipeline as a real-world example. This biodiversity accounting process reflects our current thought process for responsibly managing biodiversity risks and identifying areas for positive impact. With this being a first attempt at applying our approach, the resulting insights will guide the development of future iterations of this process.

5. Real-world Application: ACLF

Context

The Asia Climate-Smart Landscape Fund

To address the serious environmental and social challenges that are increasingly impacting the planet – particularly in Asia's energy, food, and land use sectors – ADM Capital created the Asia Climate-Smart Landscape Fund (ACLF). The fund, which is currently in development, leverages the firm's 20+ years of private credit experience as well as ADM Capital Foundation's 15+ years of driving philanthropic social and environmental impact in Asia.

The fund offers medium-term senior secured lending to SMEs in Indonesia engaged in sustainable agriculture, agroforestry, and aquaculture while integrating climate, livelihood, land use and gender equity targets. Supported by an experienced Impact Advisory Committee, the fund seeks to address the large gap in medium-term financing for these sectors while generating strong risk-adjusted financial returns.

ACLF benefits from risk mitigation solutions across the fund structure, including a 50% guaranty at asset level from the US Development Finance Corporation. As part of ACLF's gender commitments, the fund has also committed to the 2X Challenge, an initiative launched at the G7 Summit in 2018 to mobilise funding for women in developing country markets to gain improved access to leadership opportunities, quality employment, and economic participation.

Environmental & Social Objectives

The primary objective of ACLF is to incentivise investment in sustainable land use activities whilst promoting exemplary corporate governance and compliance with environmental and social safeguards, as well as delivering impact. Pipeline projects will be managed towards compliance with the IFC performance Standards (IFC PS) and according to the fund's Environmental and Social Management System (ESMS) and associated policies.

In terms of impact management, the fund operates under an Impact Management System, which will ensure ACLF meets its three primary fund-level targets (Figure 8). A 50% conditional carry pool aligns the team with achieving impact.

Figure 8

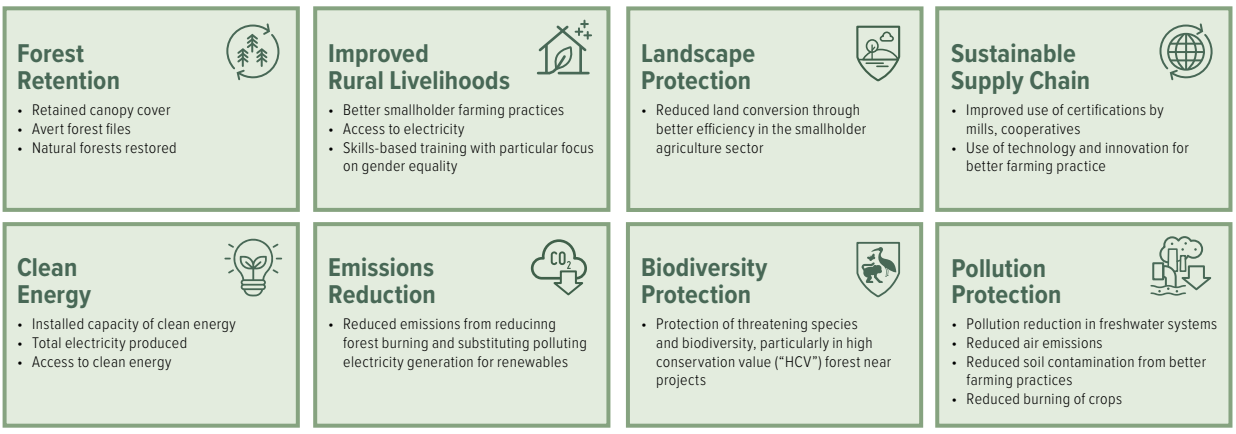
ACLF Primary Impact Targets



ACLF has also established eight core environmental and social objectives and associated indicators, which are aligned with relevant SDG targets (Figure 9). Pipeline projects will be managed according to relevant indicators that wrap up to the fund target. The Impact Advisory Committee will support monitoring of progress towards both fund-level and project-level E&S goals and impact.

Figure 9

ACLF's eight core project-level environmental and social objectives



Mitigation hierarchy and HCV-HCS approach

To manage biodiversity risks and measure impact outcomes at the fund level, each project will be monitored according to the IFC PS and the mitigation hierarchy. In the current pre-launch phase of the Fund, where management approaches for each project are still malleable, special attention will be paid to using metrics that can inform different stages of the mitigation hierarchy.

The Level 1 analysis will identify the locations of critical habitats, species, or protected areas to inform the avoidance and minimise stages, whilst the Level 2 analysis will add additional insights to develop strategies for further minimising negative impact and identifying potential areas for restoration.

From a data perspective, the HCV-HCS approach (see pg. 17 for more information) provides a crucial baseline assessment that will be conducted for projects based in terrestrial ecosystems. In addition to informing the mitigation hierarchy process, it provides the basis for site-level data that the Level 2 analysis can use. With ACLF still in its pre-launch phase at the time of writing, HCV-HCS assessments have yet to be carried out for the priority pipeline projects.

ACLF Projects

Throughout its lifetime, ACLF will have around fifteen projects in its portfolio that cover diverse land use and agricultural sectors across Indonesia. Once the baselining procedure has been completed for the entire ACLF portfolio, the metrics used for each will be then be used to set measurable targets and monitor progress on a regular basis.

For this application, four of these early pipeline projects were chosen as examples for Level 1 of the biodiversity accounting process and one was used as an example for the more in-depth Level 2 analysis (Figure 10). The analyses will focus on:

- Building an understanding of the biodiversity baseline of each project (Level 1 analysis)
- Supporting the investment thesis for each project through a biodiversity lens (Level 1 & 2 analysis)
- Identifying focal themes or management strategies for each project to facilitate positive biodiversity impacts (Level 2 analysis)

Figure 10

Four ACLF pipeline projects showcased for biodiversity accounting analysis



Coconut

Sector:	Sustainable agriculture
Loan size:	USD8m
Target net IRR:	12%
Tenor:	5 years
Collateral:	Potential use of biological assets, fixed assets, and share pledges

Context: With a rapidly ageing global stock of coconut trees that require large-scale replanting, coconut production lags the demand for derivative products such as coconut oil, water, or milk, by about 8%.[51] All but 10% of global coconut production takes place in the Asia Pacific region and 95% is harvested by smallholders.[52] Limited access to market and a lack of financial and technical know-how have resulted in stagnating yields and low-income levels for smallholders, providing an opportunity for impact-oriented financing.

Opportunity: The borrower company has secured a letter of intent consisting of an offtake agreement with a global FMCG (fast-moving consumer goods) company. The capital sought will be allocated to the production of coconut sap from existing community-owned Nipa palm and other palm tree species on 10,000ha of land in West Kalimantan. By way of comparison, these coconut palms outperform sugar cane in calorie yield per hectare, use less fertilisers and water, and are more resistant to extreme weather conditions.[53] Funds will also be placed towards increasing economic value by upgrading processing facilities.

Impact: The production process will be governed by sustainability-oriented principles including organic agronomic practices, gravity-fed irrigation, green corridors for biodiversity, and other initiatives. Tapping the existing trees growing in the project area safeguards the local mangrove forests against deforestation while also enhancing the economic viability of the ecosystem. Rural livelihoods will also be improved through increased income from fair wages, rather than the current output-based models with average wages below minimum levels. There is also potential to install a biomass energy plant to transition from the current energy source, which often involves chipped wood from nearby mangrove forests.



Bamboo

Sector:	Sustainable forestry
Loan size:	USD1.6m
Target net IRR:	12%
Tenor:	5 years
Collateral:	Share pledge and fixed assets

Context: Bamboo is a fast-growing and multifunctional member of the grass family that matures much faster than trees and does not require replanting.[54] With more than 1,500 documented uses, bamboo and its production as a commodity has been identified as a key mitigation strategy to reduce pressure on intact forests.[55] Shifts in consumer preferences towards alternative and sustainable materials has also created an opportunity to capture market share for bamboo-derived products and laminated bamboo as an alternative to wood.[56]

Opportunity: The borrowers seek funding to collaborate with 14 bamboo districts in East Nusa Tenggara for the production of high-quality laminated bamboo. The project will directly source bamboo poles from the participating network of farmers and provide upskilling opportunities through training in agroforestry, cocoon seed cultivation, and sustainable forestry management strategies. The bamboo poles will be processed on-site in village factories and assembled into finished products for both wholesale and retail markets.

Impact: This project is estimated to create 2,400 additional employment opportunities across the value chain, boosting the region's employment rate by 2.9% and producing a revenue of USD1-2 million per annum for villages (i.e., 1% of the district's forecasted 2022 GDP of USD 210 million).[57] The bamboo forests will be planted on degraded community forest concessions, aiming to restore over 14,000ha of land. As a result of the carbon storage capacity of the bamboo forests, the project has the potential to avoid approximately 11.4 million tCO_2e in GHG throughout its 10-year lifetime.[58]



Shrimp

Sector:	Aquaculture
Loan size:	USD7.7m
Target net IRR:	12%
Tenor:	5 years
Collateral:	Share pledge, fixed assets, personal and corporate guarantees

Context: A global rise in demand for seafood has driven the expansion of aquaculture practices, contributing to the large-scale degradation of coastal and marine ecosystems. In Southeast Asia, a third of mangrove destruction and coastal land use change is attributed to shrimp farming alone.[59] Unsustainable shrimp farming practices not only weaken coastal resilience by clearing wetlands, mangrove, and coastal marine habitats, but also reduce harvest and income potential for shrimp farmers by continually polluting surrounding waters. This practice feeds into the cyclical abandonment of farms to start anew in neighbouring habitats, fuelling further destruction of valuable ecosystems. Modernisation of shrimp farming practices with appropriate financial and operational strategies can help preserve natural capital while increasing production yields in a sustainable manner.

Opportunity: Leveraging years of experience in sustainable aquaculture financing, the sponsors seek to rehabilitate the highly degraded coastal habitats in West Java, through transformative shrimp farming practices. The area has historically been among the biggest shrimp producers in Indonesia,[60] providing an opportunity to redevelop and modernise aquaculture techniques, whilst improving water quality and ecosystem health. Funding will improve infrastructure that will reduce production risk and increase yield, namely through wastewater treatment facilities, pond design optimisation, and aeration technology. The sponsors seek to sustainably intensify shrimp production capacity without the use of chemicals or antibiotics, as well as improving the feed conversion ratio to reduce pressures on wild-caught fish.

Impact: In addition to the infrastructural improvements made to the shrimp farms, the project will also potentially involve a mangrove reforestation programme. Doing so will provide carbon sequestration benefits as well as build back coastal resilience for both human and natural systems. The implementation of wastewater treatment facilities at the farms will also benefit the surrounding marine ecosystem, particularly through the reduction of ammonia nitrogen, phosphorus, and other effluent pollutants. The operation of these facilities will provide additional employment opportunities with fair wages, training sessions on farming techniques, and career goal-setting workshops. These opportunities will be particularly geared towards engaging more women in the workforce.



Coffee

Sector:	Agroforestry
Loan size:	USD2.2m
Target net IRR:	12%
Tenor:	7 years
Collateral:	Share pledges and fixed assets

Context: Indonesia is the world's fourth largest coffee producer. The sector has contributed considerably to deforestation and loss of Indonesia's terrestrial habitats. Sumatra lost nearly half of its forests between 1985 and 2007 , leading to the habitat loss of critically endangered species such as the Sumatran orangutan.[61] Coffee production also faces social challenges: 96.6% of Indonesia's coffee plantations are run by smallholder farmers, who typically have limited adoption of agricultural technology, access to credit, and income stability.[62] As unsustainable practices continue to pose risks to Indonesia's tropical landscapes and local livelihoods, there is a critical need to reduce carbon emissions along the coffee value chain, halt associated habitat destruction, as well as institute inclusive and scaled market opportunities for smallholder coffee farmers.

Opportunity: The sponsor aims to restore degraded buffer zones surrounding protected areas through sustainable coffee agroforestry practices two areas of North Sumatra. Smallholder farmers will be incentivised with premium pricing for arabica coffee beans in exchange for sustainable practices, providing a direct outlet to international markets that would otherwise be inaccessible for individual farmers. The resulting restoration of degraded forest creates economic

value for ecological restoration while also capitalising on the growing global demand for sustainably-sourced and responsibly grown coffee beans. The coffee bean product will be certified carbon neutral with strict protocols demonstrating a supply chain that is committed to protecting High Conservation Value (HCV) and High Carbon Stock (HCS) forests.

Impact: The project partners with an NGO that facilitates the Sumatran Orangutan Conservation Programme across the protected ecosystems encompassed by the project's coffee production network. Sales of the coffee beans would contribute directly to this programme, which rehabilitates and rewilds illegal captive orangutans, conducts ecological research on wild populations, and raises awareness on habitat and species conservation. Throughout the lifespan of the project, additional smallholder farmers will be recruited, increasing the number of farmers who will benefit from large-scale marketing to international coffee bean suppliers from 770 to over 2,000. In addition, over 8,000 village residents within and adjacent to the project zone will benefit from the project, particularly through flexible employment opportunities offered to women, elderly, and marginalised members of the community.



Level 1: Broad baseline

Target questions:

- What are the species and key areas that contribute to the biodiversity of the different project sites?
- Which human activities should be addressed to lessen negative impacts on biodiversity for each project?

Key learnings:

- The pipeline projects are all located in areas with a high potential for positive biodiversity impact
- The three largest human-driven threats to biodiversity for all pipeline projects analysed are hunting, logging, and agriculture.

Considering the multiple early-stage projects under development in ACLF, the Level 1 analysis serves to provide an understanding of the biodiversity context for each pipeline project. The IBAT tools serve as an ideal way to do so without any technical or geospatial data specific to each site. Even if these data exist, they may not be readily accessible without formal loan commitments or agreements in place.

For each project site assessed, PS6 and STAR reports were generated for the subdistrict that each project was located in.[63] With 7,246 subdistricts dividing Indonesia, the geospatial boundaries of subdistricts served as adequate substitutes for the project's exact location – which was sometimes still unavailable from the borrowers in each project.

The biodiversity metrics calculated on the IBAT portal allow for a side-by-side comparison of the ecological context of each site (Table 2). Albeit high-level, the use of standardised metrics at this initial stage of biodiversity assessment is important for developing an understanding of how the Fund can approach the 'avoid' and 'minimise' stages of the mitigation hierarchy collectively across its projects. HCV-HCS assessments will also provide data that is collected in a standardised and consistent manner across projects while opening avenues for tailored metrics to be calculated in the Level 2 analysis.

Table 2

Level 1 results for ACLF pipeline projects

Biodiversity Metric	Coffee (A)	Coffee (B)	Bamboo	Shrimp	Coconut
Key Biodiversity Areas within 50km	2	5	8	6	2
Protected Areas within 50km	1	3	6	16	1
IUCN Red List Species*	35	42	15	87	33
Mean STAR-T Score	47.72	27.62	101.14	250.3	29.75
Mean STAR-R Score	34.44	19.33	64.97	43.03	8.05
Top 3 threats to mitigate for intact habitats	1. Agriculture 2. Hunting 3. Logging	1. Agriculture 2. Hunting 3. Logging	1. Agriculture 2. Hunting 3. Logging	1. Logging 2. Agriculture 3. Hunting	1. Hunting 2. Logging 3. Agriculture
Top 3 threats to mitigate for habitat restoration	1. Agriculture 2. Hunting 3. Logging	1. Agriculture 2. Logging 3. Hunting	1. Agriculture 2. Hunting 3. Logging	1. Logging 2. Agriculture 3. Hunting	1. Hunting 2. Logging 3. Agriculture

* Critically endangered or endangered species whose ranges lie within 50km of the site

Potential to reduce global species extinction risk (relative comparison as indicated by STAR metric)



The PS6-aligned metrics (KBAs, protected areas, and Red List species) indicate that all of the showcased pipeline projects are located within a 50km vicinity of two KBAs and one protected area. All of the sites also house a relatively large number of endangered species, indicating that the underlying biodiversity contexts of the project sites are well-aligned with the ACLF's primary aim to transform the management and usage of existing agricultural or production landscapes for sustainable land use practices, furthermore serving as buffers to preserve the surrounding habitat from encroachment. These results affirm the projects' investment theses, which are tied to positive biodiversity-related outcomes.

For each site, the mean STAR-T score was higher than the STAR-R score. This indicates that the sites have a better potential to reduce species extinction risk through mitigating threats to the existing landscape, rather than through habitat restoration. Given that most of the projects are geared first and foremost towards the former rather than the latter, these results are a positive indicator that the priorities of ACLF projects are well-suited to effectively deliver impact for local biodiversity and do not need additional adjustments at this stage.

Furthermore, comparison of the top three threats that emerged from the STAR analysis shows that the sites all share the same pressures from agriculture, logging, and hunting – despite being located in very different parts of the country. This suggests that while the context and execution of each project may be unique, the high-level biodiversity management strategies of ACLF may converge toward mitigating drivers of these three areas. By nature, the projects will mitigate illegal or unsustainable encroachment due to agriculture, logging, and hunting by implementing the restorative or well-managed land use practices planned for each project.

Level 2: Detailed accounting

Case Study on Project Coffee

The Level 2 analyses were chosen based on the availability of project data and the relevant biodiversity considerations for each project, in this case for Project Coffee (Figure 11). Much like other projects in the ACLF portfolio, Project Coffee involves some degree of landscape modification because it involves agroforestry and production. As a result, a large emphasis was placed on further exploring the habitat conditions for the Level 2 analysis.

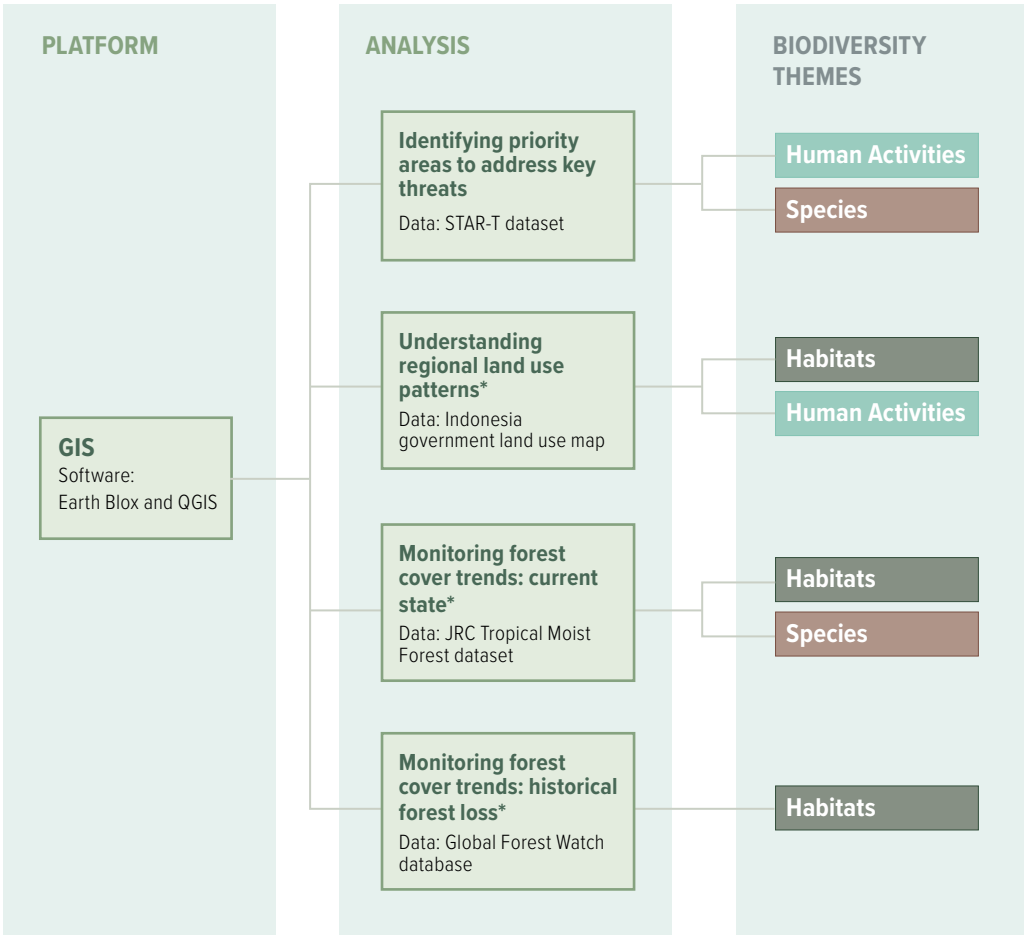
As ACLF develops further, these analytical processes will deepen and evolve with the execution of each project in the pipeline, particularly to explore the additional Level 2 analyses listed in Chapter 4 are still being trialled for future application (see Appendix II).

For Project Coffee, the on-the-ground partners possess relevant geospatial data pertaining to the project operations, including the coordinates of individual smallholder coffee farms, boundaries of neighbouring protected areas, and maps classifying land use types across the region. This allows for additional analyses, as laid out in the following sections.

Project Coffee, which partners with smallholder coffee farms in two different provinces (Aceh and North Sumatra), can produce benefits for biodiversity by acting as protective buffer zones for the surrounding forested areas – as identified in the Level 1 analysis. The network of smallholder coffee farms not only encourages the use of the agricultural practices that are non-detrimental to the immediate setting, but also offer regular monitoring and protection against illegal activities (e.g., land clearing or hunting) in its adjacent forests across the broader landscape.

Figure 11

Summary of Level 2 analysis for ACLF



* Analysis is focused only on Project Coffee

Understanding surrounding land use patterns

Target question:

- On a regional level, how is the land surrounding Project Coffee's farms being used or conserved in other ways?

Key learnings:

- Regional land use data provided by government sources or local partners are valuable for identifying particular species or habitats that projects can help protect.

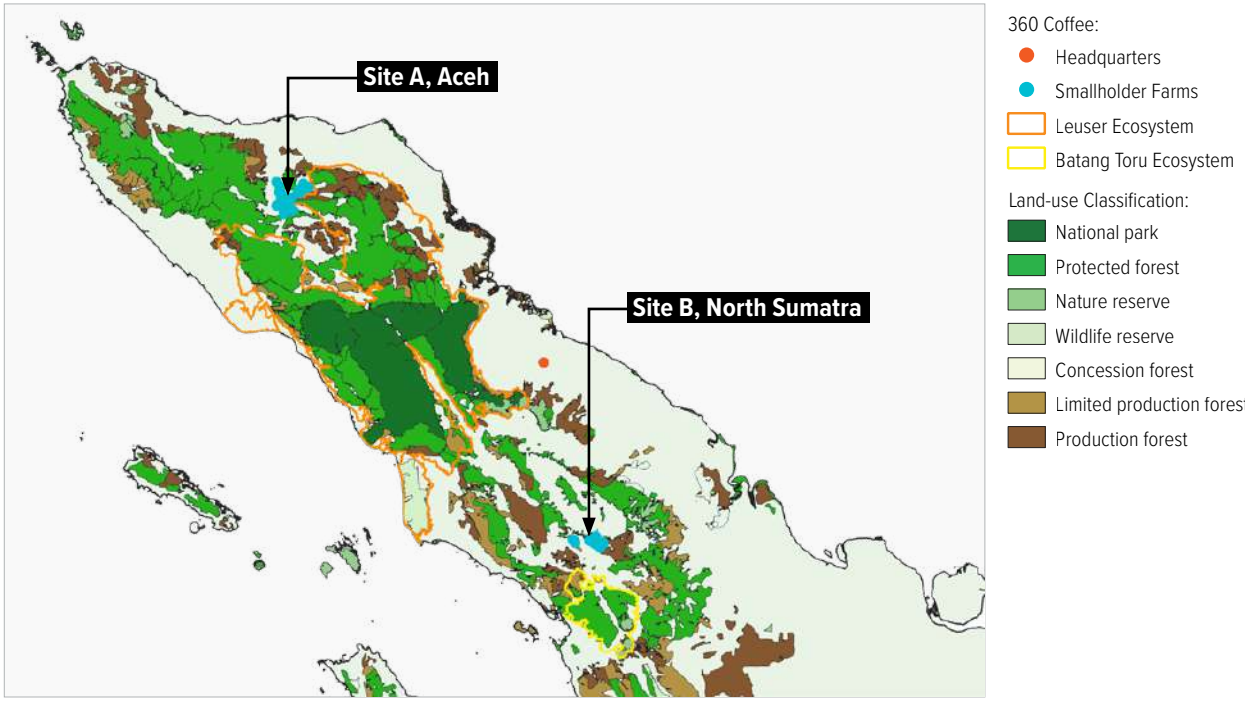
Various GIS analytical tools were used to gain a better sense of the broader environmental context of the areas surrounding the sites. Firstly, a government land use classification layer provided by the conservation NGO shows that much of the area surrounding the Aceh coffee farms are protected forests, national parks, and nature reserves – some of which were overlooked in the global database used for the PS6 report (Figure 12). The farms also border the Leuser ecosystem, which has been recognised as the only area in the world where critically endangered species such as the Sumatran elephant, tiger, rhino and orangutan are found coexisting in the same ecosystem. The importance of the ecosystems adjacent to the Aceh farms further emphasise the important role that this site will play as a buffer zone and safeguard for biodiversity, which was also reflected in the STAR scores.

The North Sumatra coffee farms (Site B) are surrounded by comparatively more commercial production forests in addition to protected forests – than the Aceh (Site A) farms. The farms border the north part of the Batang Toru Ecosystem, which is the sole habitat of a newly identified ape species, the Tapanuli orangutan (*Pongo tapanuliensis*), and houses other endangered species such as Sunda pangolins, sun bears, and tapirs.[64] Similar to the Aceh sites, the North Sumatra smallholder farms can have an important role in protecting these ecologically significant habitats that will preserve biodiversity.

The additional regional context gained through GIS analysis of the sites supports the results drawn from the Level 1 analyses that highlight the importance of addressing pressures from improper land use and illegal exploitation of natural resources, further validating the positive contributions to biodiversity that Project Coffee can make.

Figure 12

Regional land use and protected areas surrounding Project Coffee sites in Aceh and North Sumatra



Monitoring forest cover trends

Target question:

- On a regional and site level surrounding the coffee farms, what are the historical trends in forest cover loss?

Key learnings:

- The two smallholder farm networks have different historical trends in forest cover loss, suggesting that targeted management actions need to be considered for each area individually

- Developing a contextual understanding of the historical and present-day losses in forest cover is important in monitoring future progress towards reducing biodiversity threats

With much of the biodiversity that this project supports being dependent on the forest habitats, deforestation rates can act as an important proxy in measuring progress to alleviate threats such as illegal land clearing, destructive agricultural practices, and logging as well as prioritising management efforts. As a result, two further datasets were analysed to understand a) the current state of tropical rainforest habitats surrounding the coffee farms, and b) historical losses in forest cover.

Current state of forest habitats: Present-day forest cover in the two coffee farm networks was modelled using the European Commission Joint Research Centre's dataset on tropical moist forest cover in 2020 (Figure 13).[65] For each site, the proportion of undisturbed and degraded forest cover was analysed in a 15km radius surrounding the coffee farm coordinates (Figure 14).[66] As expected from the results shown by the land use map in the previous analysis, Site A was generally surrounded by more forest (60% of land cover) than Site B (25% of land cover).

This result suggests that in planning management strategies relating to the 'minimise' stages of the mitigation hierarchy, greater attention should be paid to preserving Site A's larger proportion of intact and undisturbed forest areas. In contrast, biodiversity management actions taken in Site B could be more focused on the 'rehabilitate/restore' stage of the mitigation hierarchy since it contains more disturbed forest cover.

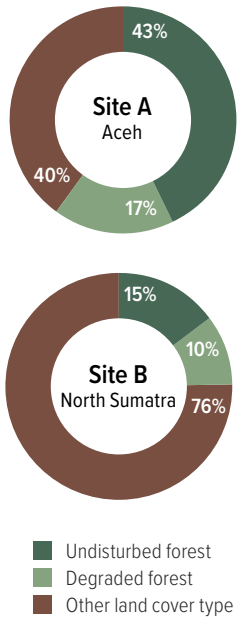
Figure 13

Undisturbed and degraded forest cover in Aceh and North Sumatra



Figure 14

Proportion of undisturbed and degraded tropical forest cover in a 15km radius from Project Coffee smallholder farms, 2020



Historical forest loss: Data obtained from the Global Forest Watch database provides the year that each 30 by 30m land area was lost due to natural mortality or deforestation.[67] Earth Blox and QGIS (an open-source GIS software) were used together to create rapid visualisations of forest cover loss in the 15km buffer zone surrounding the farms, showing the year in which a loss was detected for each pixel area (Figure 15). Identifying the distinct areas of recent forest cover loss, such as the northern edge of the Aceh site, is valuable in spatially pinpointing where management efforts should be prioritised to most effectively address forest cover loss associated with human activities.

Analysis of historical forest cover loss demonstrates that the two sites had similar rates of loss in forest cover between 2001 and 2021: 0.7% per year and 0.8% per year for Site A and B respectively (Figure 16). The trends throughout time, however, show slightly different stories that may be useful in informing current management strategies at the respective sites.

Prior to 2013, loss in forest cover was consistently higher in Site B compared to Site A (Figure 16), with rates peaking in 2010. From 2013 to 2021, Site A had higher rates of forest cover loss, peaking in 2016 and steadily decreasing thereafter. While Site B followed a similar trend, data for 2020 and 2021 show forest cover loss increasing.

Figure 15

Forest cover loss by year from 2001 to 2021 in Project Coffee's Aceh (right) and North Sumatra (left) farm networks

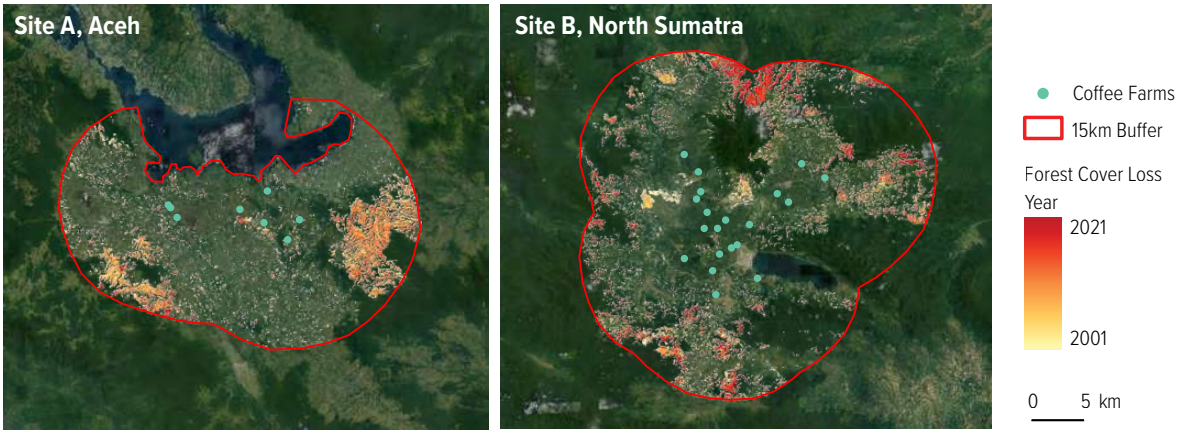
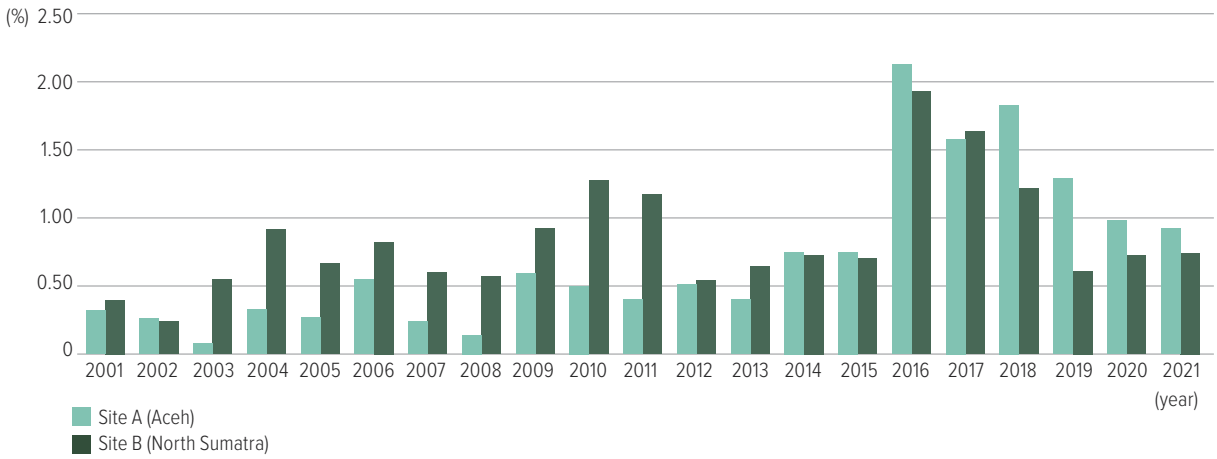


Figure 16

Historical forest loss in areas surrounding Project Coffee farms (15km buffer)



These results indicate a possible uptick in activities contributing to forest cover loss nearby the North Sumatra coffee farms in recent years, whereas such activities may be declining nearby the Aceh farms. These dynamics are something to keep in mind when developing biodiversity management strategies for the two sites of Project Coffee. The site that has had more recent forest loss may warrant greater resources devoted to active monitoring or patrolling of the surrounding area, whereas the other site may be more suitable for passive monitoring or restoration activities.

Fund-level landscape analysis

While the Level 2 analysis provides an opportunity for tailored tools and metrics to be used given the unique ecological context of each investment project, further analyses can also be conducted holistically across the landscape to draw deeper biodiversity insights at a fund level. One such example is outlined below.

Identifying priority areas to address key threats

Target questions:

- Which parts of Indonesia would have the greatest biodiversity impact if threats from agriculture, logging, and hunting were addressed?
- How do the ACLF sites fit into these priority areas?

Key learnings:

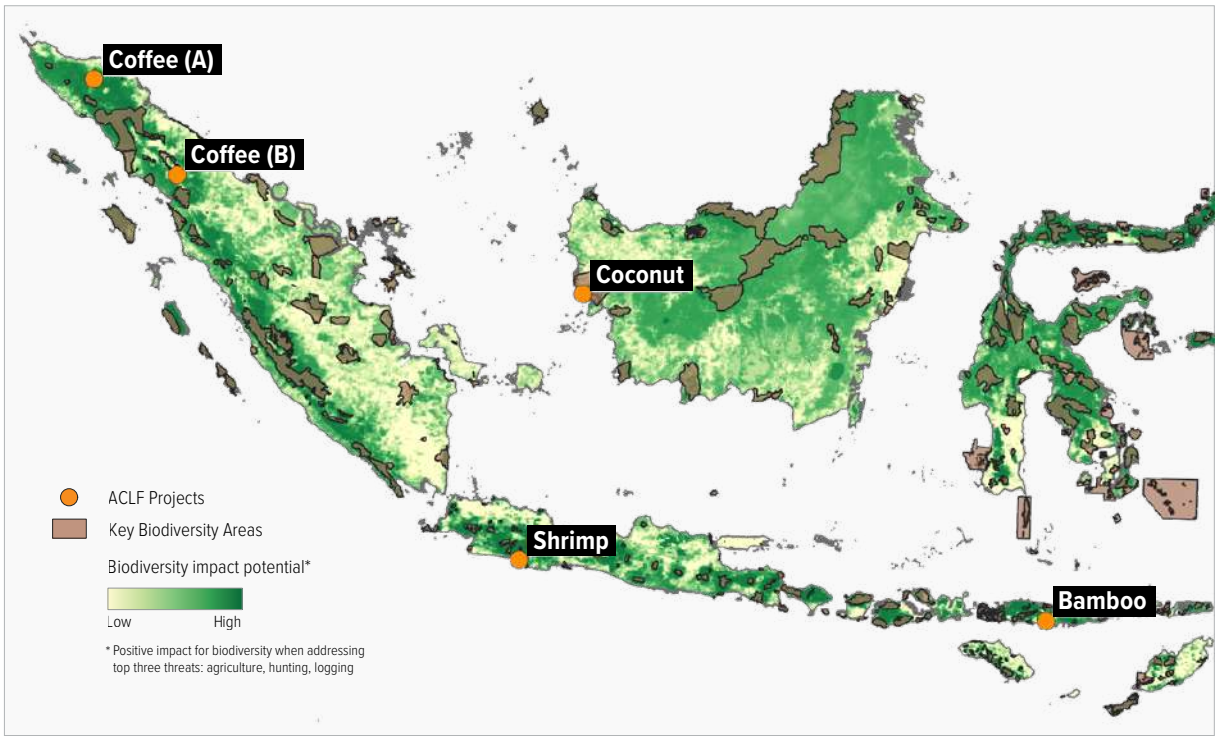
- All ACLF projects are located in or immediately adjacent to areas that will have high positive impacts for biodiversity when addressing the top three threats analysed (agriculture, logging, hunting)

To gain a better idea of the broader landscape for biodiversity impact for ACLF in Indonesia, a map was produced to visualise areas in Indonesia that would benefit the most from mitigation of these threats (Figure 17).[68] This was done by averaging the individual STAR-T scores for hunting, logging, and agriculture, obtained from a country-wide dataset provided by the IBAT Alliance.[69] This dataset was also overlaid with KBA locations to further highlight priority areas to deliver maximised positive impact through monitoring and addressing these threats.[70]

Figure 17

Positive biodiversity impact potential for three priority threats across Indonesia

Higher impact potential scores indicate that addressing these threats can produce a greater contribution towards species extinction risk reduction.



The resulting map shows that many of Indonesia's KBAs overlap with high impact areas with respect to threats from logging, hunting, and agriculture – affirming the importance of investments that support shifts towards the sustainable usage of landscapes. Within the context of ACLF, the projects selected for this case study are all located within or immediately adjacent to areas with high impact potential (Figure 18). Projects such as Shrimp and Coconut are located directly in high biodiversity impact areas, suggesting that the direct management of threats on-site will be important to delivering the projected positive outcomes for biodiversity.

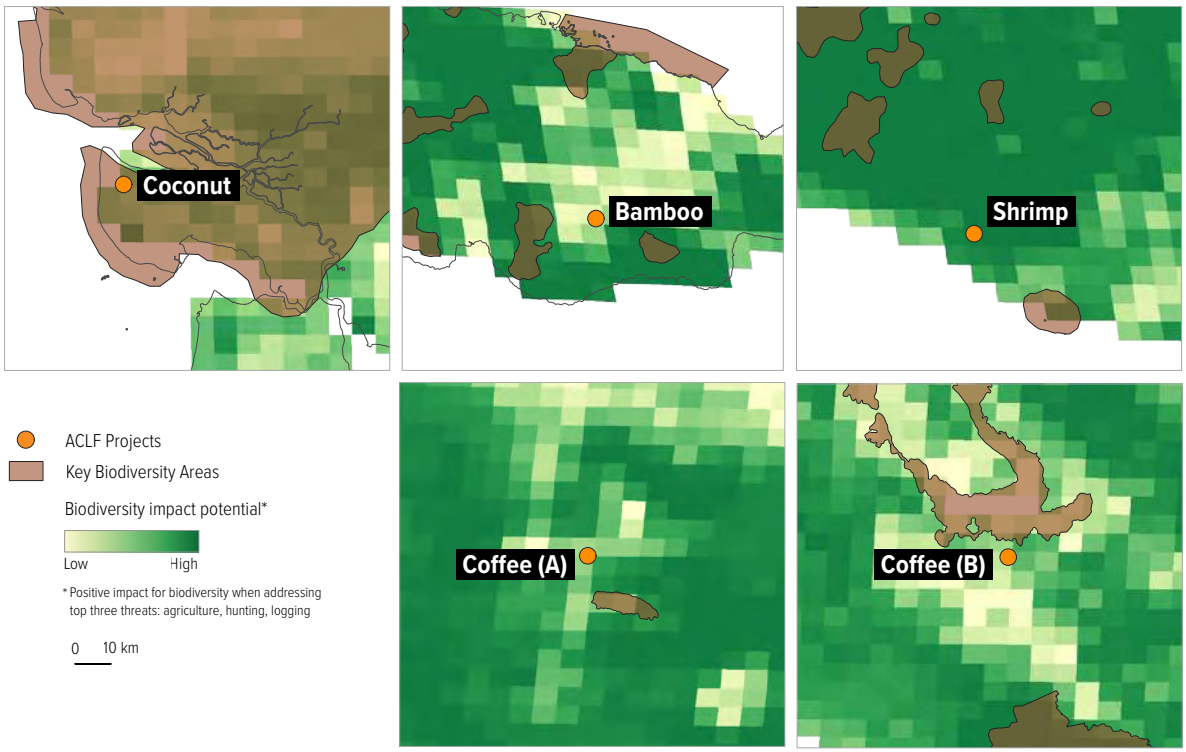
In contrast, the projects Coffee and Bamboo are located in areas with low impact potential but are surrounded by high impact potential areas. This outcome is expected, given that the project sites themselves have already altered the landscape and could no longer serve as valuable habitats for endangered species without large restoration efforts.

Rather, these sites would serve as valuable buffer zones and monitoring points to manage the threats in the areas in their immediate surrounding. This could translate to actions such as regular border patrols to monitor for illegal logging or poaching, or community engagement programmes to educate farmers on more sustainable agricultural practices.

These findings serve as a basis for prioritising actions to create maximised positive impact on biodiversity, taking into account the context of each site. Going forward, steps should be taken to establish baseline rates for each of the threats (e.g., for agriculture: the percentage of land conversion from forest to cropland or plantations within or around the area of interest) such that targets can be set to reduce the intensity of such threats and measure progress. Such targets can also be designed to align with existing standards, such as the IFC PS6, World Bank ESS6, or Science Based Targets for Nature.

Figure 18

Close-up of biodiversity impact potential for each of the ACLF projects



Next steps for the ACLF biodiversity accounting process

The Level 1 and Level 2 analyses have outlined our initial iteration of the biodiversity accounting framework developed for ACLF. As the ACLF pipeline continues to be finalised, we expect to carry out Level 2 analyses for all pipeline projects and develop a tailored methodology that suits the operational and environmental context of each site. With some projects also interacting with coastal and freshwater systems, rather than just terrestrial ones, there is further development needed for complementary metrics that model biodiversity drivers in these ecosystems.

The initial stages of the framework give rise to opportunities to set targets for each project as it is implemented. Using Project Coffee as an example, one such goal could be to reduce forest cover loss to 0.5% of the land area per year in the next five years. Forest cover could then be monitored on a quarterly basis using the aforementioned analytical tools, as well as other remote sensing data products, to monitor progress towards this goal and provide feedback to ongoing management actions. Doing so would provide tangible and quantifiable benefits for biodiversity that could then translate into fund-wide impact outcomes.

Throughout this process, we fully expect for the framework to be updated and iterated upon as we trial new approaches and collect new data for ACLF. As the projects mature, the implementation of on-site data collection capabilities or the trial of new collection methods, such as through eDNA or acoustic monitoring, can contribute to the development of metrics for biodiversity loss drivers that are more difficult to quantify (e.g., hunting or poaching).

These data collection systems will also allow for the application of other Level 2 analyses that allow for more granular or extensive biodiversity accounting methods. We have already begun trialling and developing workflows certain analytical approaches, such as the Calibrated STAR validation process and machine learning land-use classification algorithm, in preparation for potential use for ACLF in the future. Further details on these beta testing processes can be found in Appendix II.

6. Looking Forward

The biodiversity accounting framework outlined in this report documents what is just the beginning of our ongoing process to support the integration of nature-related impacts in our investments. The framework is the first stage of our evolving approach to biodiversity, which will continue to be updated, improved, and refined as our own capabilities develop in the future alongside the maturity of ACLF and other impact initiatives.

As we have established, there is no definitive or one-size-fits-all methodology when it comes to quantifying biodiversity for investment purposes. Our own approach has highlighted several recommendations for institutions wishing to engage with and push forward the biodiversity-finance nexus:

- Develop and improve site-based data collection by strengthening local partnerships, supporting technological innovation for biodiversity measurement, and devoting more resources towards streamlining data sharing and communication channels.

- Integrate geospatial modelling tools with existing risk or impact assessment workflows, increase capacity for geospatial analysis skills within internal team capabilities, and improve firm-wide literacy of fundamental ecological and climate principles.

- Support and contribute to cross-sectoral dialogues that facilitate the alignment of standards, taxonomy, and approaches to nature-related risks, biodiversity impacts, and natural capital financing across academic, public, and private stakeholders.

Going forward, we will continue monitoring the metrics and indicators applied to ACLF on a regular basis and evaluate how impact has been made in real time. The analyses will be applied to each project executed in the fund, which will serve as our first opportunity to integrate the biodiversity accounting process throughout the lifetime of ACLF. We also look forward to expanding our range of analytical tools and metrics to encompass not just terrestrial ecosystems, but also marine and freshwater ecosystems.

2023 will be a crucial year for emerging industry-level guidance on nature-related risks and impacts, particularly with the anticipated release of the TNFD's Disclosure Recommendations and the Science-Based Targets for Nature. We will align our existing analytical components with those of industry-level guidance. As a member of the TNFD Forum, ADMCF will also share any insights, approaches, and findings with the broader financial community on an ongoing basis.

We also look forward to deepening our collaboration with providers of emerging technologies and metrics – such as Earth Blox and IBAT – to showcase how they can be applied to address quantitative gaps in the biodiversity impact monitoring sphere. As other innovations (e.g., eDNA, acoustic monitoring, drone data) become available for us to apply in future iterations of this framework, we will continue to share our experiences with others in the industry who may find the feedback useful.

Regardless of whether institutions are just starting out on their biodiversity accounting journey or already possess a well-established approach, we believe that it is critical to develop a solid, quantitative understanding of both the baseline and changes in biodiversity over time. We hope that the report serves as a useful source of guidance on this endeavour, and that you will join us in this ongoing process to strive towards a nature positive future for finance.

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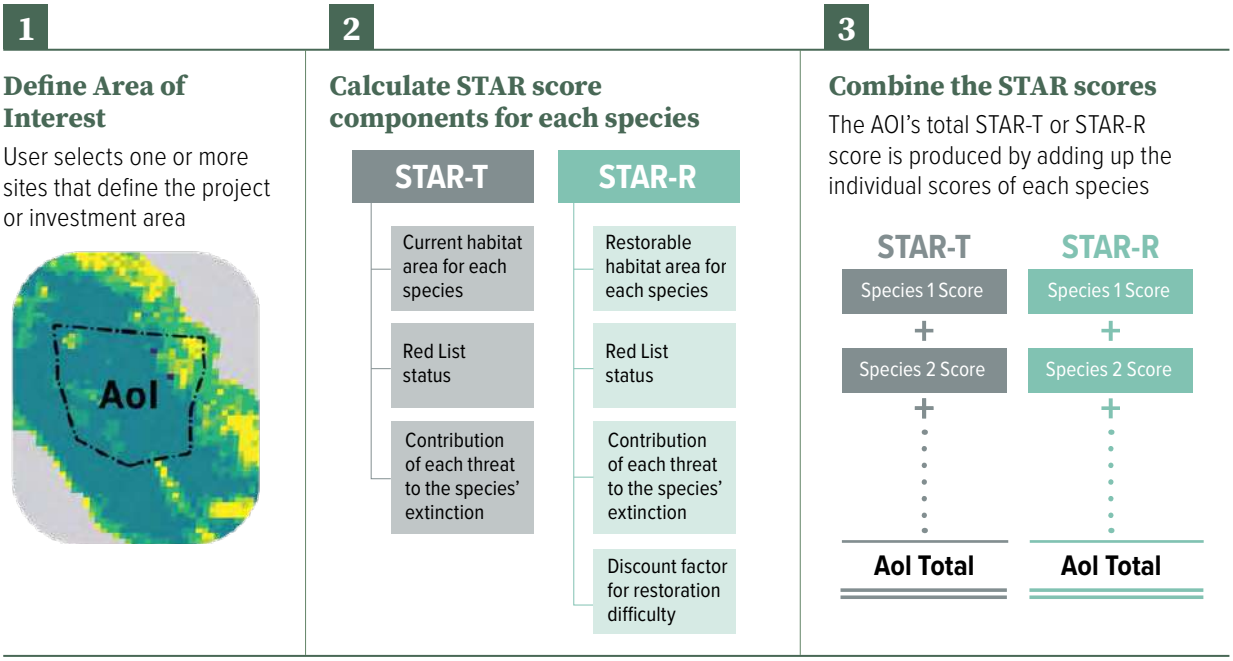
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8. Appendices

Appendix I: STAR Calculation Process

Flow chart showing the STAR calculation process for both STAR-T and STAR-R.
Adapted from the STAR Business User Guidance, available from: https://www.ibat-alliance.org/pdf/star-business-user-guidance.pdf.



The STAR-T score is calculated with data pertaining to each species' habitat range that is included in the Area of Interest (AOI), its Red List status (critically endangered species receive the highest weight), and the contributions of different threats (e.g., logging, hunting, agriculture) to its extinction.

The STAR-R score is calculated in a similar manner, but instead looks at the species' former habitat range (that can theoretically be restored). It also includes a discount factor to the overall score to reflect that slower and lower success rate in delivering species benefits through restoration activities.

The table below describes the score components that make up each species' STAR scores, which are then calculated and summed for all species identified within the AOI. More information on the equations, data, and assumptions involved with the calculation process can be found in the publication by Mair et al., 2021.

Score Component Calculated and summed for each species	Unit of Measurement	STAR-T	STAR-R
Current habitat range overlapping with AOI	Percentage of the species' current habitat range	●	
Former habitat range overlapping with AOI (i.e., restorable habitat)	Percentage of the species' current habitat		●
IUCN Red List status	Weighted based on status level: 4 = Critically endangered 2 = Vulnerable 3 = Endangered 1 = Near Threatened	●	●
Contribution of each threat to the species' extinction risk	Percentage of population decline caused by that threat (derived from the threat severity and scope outlined for each species' IUCN Red List profile)	●	●
Discount multiplier to account for restoration difficulty	Multiplier of 0.29 applied based on a global study of restoration projects		●

The IUCN Red List outlines ten different threat types and their contributions to each species' extinction risk. The STAR scores generated for the AOI can therefore rank the threat types in order of highest to lowest contributions to species extinction risk, allowing users to identify priority actions for biodiversity conservation. The ten threat types and their descriptions are provided below.

IUCN Threat Classification Scheme used in STAR

(Adapted from the STAR Business User Guidance)

Threat type	Definition
Residential & Commercial Development	Threats from human settlements or other non-agricultural land uses with a substantial footprint
Agriculture & Aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture (includes the impacts of any fencing around farmed areas)
Energy Production & Mining	Threats from production of non-biological resources, including oil and gas, mining and renewable energy
Transportation & Service Corridors	Threats from long narrow transport corridors and the vehicles that use them including associated wildlife mortality
Biological Resource Use	Threats from consumptive use of "wild" biological resources including both deliberate and unintentional harvesting effects; also persecution or control of specific species
Human Intrusions & Disturbance	Threats from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources
Natural System Modifications	Threats from actions that convert or degrade habitat in service of "managing" natural or semi-natural systems, often to improve human welfare
Invasive & Other Problematic Species, Genes & Diseases	Threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance
Pollution	Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources
Climate Change & Severe Weather	Threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation, or potentially can wipe out a vulnerable species or habitat

Appendix II: Beta Testing for Level 2 Biodiversity Accounting Analyses

The following analyses have been performed on a matured investment project of ADM Capital, in efforts to explore the workflows and technical tools needed to execute additional Level 2 analyses. With the investment project already having concluded after several years of engagement and on-site data collection (e.g., HCV-HCS assessments), this provided a unique opportunity to plan ahead for future stages of the ACLF biodiversity accounting process.

The project will be referred to as the 'Beta Project' for the purposes of this paper.

Analysis I:

Confirming endangered species presence with Calibrated STAR

Target questions:

- Which endangered species have been detected at the site that are listed on the IUCN Red List?
- Which species should be prioritised for further monitoring or detection?

Key learnings:

- All of the species detected in the site were correctly predicted by the STAR metric
- Consultation of an expert ecologist identified priority species for future monitoring and identification

The STAR metric predicts species presence at a user-defined site based on habitat range, which is documented by the IUCN Red List. As described previously, it is crucial to validate – as best as possible – the actual presence of these species on-site in a ground-based verification process. This will allow for the adjusted calculation of a Calibrated STAR score (see pg. 27 for more detail) that can serve as a basis to quantify progress made towards species conservation.

With the Calibrated STAR score still under development by the IBAT team, there is not yet a distinct methodology for carrying out the validation process. In the case of the Beta Project, species identification data are collected regularly through patrols, monitoring activities (e.g., camera traps), and biodiversity surveys in partnership with local organisations.

Endangered species identified through on-site monitoring activities at the project site were compiled into a unified database for comparison with the species predicted by the STAR metric. In some cases, species identified on-site were missing from the STAR list, or vice versa. To reconcile these differences, an ecologist who had previously conducted extensive research on the surrounding ecosystem was consulted to provide further insight.[71]

Comparison of the two species lists – the 'predicted' list generated from the STAR metric and the 'detected' list from the site surveys – indicated a select few species that warrant further investigation for confirmation. In general, the species validation process found that all of the species detected on site were present in the predicted list generated by STAR. That is, the STAR metric accurately predicted all of the species found at the site that are classified as Threatened (i.e., vulnerable, endangered, or critically endangered) by the IUCN Red List.

The site survey data confirmed that 26 out of the 61 species listed in the STAR report (43%) were sighted in the Beta Project site. 18 species were identified from site surveys but were not listed in the STAR report, however, the expert ecologist was able to eliminate eight of these species due to misidentification or taxonomic duplicity (i.e., the species is known by two different names). The remaining species were confirmed by the expert to hold the Near Threatened conservation status and for this reason would not be included in STAR calculations.

Of the 35 mammal and bird species that were predicted by STAR but not yet detected on site, 16 were earmarked by the expert ecologist as being particularly valuable to the project's biodiversity impact if they could be identified at the site. These species were prioritised for one of two reasons: a) the species is thought to have a very small habitat range and therefore the project area could be highly valuable to its conservation if the species were detected on site; b) the species is a 'flagship species' that has a high public profile, and would therefore be useful in attracting attention to or recognition for the conservation work being done at the site.[72]

As the STAR calibration process continues to develop in collaboration with the IBAT team, more information will be shared on resulting analytical results and conservation management recommendations. At the time of writing, the IBAT technician team is using this case study to manually test the Calibrated STAR calculation process. Once this metric is produced, it will serve as a benchmark for regular assessment to quantify progress made towards biodiversity conservation.

If applied to ACLF in the future, the results of this analysis could provide useful for on-the-ground teams for species that could be prioritised for identification or monitoring. However, while the Beta Project team possessed well-documented species identification lists on-hand, we do not expect all projects to have this data available. The collection of site-based species data, especially through manual surveys, can be highly time- and resource-intensive and therefore not feasible for all projects to facilitate.

This validation process, however, is crucial in the biodiversity accounting process, as gaining an understanding of the species present at the site is a foundational element in quantifying biodiversity. As discussed in Box 4 (pg. 15), there are a variety of technologies under development to perform biodiversity assessments at a fraction of the time and cost. As these technologies continue to evolve, we expect that the data required for this segment of the biodiversity accounting process will become more accessible and scalable for corporate stakeholders.

Analysis II:

Machine learning for automated land use classification

Target question:

- How can the process of land use classification be automated using artificial intelligence to regularly monitor changes in land use?

Key learnings:

- Developing an accurate training dataset is crucial to developing an accurate machine learning algorithm
- At least one survey that defines the site's different land use types must be carried out in order to train and develop the algorithm

Background on machine learning

As discussed previously, understanding how the land is utilised in and around the project site is important in determining biodiversity targets, monitoring progress, and providing context to other biodiversity analyses that are carried out at coarser resolutions. While the Beta Project was well-positioned to hold regular assessments of the site through its local partnerships and daily site patrols, these surveys would be undeniably cost- and labour-intensive to conduct for all of ACLF's pipeline project. This is where automation through machine learning would help reduce manual surveying costs and capacity needs.

The Beta Project's daily patrols were valuable in providing regular updates for ongoing management activities. However, these types of manual monitoring processes are limited in that they cannot provide spatially-explicit data that span the site at equal intervals. Performing a more detailed inventory of land use on a larger scale almost always relies on hiring external contractors for technical expertise and manpower, and is often too costly to perform on a regular basis.

This gap can be addressed by automating the land use classification process with machine learning. Once it is trained and attuned to the characteristics of the site on satellite imagery, the algorithm can produce detailed classifications on much shorter time intervals and at a fraction of the cost.

In a 2022 review of data processing and technical methods available for geospatial ESG applications, machine learning was identified as one of the most promising yet complex tools on the market for producing environmental insights on investments.[73] A primary challenge is that machine learning algorithms require specialised technical skills to implement, typically outside the remit of financial stakeholders.

ADMCF's partnership with Earth Blox has been helping overcome this challenge, with the Earth Blox team developing a customised algorithm for us to apply on a coding free interface.[74] Once the algorithm is ready for use, ACLF stakeholders will be able to shift the analysis to an in-house process, giving greater flexibility and control over when and how the outputs are produced.

Supervised classification

For ADMCF's particular application, a supervised classification algorithm would be used to detect different types of land cover with a much higher granularity than off-the-shelf global data products provide.

This technique is most often used for quantitative assessment of satellite imagery and relies on an initial dataset, or 'training dataset', that provides representative sample areas of each land use type.[75] The training dataset is specific to each project, and requires prior data collection on-site. Some government bodies have detailed records of land use that would be suitable for training datasets, while other areas that lack this information would need to conduct an initial survey to define land use classes.

Once the training data is fed into the algorithm as an input, the machine learning process identifies the spectral characteristics that define a particular land use class (e.g., shrubs, dense forests, or open land) and applies these observations to classify new imagery. Half of the polygons provided for training are used to train the model, while the other half are then used to 'validate' or check how well the classification has performed. The resulting output can then be evaluated for its accuracy in an output table known as a 'confusion matrix'.

With the quality of the supervised classification hinging so heavily on the input training datasets, the development of high-quality training data is another key challenge in the execution of this analysis. Even with machine learning being an automated process, a baseline study (conducted through a traditional field survey or other methods) is almost always required to set the foundation for training the algorithm.

The Beta Project and its partners conducted two HCV-HCS land use studies, four years apart, which provided maps defining land use types in alignment with government classification taxonomy (see Table A-1). This was ideal to use as training data for the algorithm.

Table A-1

Land use class inputs for algorithm training

High density forest
Medium density forest
Young regeneration forest
Bushes
Scrub
Low density forest
Rubber plantation
Oil palm plantation
Eucalyptus plantation
Acacia plantation
Mix agriculture
Open land
Settlement
Water

Algorithm training process

The training dataset was created by selecting and labelling random portions of each land use type in and around the project site, ultimately producing a geospatial data layer that could be used to train the model. Since this is the first application of the algorithm, which is still under development by the Earth Blox team, their developer team directly carried out the training process to trial the programme. Once this capability is fully integrated into the platform, algorithms and models can be evaluated and trained directly on the coding-free interface by users.

The first round of model training in the machine learning process resulted in an algorithm that was able to correctly identify approximately 63% of land cover classes across the site in the validation process (see Tables A-2 and A-3 for full confusion matrix results). Considering that the target accuracy for the output algorithm is about 80-90%, this outcome is relatively promising for a first attempt.

The algorithm was less accurate in identifying certain land use classes over others, indicating areas for further improvement or additional clarification in the training data. In particular, the high-density forest, open land, and mixed agriculture classes had the highest error percentages, likely due to these land cover types displaying higher variability in spectral characteristics than others.

With the algorithm training process still ongoing at the time of writing, the fully trained model and workflow have yet to be finalised for future use. Future iterations of the machine learning process will likely involve changes to the training data to improve identification of the land classes that had the highest error percentages, as well as the integration of other remote sensing datasets (e.g., multispectral imagery, radar imagery) to better inform the classification algorithm.

Once this workflow has been integrated with the Earth Blox platform, ADMCF and ACLF teams will be able to perform this training process directly without the assistance of the Earth Blox technical team. The training polygons will be directly uploaded to the platform or manually drawn directly on the interactive interface. Additionally, the fully trained algorithm can be used to classify new satellite imagery at regular intervals to quantify changes in the project landscape on a highly precise and granular level.

This capability will allow ACLF stakeholders to performing these analyses in-house at much shorter intervals without the need to contract expensive third-party services. Platforms such as Earth Blox demonstrate the importance of emerging technologies in making previously inaccessible technical processes available to a wide range of stakeholders – a crucial component of making biodiversity accounting possible for financial institutions.

Table A-2

Confusion matrix for algorithm training

Confusion matrix showing the number of pixels that are correctly identified by the algorithm during the training process (predicted) for the input (observed) land use classes, indicated by the blue cells for each land use type.

		Predicted																
	TRAINING	Acacia plantation	Bushes	Eucalyptus plantation	High density forest	Low density forest	Medium density forest	Mixed agriculture	Oil palm	Oil palm plantation	Open land	Rubber plantation	Scrub	Settlement	Water	Young regeneration forest	TOTAL	Sensitivity / Producers Acc.	Omission Errors
Observed	Acacia plantation	684	1	0	55	0	0	4	0	0	0	0	0	0	0	0	**744**	91.9%	8.1%
	Bushes	0	67	0	7	0	0	3	0	0	0	0	0	0	0	0	**77**	87.0%	13.0%
	Eucalyptus plantation	1	0	10	0	0	0	0	0	0	0	0	0	0	0	0	**11**	90.9%	9.1%
	High density forest	8	0	0	4092	0	1	24	0	0	0	0	1	0	0	0	**4126**	99.2%	0.8%
	Low density forest	0	0	0	3	13	0	2	0	0	0	0	0	0	0	0	**18**	72.2%	27.8%
	Medium density forest	2	0	0	70	0	325	18	0	0	0	0	0	0	0	0	**415**	78.3%	21.7%
	Mixed agriculture	7	0	0	103	0	4	1742	0	0	3	1	0	0	0	0	**1860**	93.7%	6.3%
	Oil palm	3	0	0	33	0	3	26	211	0	2	0	0	0	0	0	**278**	75.9%	24.1%
	Oil palm plantation	1	0	0	4	0	0	2	0	26	0	0	0	0	0	0	**33**	78.8%	21.2%
	Open land	3	0	0	10	0	0	14	2	0	187	0	0	0	0	0	**216**	86.6%	13.4%
	Rubber plantation	2	0	0	14	0	0	40	0	0	6	277	0	0	0	0	**339**	81.7%	18.3%
	Scrub	1	1	0	15	0	0	12	0	0	1	0	105	0	0	0	**135**	77.8%	22.2%
	Settlement	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	**1**	100.0%	0.0%
	Water	0	0	0	1	0	0	2	0	0	3	0	0	0	40	0	**46**	87.0%	13.0%
	Young regeneration forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**	100.0%	0.0%
	TOTAL	**712**	**69**	**10**	**4407**	**13**	**333**	**1889**	**213**	**26**	**202**	**278**	**106**	**1**	**40**	**1**	**7781**		
	Precision / Users Acc.	96.1%	97.1%	100.0%	92.9%	100.0%	97.6%	92.2%	99.1%	100.0%	92.6%	99.6%	99.1%	100.0%	100.0%	100.0%		8300	
	Commission Errors	3.9%	2.9%	0.0%	7.1%	0.0%	2.4%	7.8%	0.9%	0.0%	7.4%	0.4%	0.9%	0.0%	0.0%	0.0%			
	Overall Accuracy																		**93.75%**

Table A-3

Confusion matrix for algorithm validation

Confusion matrix showing the number of pixels that are correctly identified by the algorithm during the validation process (predicted) for the input (observed) land use classes, indicated by the blue cells for each land use type.

		Predicted																
	VALIDATION	Acacia plantation	Bushes	Eucalyptus plantation	High density forest	Low density forest	Medium density forest	Mixed agriculture	Oil palm	Oil palm plantation	Open land	Rubber plantation	Scrub	Settlement	Water	Young regeneration forest	TOTAL	Sensitivity / Producers Acc.	Omission Errors
Observed	Acacia plantation	79	1	0	97	0	2	17	0	0	1	0	0	0	0	0	**197**	40.1%	59.9%
	Bushes	0	0	0	10	0	0	9	1	0	0	0	0	0	0	0	**20**	0.0%	100.0%
	Eucalyptus plantation	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	**5**	0.0%	100.0%
	High density forest	34	1	0	925	0	5	93	3	0	0	0	0	0	1	0	**1062**	87.1%	12.9%
	Low density forest	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	**3**	0.0%	100.0%
	Medium density forest	3	0	0	49	0	9	22	1	0	0	1	0	0	0	0	**85**	10.6%	89.4%
	Mixed agriculture	15	1	0	144	2	6	226	6	0	3	7	1	0	0	0	**411**	55.0%	45.0%
	Oil palm	3	0	0	31	0	2	23	1	0	2	0	1	0	0	0	**63**	1.6%	98.4%
	Oil palm plantation	0	0	0	6	0	1	2	0	0	0	0	0	0	0	0	**9**	0.0%	100.0%
	Open land	0	0	0	8	0	0	15	0	0	19	2	0	0	1	0	**45**	42.2%	57.8%
	Rubber plantation	1	1	0	13	0	0	53	0	0	5	10	0	0	0	0	**83**	12.0%	88.0%
	Scrub	2	0	0	16	1	2	20	0	0	0	0	1	0	0	0	**42**	2.4%	97.6%
	Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0.0%	100.0%
	Water	0	0	0	4	0	0	1	0	0	4	0	0	0	7	0	**16**	43.8%	56.3%
	Young regeneration forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0.0%	100.0%
	TOTAL	**138**	**4**	**0**	**1307**	**3**	**29**	**482**	**12**	**0**	**34**	**20**	**3**	**0**	**9**	**0**	**1277**		
	Precision / Users Acc.	57.2%	0.0%	0.0%	70.8%	0.0%	31.0%	46.9%	8.3%	0.0%	55.9%	50.0%	33.3%	0.0%	77.8%	0.0%		2041	
	Commission Errors	42.8%	100.0%	100.0%	29.2%	100.0%	69.0%	53.1%	91.7%	100.0%	44.1%	50.0%	66.7%	100.0%	22.2%	100.0%			
	Overall Accuracy																		**62.57%**

Analysis III:

Ecosystem services valuation

Target question:

- What is the estimated monetary value of the ecosystem services provided by the site?

Key learnings:

- Primary forests have the highest value in the ecosystem services they provide for the site
- The benefit transfer method should only be viewed as a rough estimate of monetary value, rather than a direct valuation of the site's natural capital

There are many different types of analyses stemming from land use classification maps that can contribute to biodiversity valuation. One such technique involves a monetary valuation of the ecosystem services provided by the landscape. As discussed previously, the benefit transfer method can be applied to roughly estimate the total economic value (TEV) of ecosystems where primary valuation data is not available.

A 2019 study by Sharma et al. applied this approach to estimate the TEV of oil palm plantations in West Kalimantan, Indonesia, using average global values for each of the ecosystem service types (provisioning, regulating, maintaining, and cultural) in tropical biomes. With the land use classes of this study being very similar to those of the Beta Project (Table A-4), the same values were applied to perform a benefit transfer assessment.

Table A-4

Land use classes used for benefit transfer assessment

Rubber
Agriculture
Other plantations
Forest (Primary)
Forest (Secondary)
Palm oil
Roads
Villages
Water
Shrub
Bare Area

A land use classification map of the Beta Project's site was used to calculate the total area for each land use class. The per-hectare value for each ecosystem service category, referenced from Sharma et al., were summed for each of the land use classes. The TEV of the project site was then calculated as follows:

$$TEV = \sum_{(c=1)}^{n} A*V$$

Where:

TEV = Total Economic Value (USD/yr)
A = Area covered by each land use class (ha)
V = Value of all ecosystem services for each land use class (USD/ha/yr)
c = Land use class

The valuation process shows that the project site produced an estimated value of USD234 million in the ecosystem services it provides, averaging to USD4,033 per hectare. While this value is a big-picture estimate at best, the breakdown in economic values attributed to each land use class provides useful insights into the additional value that can be generated through actions to conserve and restore biodiversity.

The total economic value provided by primary (intact) forests, for instance, is more than double that of secondary (regrowth) forests and ten times the estimated value of rubber plantations. Though the monetary value of forests is not typically represented in investments, this analysis highlights the additional value that sustainable land use projects provide.

These results yield valuable insights for informing biodiversity and land use management strategies for future application to ACLF. For example, even if the Beta Project were to maintain the same amount of commodity production area, there would still be large economic benefits that arise from the recovery of degraded open land to shrubland, or from shrubland to regrowth forests.

Through the restoration and improved health of these habitats, the value provided by regulating and maintaining services will continue to increase as the ecosystems are able to store more carbon, better regulate nutrients, buffer communities from natural disasters, and more. Demonstrating the additional gains through ecosystem services valuation is another useful tool in the biodiversity accounting process that complements all the aforementioned metrics that describe changes in habitat, species, and land use.

There are several limitations to the ecosystem services valuation we performed that would warrant further refining going forward.

- The relevance of these valuations is dependent on the underlying land use maps that they are calculated from, and how accurately they represent each land use class. This could be addressed in the future through the use of more accurate land use classifications with the Earth Blox workflow described previously.

- The values applied for benefit transfer are, by nature, not derived from the site itself. Ecosystem services that are unique to the Beta Project site are therefore not taken into account into the valuation. Much like the biodiversity accounting framework has a place for both global and local indicators, the ecosystem services valuation process can better represent the site's true value when site-specific data are taken into account.

- If ecosystem services valuation was to take place at regular intervals in the future, it is crucial that the land use maps are also updated to reflect any changes in the different land use classes throughout the site. The automated land use classification process could be a complementary approach to fill this data gap.

Despite these limitations, the application of ecosystem services valuation provides another facet by which the biodiversity of investment projects can be monitored. As our accounting process develops further and we generate more granular and precise data characterising the landscape, we expect that these monetary values will be quantified with greater accuracy.

These efforts will be expedited with concurrent initiatives on the broader biodiversity landscape that bridge academic expertise with industry practitioners (e.g., the NGFS platform, Stanford University's Natural Capital Project) to better inform ecosystem services valuation processes.

Analysis IV:

Measuring changes in time with satellite data

Target question:

- How successful has the Beta Project been in preserving habitats that support biodiversity?

Key learnings:

- Satellite data shows overall gains in vegetation across the site, signalling a positive trend for biodiversity impact
- Consulting local teams and obtaining ground-truthing data is crucial in making accurate interpretations of remotely sensed data

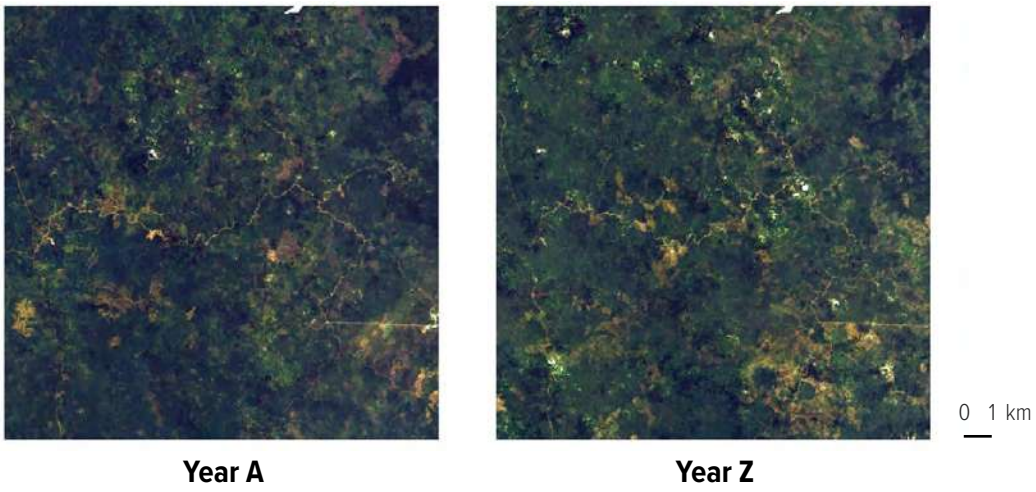
The analysis of historical satellite imagery can provide spatial comparisons of how vegetation has changed throughout the duration of the project. For this analysis, we retrieved Landsat 8 satellite imagery from Earth Blox to compare the site's surrounding landscape in the year prior to engagement in the project (referred to as 'Year A') and with the landscape on the project's final year of engagement (referred to as 'Year Z').

The two satellite images were produced as composites averaged over the course of the year, smoothing out any seasonally-driven differences in vegetation. It can be seen from initial observations that some parts of the landscape that were more barren in Year A have increased in vegetation cover by Year Z, or vice versa (Figure A-1).

While this type of satellite imagery is useful in providing a bird's eye view of how the landscape looks at a certain point in time, it is still challenging to distinctly quantify how much change has taken place through visual comparison alone. This is where additional satellite data products (such as infrared or multispectral imagery) can be employed to provide quantitative, rather than qualitative, insights.

Figure A-1

Satellite imagery comparison of part of the Beta Project site

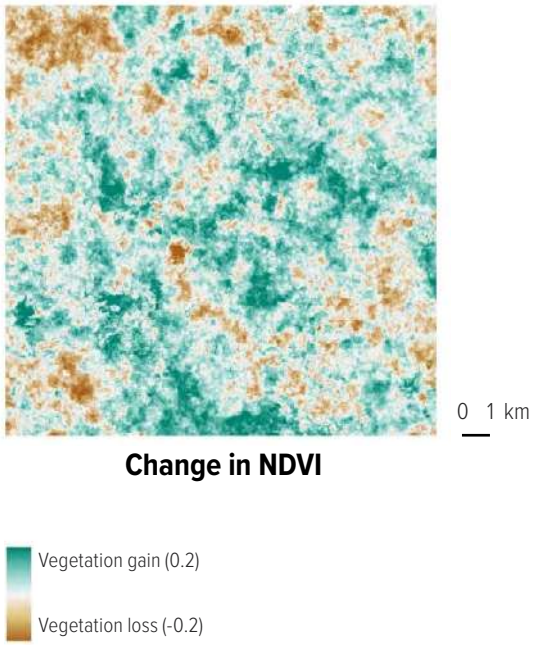


One such remote sensing product, known as the Normalised Difference Vegetation Index (NDVI), is commonly used to model changes in live vegetation across the landscape. NDVI is calculated through measurements of visible and near-infrared wavelengths detected by satellites.[76] They are often pre-packaged by remote sensing databases (e.g., from the Landsat or MODIS satellites) and provided as directly downloadable spatial data files (hence the name remote sensing products). High NDVI values indicate dense vegetation or crops in their peak growth stage, whereas low values indicate sparse vegetation or crops in the later stage of their life cycles.[77]

The Earth Blox platform was used to calculate NDVI at the site (with a 5km surrounding buffer) and mean annual values were compared between Year A and Year Z. The geospatial change in NDVI was then calculated on GIS to identify areas that have gained and lost vegetation in relation to the 2017 baseline (Figure A-2).[78]

Figure A-2

Change in vegetation across a portion of the Beta Project between Year A and Year Z, as measured by NDVI



The resulting changes in NDVI can be caused by any number of changes in vegetation – man-made or natural. Therefore, site-based context on how the landscape has been utilised during the project is crucial for understanding the observed changes. The Beta Project's team were able to share prior land cover assessment data that suited this purpose, once again highlighting the importance in data sharing in aiding the execution of biodiversity assessments.

Consultation with the Beta Project's team and documentation of historical land use showed that areas that exhibited the greatest reduction in vegetation cover throughout the project period likely arose from planting or other land use by smallholder farmers that are not involved with the project. This result could emphasise the need to monitor and mitigate any land tenure conflicts arising from unsanctioned land claiming, which would be useful for ACLF projects involved in similar contexts.

Much of the areas of vegetation gain identified in analysis overlapped with areas that the Beta Project dedicated for wildlife conservation and habitat protection. The increase in vegetation cover detected in the project area suggest that these conservation efforts have been successful in preventing habitat loss for endangered species and have even led to regeneration and increased density of vegetation in certain areas.

As demonstrated with this test-case for the Beta Project, remote sensing products such as NDVI will serve as a key indicator for tracking the progress and impact of sustainable agroforestry and biodiversity conservation strategies. Annual NDVI calculations, in conjunction with context provided by ground-based land use data, could be used to monitor changes in vegetation and habitat for ACLF projects.

9. Endnotes

1. Burki & Tahir (2022)
2. Ibid.
3. McKinsey (2020)
4. Rainforest Action Network (n.d.)
5. Whiting (2022)
6. Convention on Biological Diversity (2006)
7. These categories have been adopted by industry standards and alliances such as the TNFD.
8. Buotte et al. (2019); Chen et al. (2018); Hicks et al. (2014)
9. Greenfield & Weston (2021)
10. IPBES (2019)
11. IPBES (2019), Almond et al. (2022)
12. Ibid.
13. Hughes (2017)
14. The World Economic Forum and PwC (2020)
15. Principle Adverse Impacts are defined as "negative, material, or likely to be material effects on sustainability factors that are caused, compounded by or directly linked to investment decisions and advice performed by the legal entity." See more at: https://finance.ec.europa.eu/sustainable-finance/disclosures/sustainability-related-disclosure-financial-services-sector_en.
16. Bradbury et al. (2021)
17. The World Economic Forum (2020)
18. IUCN (2021)
19. UK Parliamentary Office of Science & Technology (2011)
20. CPIC (2022)
21. Deutz A et al. (2020)
22. See Nature-based Insetting as an example: https://www.naturebasedinsetting.com/.
23. The World Economic Forum and PwC (2020)
24. Mace et al. (2018)
25. Principles for Responsible Investment (2020)
26. 'Nature positive' refers to enhancing the resilience of our planet and societies to halt and reverse nature loss, while 'net zero' refers to achieving a balance between the amount of emissions production and reduction. The Global Goal for Nature, proposed by a coalition of the world's leading conservation organisations, has defined a target for zero net loss of nature from 2020, net positive by 2030, and full recovery by 2050. For more information, see: Charting a course to nature positive (The Biodiversity Consultancy, 2022).
27. EU (2020)
28. University of Oxford (2022). Examples of nature-based solutions being implemented around the world can be viewed on the University' Nature-Based Solutions Initiative case study platform: https://casestudies.naturebasedsolutionsinitiative.org/.
29. Global Commission on Adaptation (2019)
30. CSBI (2015)
31. European Council (2022)
32. EU (2019)
33. EU (2020)
34. TNFD (2022)
35. The EU is requiring financial institutions to disclose climate-related information under the European Banking Authority's standards by early 2023, while the US Securities and Exchange Commission (SEC) has proposed rule changes to require registrants to include climate-related disclosures for the 2023 fiscal year. In Asia, Singapore is mandating climate reporting from 2022 and the Hong Kong's Monetary Authority has set expectations for companies to produce TCFD-aligned disclosures by 2025.
36. PRI (2019)
37. Stephens et al. (2014)
38. Ibid.
39. Patterson et al. (2022)
40. Ibid.
41. Example: see NatureMetrics, a start-up offering eDNA analytical services, and Pivotal Future, a start-up providing scalable biodiversity data analytics and assessment, based on datasets sourced from high tech monitoring.
42. Example: see Chloris Geospatial, a start-up applying machine learning algorithms to advanced remote sensing technologies for carbon stock assessments.
43. Other organisations have also compiled lists of relevant resources for nature and biodiversity-related data. See: 'Guidelines for planning and monitoring corporate biodiversity performance' (IUCN), 'A Landscape Assessment of Nature-related Data and Analytics Availability' (TNFD), and publications by the Finance for Biodiversity Pledge.
44. More information at: https://www.iucn.org/resources/conservation-tool/iucn-red-list-threatened-species
45. More information at: https://www.ibat-alliance.org/pdf/wdpa_manual.pdf
46. More information at: https://portals.iucn.org/library/sites/library/files/documents/2016-048.pdf
47. At the time of writing, the metrics selected for our framework were free to use under a Beta Programme. However, future users may need to pay subscription fees depending on the capacity and purpose of use.
48. The term 'polygon', used in the context of GIS, refers to a shape defined by a connected sequence of geospatial coordinates. Polygons are used to define boundaries and static objects on maps, such as city boundaries, national park areas, or the bodies of water.
49. Costanza et al. (1997)
50. UK Dept. for Environment, Food and Rural Affairs (2007)
51. Gro Intelligence (2016)
52. UN FAO (2013)
53. Pamplona (2016)
54. Project Drawdown (2022)
55. Ibid.
56. Sulistiyono & Mulyono (2019)
57. Statistics Indonesia (2021)
58. Calculations based from: Bose HK (2019) Grow bamboo, capture carbon.
59. Planet Tracker (2020)
60. Delphino M (2022)
61. Supriatna J et al. (2017)
62. Wulandari et al. (2022)

63. With the exception of the Coffee Project, which had two sites with the exact coordinates provided for the farm locations. In this case, the STAR was run for the farm areas at each site, which was smaller than most subdistricts.
64. Nater et al. (2017)
65. Source: EC JRC, accessed from: https://forobs.jrc.ec.europa.eu/TMF/.
66. This analysis was performed by clipping the raster layer to a 15km buffer polygon surrounding the sites using the 'Clip raster by mask layer' tool, then counting pixel values with the 'Raster layer unique values report' tool on QGIS3 (v.3.2.22)
67. Hansen et al. 2013; An important caveat to this dataset is that it only shows loss in forest cover and does not include information about gains in forest cover.
68. This analysis was performed using the Raster Calculator processing tool on QGIS3 (v.3.2.22)
69. Protected Area and Key Biodiversity Area data downloaded from the Integrated Biodiversity Assessment Tool (IBAT) (http://www.ibatforbusiness.org). Provided by BirdLife International, Conservation International, IUCN and UNEP-WCMC. Please contact ibat@ibat-alliance.org forfurther information.
70. Data source: BirdLife International (2021) World Database of Key Biodiversity Areas. Developed by the KBA Partnership: BirdLife International, International Union for the Conservation of Nature, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, Wildlife Conservation Society and World Wildlife Fund. September 2021 version. Available at http://keybiodiversityareas.org/kba-data/request.
71. The expert consulted was Dr. Frank Hawkins (Policy Advisor, IUCN)
72. The species in Category A are: *C. bennettii, D. brooksi, H. orbiculus, M. rajah, M. whiteheadi, M. wetmorei, P. genibarbis, P. setosus, and P. pulverulentus*. The species in Category B are: *A. scutulata, C. sumatrensis, C. alpinus, H. personatus, P. planiceps, R. corrugatus, and T. cristatus*.
73. Patterson et al. (2022)
74. This algorithm development process is still ongoing at the time of writing.
75. Richards JA (2013)
76. USGS (2018)
77. NDVI values range between -1 and 1, with negative values indicating clouds or water. Positive values near zero indicate bare soil, while. values above 0.6 typically indicate dense green vegetation.
78. This analysis was performed by subtracting the two raster layers using the Raster Calculator processing tool on QGIS3 (v.3.2.22).



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