Biodiversity Risk and Conservation Finance: A Quantitative Framework for Evaluating Ecological and Economic Synergies

Abstract

Biodiversity loss and climate variability are increasingly discussed as potential sources of economic and financial risk, yet there is limited empirical work on how conservation-finance mechanisms relate to ecological and macroeconomic conditions. This paper introduces a quantitative framework, based on a synergy-degree approach, to examine how financial inflows into conservation align with changes in forest loss, temperature variability, and economic-political stability. The analysis focuses on two long-standing conservation funds, the Bwindi Mgahinga Conservation Trust in Uganda and the Guanacaste Dry Forest Conservation Fund in Costa Rica, using annual data on fund revenues, ecological indicators, and broad macro-institutional measures.

The results show fluctuating and region-specific patterns of interaction between conservation funding, ecological trends, and socio-economic conditions, rather than a consistent stabilizing or destabilizing relationship. A comparative assessment of the two mechanisms suggests some common dynamics, but also differences shaped by local climate exposure and institutional context. While the model does not establish causal effects, it offers a structured way to examine how conservation-finance activities move in relation to ecological and economic variables over time. The findings may be useful for researchers and practitioners interested in how conservation finance behaves within broader climate- and nature-related systems.

I. Introduction

Biodiversity loss is increasingly recognized not only as an ecological concern but also as a source of economic and financial risk. Degraded ecosystems can affect supply chains, tourism, agricultural productivity, and the stability of communities that depend on natural resources. These channels have implications for credit, fiscal, and market conditions, yet the financial literature has only recently begun to incorporate nature-related risks into broader assessments of financial stability. Compared with climate-related financial risks, where tools such as stress testing, transition-risk metrics, and asset-pricing studies have developed rapidly but the biodiversity dimension remains less explored and is supported by fewer empirical datasets.

Central banks and financial supervisors are beginning to integrate nature-related risks into macroprudential analysis. The Network for Greening the Financial System (NGFS) has incorporated biodiversity into its scenario design, acknowledging that the degradation of natural capital can act as both a physical and transition risk. Empirical work at the national level, such as Van Toor et al. (2021) for the Netherlands and Freystätter et al. (2024) for Finland, suggests that biodiversity degradation can amplify credit stress in banking systems. Yet few studies measure how conservation-finance mechanisms themselves interact with ecological and economic systems, or whether they exhibit stabilizing dynamics similar to hedging instruments in financial portfolios

In financial markets literature, the idea that non-traditional exposures (e.g. pollution, climate) carry risk premia has already gained traction. Delis, de Greiff, Iosifidi & Ongena (2024) show that transition risk is priced in bank loans, with firms exposed to fossil-fuel reserves paying higher spreads. Similarly, Kosmidou, Kousenidis, Ladas & Negkakis (2024) document that climate-related performance affects stock-price crash risk, highlighting how environmental shocks generate asymmetric downside risk.

These studies help bridge environmental externalities and market outcomes; we seek to do the same for biodiversity finance, but along a different dimension. Instead of measuring ex post pricing, we measure co-movement and systemic interdependencies between conservation finance, ecological variables, and macro-economic indicators.

This paper contributes to this discussion by examining how two long-standing conservation-finance mechanisms—the Bwindi Mgahinga Conservation Trust (Uganda) and the Guanacaste Dry Forest Conservation Fund (Costa Rica)—interact with ecological and macroeconomic variables. We develop a synergy-degree framework to track how fund revenues, forest-cover change, temperature variability, and economic-political stability move relative to each other, without making causal claims. The approach allows us to observe periods when conservation investments appear to move in alignment with ecological improvement or deterioration, and periods when the relationships are less consistent.

By focusing on two different institutional and ecological settings, the study offers a comparative perspective on how conservation finance relates to changing climate and biodiversity conditions. The analysis is intended as a structured, data-driven way to explore the behaviour of conservation-finance mechanisms within broader climate- and nature-related systems, and to provide a foundation for future empirical and policy-oriented research in this area.

The remainder of the paper is structured as follows. Section II introduces the key concepts and financing mechanisms that form the basis of the analysis. Section III reviews related literature on biodiversity finance, climate variability, and systemic-risk linkages. Section IV describes the data sources, variable construction, and the synergy-degree methodology. Section V presents the empirical results for each conservation-finance mechanism and the cross-mechanism comparison, followed by a discussion of their implications. Section VI concludes with limitations and potential avenues for future research, including opportunities to incorporate causal-inference and machine-learning approaches into the study of biodiversity–finance interactions.

II. Background

This section provides a short overview of the concepts that inform the study and a factual description of the two conservation-finance mechanisms we analyse. The aim is not to survey the landscape exhaustively but to clarify how the mechanisms operate and why they are suitable cases for examining interactions between conservation finance, ecological conditions, and broader economic environments.

II.i Key Concepts

Innovative finance generally refers to financial structures designed to mobilize capital for public-good objectives through mechanisms that differ from conventional donor funding. Rather than relying on annual budget allocations, these approaches emphasise long-term funding, diversified sources of capital, and incentive structures that can link financing to outcomes.

The term gained currency in the early 2000s, with Panayotou (2002) using it in the context of mobilising non-traditional resources for the MDGs (UN, 2000). (Panayotou, 2002). Examples since then include applications to epidemic response and sustainability initiatives, as well as SDG-oriented projects. (Seth, 2021).

Impact investment models supply upfront capital for activities expected to generate measurable social or environmental outcomes, with repayment typically tied to **verified results**. This includes arrangements where an **outcome payer**, often a government agency in social impact bonds or a philanthropic/donor entity in development impact bonds, pays only if agreed outcomes are achieved

(So & Staskevicius, 2015; Government Outcomes Lab, n.d.; Brookings, 2015).
Although most examples come from social-sector applications, the framework helps clarify how conservation funds differ from traditional project grants: they prioritise outcomes, continuous performance monitoring, and financial discipline.

Conservation finance vehicles seek to generate environmental benefits while maintaining some degree of financial discipline, such as capital preservation or modest investment returns. In practice, the field includes a wide range of arrangements, from philanthropic endowments to debt-for-nature swaps. The two funds examined in this study fall toward the "hybrid" end of the spectrum: although dependent on donor contributions, both operate with investment portfolios and multi-year planning horizons.

E*nvironmental trust funds* are institutional structures created to manage and allocate financial resources for conservation purposes. They typically take the form of endowment funds which are intended to preserve capital while financing activities from investment income, or sinking funds which disburse capital over a fixed horizon. Both models are used in biodiversity conservation, often in lower-income countries where protected-area agencies confront chronic budget shortfalls.

II.ii Mechanisms Examined

II.ii.i Mgahinga and Bwindi Impenetrable Forest Conservation Trust, Uganda

Established in the mid-1990s, the Bwindi–Mgahinga Conservation Trust (BMCT) was one of the earliest conservation-trust-fund experiments in Africa. The initial capitalisation combined support from the Global Environment Facility, USAID, and bilateral donors. Over time, the Trust has blended endowment-style management with periodic injections of grant finance and smaller contributions from NGOs.

BMCT funds three main areas of work: community development projects proposed by groups in park-adjacent areas; park-management activities such as patrolling and boundary maintenance; and research and ecological monitoring, especially on mountain gorillas and associated forest ecosystems.

Although the Trust's activities are widely regarded as important for local livelihoods, assessments have noted that the emphasis on social-sector projects sometimes dilutes the direct ecological focus. BMCT has adjusted its programming at various points, for example by expanding agroforestry components and introducing energy-saving technologies to integrate community objectives with conservation outcomes. Because the Trust operates in a context of fluctuating donor flows, fragile-state governance, and variable ecological pressures, it offers a useful case for studying how conservation finance interacts with ecological and macro-institutional conditions over time.

From the period of 1999 to 2009, the national parks received USD 17 Million from USAID's PrimeWest project, USD 4 Million from the Danish Development Agency (DANIDA), and USD 1.22 Million from the MacArthur Foundation and Wildlife Conservation Society, with the Trust being only one of the important actors in the parks. To date, community conservation for the protection and management of wildlife has been adopted by many African countries to involve local communities to participate in decision-making and management of protected areas (Byaruhanga, 2008).

On the conservation front, the Trust supports conservation activities directly through incremental support for park management and related research activities while indirectly supporting through grants to local community groups to develop economic activities that provide alternative means of subsistence traditionally met by harvesting forest resources (Dannels, 2018). Tourism programmes (such as the Buhoma Village Walk established in 2002 in the community adjacent to Buhoma gate

and Park headquarters) have also been funded by the Trust along with revenue sharing programmes for local development (Twinamatsiko et al., 2019). The Trust has also driven up tourist potential and instituted tourism as one of the key growth sectors of the economy of the region since currently, the Gorilla flagship tourism of the Bwindi and Mgahinga National Parks accounts for about 60% of Uganda Wildlife Authority's revenue (Bakiika et al., 2020).

II.ii.ii Guanacaste Dry Forest Conservation Fund, Costa Rica

The Guanacaste Dry Forest Conservation Fund (GDFCF), created in 1997, supports conservation activities within the Área de Conservación Guanacaste (ACG), an area spanning several linked ecosystems in north-western Costa Rica. The fund combines land-acquisition efforts, biodiversity inventory programmes, education initiatives, and the long-running parataxonomist programme, which trains local residents to conduct ecological research and specimen collection.

GDFCF revenue largely supports scientific and monitoring work, the maintenance of research stations, and the barcoding programme used for biodiversity documentation. A smaller share funds land purchases to maintain ecosystem connectivity. Unlike BMCT, the fund operates in a relatively stable political environment with higher per-capita income and a well-established conservation sector, though the region faces significant climate-related pressures such as wildfire risk and erratic rainfall.

II.iii. Rationale for Case Selection

The two mechanisms differ in ecological context, institutional history, and funding composition, but they share several features that make them analytically comparable:

- Both operate as long-standing conservation-finance institutions with multi-year funding flows.
- Both serve ecosystems facing climate-related stressors—temperature variability, altered precipitation patterns, and habitat loss.
- Both allocate resources across ecological management, research, and community-facing activities, though with different emphases.
- Both provide sufficiently long time series of financial, ecological, and macro-institutional indicators for a synergy-degree analysis.

Given these attributes, the mechanisms allow us to explore how conservation finance moves relative to ecological and economic conditions in two contrasting but structurally comparable settings. This comparative lens is meant to illuminate patterns of co-movement rather than to draw causal conclusions.

III. Literature Review

III.i Climate–biodiversity interactions and implications for conservation

A large body of evidence links biodiversity loss to multiple direct drivers, including land/sea-use change, direct exploitation, climate change, pollution, and invasive species. The IPBES Global Assessment synthesizes these drivers and documents continuing declines in nature's contributions to people, including risks to food systems and coastal protection.

For climate specifically, impacts are multidimensional: beyond shifts in mean temperature and precipitation, systems experience changes in extremes, seasonal timing, spatial redistribution of climates, "novel" climate emergence, and velocity of change. These dimensions map onto distinct

ecological stresses and adaptation needs. In combination with land-cover change, climate change can amplify extinction risks and alter the spatial pattern of threats; global modelling indicates that interactions can increase the impact of habitat loss on birds and mammals by up to 43% and 24%, respectively.

Given data gaps for many species and regions, conservation planners often rely on species distribution models (SDMs) and climate metrics as first-order assessments, while acknowledging limits (e.g., presence-only data, transferability, and biotic interactions). In practice, adaptation planning frameworks emphasize clear problem framing, forward-looking goals, uncertainty management, and iterative monitoring. Two commonly used references are the Climate-Smart Conservation guide (National Wildlife Federation) and the Adaptation for Conservation Targets (ACT) framework; both provide stepwise processes to link actions to climate impacts and to structure decisions where projections are uncertain. Both provide step-by-step ways to link actions to climate impacts and to plan under uncertainty. Table 1 summarises these frameworks and shows the decision logic that informs our indicator choices.

Table 1. Common conservation–adaptation frameworks used in biodiversity planning and their decision logic (illustrative summary of core steps and how each handles uncertainty).

Adaptation for Conservation Targets	Identifying the conservation feature of interest and objectives ↓ Building a conceptual model for assessing the impacts of future scenarios ↓ Identifying management options, prioritizing actions, implementation, and monitoring
Climate-Smart Conservation	Defining conservation objectives ↓ Identifying climate vulnerabilities and revising objectives ↓ Identifying management options, prioritizing actions, implementation, and monitoring
Portfolio Decision Analysis	Identifying natural and human aspects of interest ↓ Determining vulnerabilities and risks to assets ↓ Identifying potential management actions and quantifying the effectiveness and cost of management actions ↓

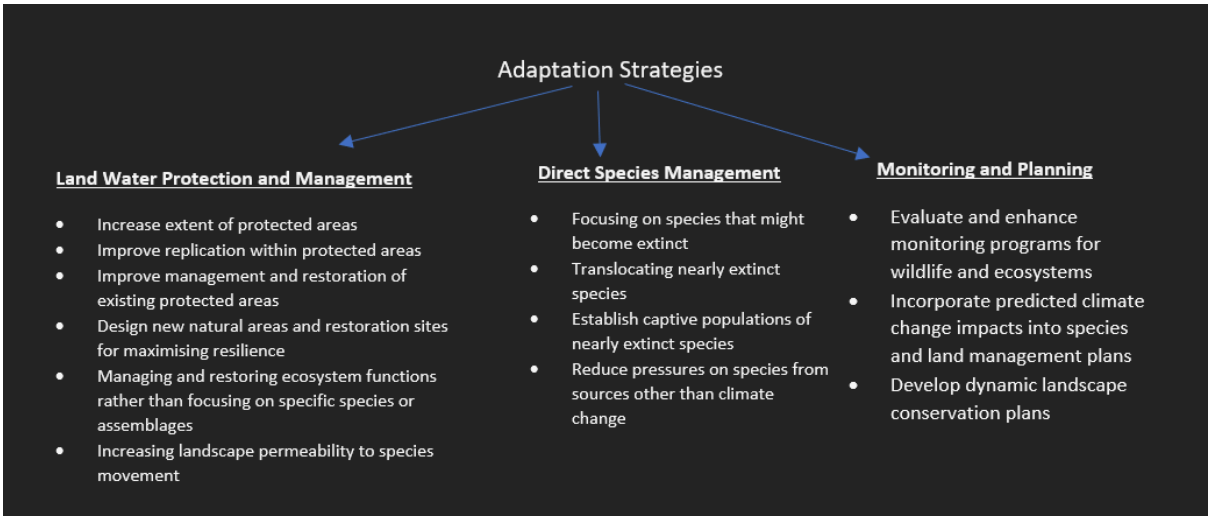
	Determining the optimal set of management actions given the budget constraints

Table 1: Alternative Frameworks for Biodiversity Climate Change Adaptation

Drawing on the decision logic summarized in Table 1, we adopt simple, comparable indicators of ecological exposure (forest loss; temperature variability) and interpret relationships as co-movement rather than causal effects.

In practical terms, adaptation guidance in biodiversity conservation typically groups management responses into a few broad families: land and water protection and management, direct species management, and monitoring and planning measures. These strategy families appear across many applied frameworks and serve as a high-level organising structure for conservation actions under climate pressure (e.g., Mawdsley et al., 2009; Stein et al., 2014). Figure 1 provides a simple illustration of these major strategy categories.

Figure 1. Major categories of biodiversity-adaptation strategies.



Drawing on the broad strategy categories illustrated in Figure 1, we focus on a small set of simple, comparable ecological indicators in the empirical analysis.

III.ii Financing Biodiversity Conservation: what we know

Global reviews agree that biodiversity finance remains insufficient, and that better tracking and disclosure are needed. The OECD's comprehensive overview (2020) compiles public and private biodiversity-related flows and highlights the need to scale up positive finance and reduce harmful support that undermines biodiversity. Complementing this, Financing Nature (Paulson Institute–TNC–Cornell, 2020) estimates an annual financing gap of roughly US$598–824 billion by 2030 and identifies a menu of reforms spanning subsidy reform, fiscal tools, green financial products, nature-based solutions, and supply-chain standards.

Within this landscape, conservation trust funds (CTFs) have emerged as long-horizon vehicles that blend endowments, sinking funds, and revolving instruments to support protected areas, research, and community programs. The Conservation Finance Alliance Practice Standards (2020 update) codify governance, asset management, monitoring, and resource-mobilization norms for CTFs, reflecting their evolution as multi-fund institutions.

The policy debate has also shifted toward mobilizing private capital. A World Bank Group paper outlines five avenues to integrate biodiversity risk and opportunities into private-sector decisions—environmental fiscal reform, national biodiversity data/planning, support for TNFD-style disclosures, investor engagement ("Nature Action 100"), and catalytic capital. These recommendations align with calls from OECD and others for improved metrics and reporting, which remain prerequisites for scaling and evaluating nature-related finance.

III.iii. Empirical gaps relevant to this study

Even with expanding work on policy and finance, we still lack long-term studies showing how conservation-finance inflows move with ecological and macro-institutional trends.

Reviews emphasize the need for better tracking of biodiversity-relevant spending, standardized taxonomies, and evaluation protocols that allow comparison across funding vehicles and contexts. Practice standards for CTFs focus on governance and fiduciary issues, but time-series evidence on co-movement between revenues, ecological pressures, and macro-stability is sparse—motivating our descriptive framework.

Our contribution is therefore modest and specific: we assemble annual series for two long-standing funds operating in distinct ecological and institutional settings, and apply a synergy-degree approach to characterize co-movements among fund revenues, forest-loss and temperature variability metrics, and macro-institutional indicators—without making causal claims. This provides a structured way to examine how conservation-finance activity moves relative to ecological conditions and economic-political stability over time, in line with calls for better data and transparent methods.

IV. Methodology and Data

IV.1. Objective and design

Our objective is descriptive: to examine co-movement between conservation-finance inflows and selected ecological and macro-institutional indicators over time for two long-standing funds (BMCT, GDFCF). We do not estimate causal effects. Instead, we apply a synergy-degree framework that summarises how pairs of subsystems move together across discrete time intervals.

IV.2. Systems, subsystems, and variables

For each fund $mechanism$, we treat three subsystems:

- Finance subsystem: annual fund revenues (nominal currency, as reported by the fund).
- Ecological subsystem: (i) primary forest loss (hectares per year) in the relevant geography; (ii) temperature variability, proxied by a standardised Euclidean distance between current-year monthly temperatures and a baseline year.
- Macro-institutional subsystem: (i) GDP per capita (current USD); (ii) Stability Index defined as $1 - Fragile\ States\ Index\ (rescaled)$.

We use annual frequency to align financial reporting with widely available ecological and macro series. Results are reported per mechanism and then compared across mechanisms.

Geographies covered are:
BMCT: administrative units covering the Bwindi–Mgahinga landscape (Uganda).
GDFCF: the Área de Conservación Guanacaste region (Costa Rica).

IV.4. Pre-processing

1. Temporal alignment.
   Align all variables to calendar year t. When a fund's fiscal year differs, assign to the calendar year in which the fiscal year ends and check that the choice does not change the sign of year-to-year changes in revenues.

2. Transformation.
   We retain fund revenues in nominal terms as reported, because our interest is in year-to-year co-movement rather than the absolute (or inflation-adjusted) level of resources. To represent ecological pressure, we use annual primary forest loss measured in hectares within the relevant geography, which provides a consistent, interpretable signal of habitat change. To capture climatic variability, we summarise each year's temperature profile with a standardised Euclidean distance: for every calendar year t, we take the 12-month vector of mean temperatures and compute its distance from a chosen baseline year t_0, standardising by the baseline month-level standard deviations. The resulting single value for each year quantifies how far that year's temperature pattern departs from baseline conditions and can be compared directly across years and between locations.

$$SED_t = \sqrt{\sum_{m=1}^{12} \left(\frac{k_{m,t} - k_{m,t_0}}{\sigma_{m,t_0}} \right)^2}$$

where $k_{m,t}$ is the monthly mean temperature and σ_{m,t_0} is the baseline-year standard deviation.

3. Normalisation (0–1).
   For each variable within a mechanism, scale to $[1]$across the sample window using min–max transformation to make variables comparable in the synergy computation.
4. Sign convention.
   Where a higher raw value indicates worse conditions (e.g., forest loss; Fragile States Index), reverse-code as needed so that higher normalised values correspond to more ordered states for that subsystem. We report sign choices in an appendix.

IV.5. Weights within subsystems

To aggregate multiple indicators inside a subsystem, we use **objective weights**:

- **ENTROPY weights** (information content of each indicator);

- **CRITIC weights** (variance and inter-indicator contrast).
  For each subsystem and mechanism, we compute both sets and take their **average** to reduce sensitivity to any single weighting rule. (The ecological subsystem thus averages weights from forest-loss and temperature-variability indicators; the macro-subsystem averages GDP-per-capita and stability.)

IV.6. Ordering degree and synergy-degree computation

1. **Ordering degree (per subsystem).**
   For each year t and subsystem S, the ordering degree U_t^S is the weighted combination of the normalised indicators (linear mean and geometric mean averaged, as in prior synergy applications). Intuitively, U_t^S increases when the subsystem's indicators move toward more "ordered" states relative to the sample window.
2. **Synergy degree (between two subsystems).**
   For each pair of subsystems (e.g., Finance vs Ecology), define:
   $$\Delta U_t^{S_1} = U_t^{S_1} - U_{t-1}^{S_1}, \Delta U_t^{S_2} = U_t^{S_2} - U_{t-1}^{S_2}$$
   The synergy degree at year t is positive when $\Delta U_t^{S_1}$ and $\Delta U_t^{S_2}$ have the same sign (both improve or both deteriorate) and negative otherwise. We report annual series and simple counts of positive/negative years.
3. **Interpretation.**
   Positive synergy indicates co-movement (in the sense of both subsystems trending in the same direction that year). Negative synergy indicates divergence. We do not interpret signs as causal effects.

IV.7. Time windows and baselines

- **Sample windows.**
  Use the maximal overlapping years for which the fund's revenues and all indicators are available. We report the exact span for each mechanism in the results section.
- **Temperature baseline.**
  Choose a baseline year t_0 at the start of the sample. Robustness checks (below) shift t_0 within the first three years to confirm that inferences do not depend on the specific baseline.

IV.8. Robustness checks

- **Alternative weights.**
  Re-compute ordering degrees using Entropy-only and CRITIC-only weights; confirm that the signs of annual synergy do not systematically flip.
- **Alternative ecological scaling.**
  Replace forest-loss levels with **share of forest area lost** to check sensitivity to absolute scale; repeat synergy computation.
- **Lag structure (informal).**
  Re-compute synergy with a **one-year lag** of the ecological subsystem relative to finance; report whether the overall positive/negative counts materially change. (We avoid formal time-series models given the short panels and our descriptive aim.)
- **Outlier years.**
  Winsorise the top 1% of forest-loss observations within each geography; confirm that results are unchanged.

IV.9. Limitations

The approach is **sensitive to measurement error** and **geographic definitions** of the ecological series. Annual financial data can also reflect accounting or timing choices. Because we summarise each subsystem into a scalar ordering degree, the method trades detail for comparability and interpretability. Finally, synergy is a **co-movement** measure and should not be interpreted as evidence of impact.

V. Results

V.i) Bwindi-Mgahinga Conservation Trust (BMCT) mechanism

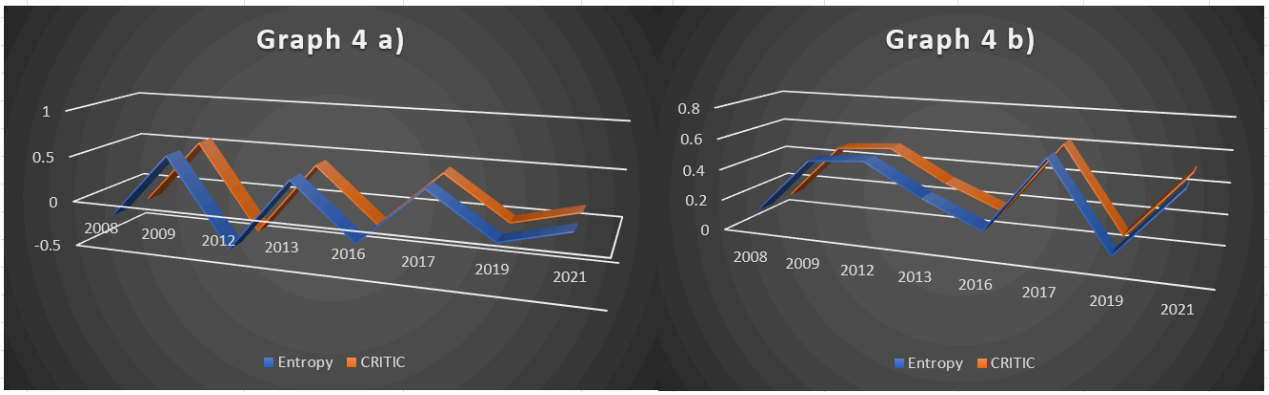


Figure 4: Synergy Degree Analysis for Bwindi Mgahinga Conservation Trust. a) shows the graph for Synergy degree between the Fund Income subsystem and the Ecological subsystem. b) shows the graph for Synergy degree between the Fund income subsystem and the Economic-Political subsystem.

For BMCT, the Finance–Ecology series alternates between positive and negative years, indicating non-persistent co-movement between revenue inflows and the ecological ordering degree over the sample window. Periods of positive synergy correspond to years in which both subsystems moved in the same direction (improvement or deterioration), whereas negative years reflect divergence. We do not interpret these signs as causal effects; they simply summarize annual co-movement.

By contrast, the Finance–Macro series is predominantly positive and generally lies in the mid-range of the synergy scale. This pattern is consistent with the notion that year-to-year movements in aggregate macro-institutional conditions (GDP per capita and stability) are more likely to trend in the same direction as movements in fund revenues, without implying any directional impact.

To aid interpretation, Appendix B reports the annual ordering degrees for each subsystem and simple counts of positive/negative years.

V.ii. Guanacaste Dry Forest Conservation Fund (GDFCF) mechanism

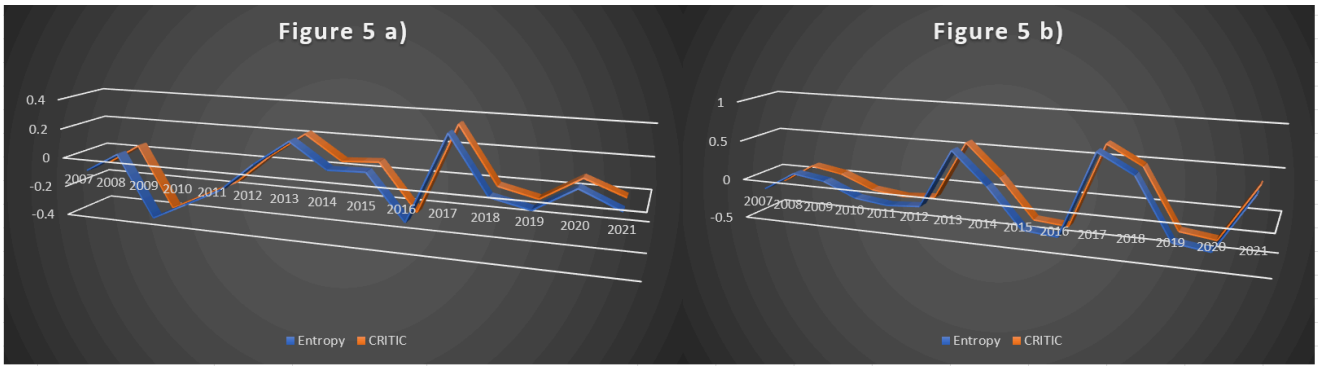


Figure 5: Synergy Degree Analysis of Guanacaste Dry Forest Conservation Fund. a) shows the graph between Fund income subsystem and Ecological subsystem. b) shows the graph between Fund income subsystem and Economic-Political subsystem.

For GDFCF, the Finance–Ecology synergy appears irregular across years, with sign changes that reflect the combined behaviour of primary-forest-loss and temperature-variability indicators relative to revenue movements. Given the ecological setting—where interannual climate variability and disturbance risk can be pronounced—this irregularity in co-movement is unsurprising. As with BMCT, we do not assign directionality or impact to the signs.

The Finance–Macro series shows modest, mixed co-movement over time. This is compatible with relatively stable macro-institutional conditions and revenue flows that can fluctuate due to idiosyncratic fundraising cycles, project timing, or accounting periods. Again, synergy captures only the sign of annual co-movement, not its causes.

V.iii Cross-mechanism comparison

After analysing the synergy degrees within both of the mechanisms independently, we now study the synergy degree between the two mechanisms (Figure 6).

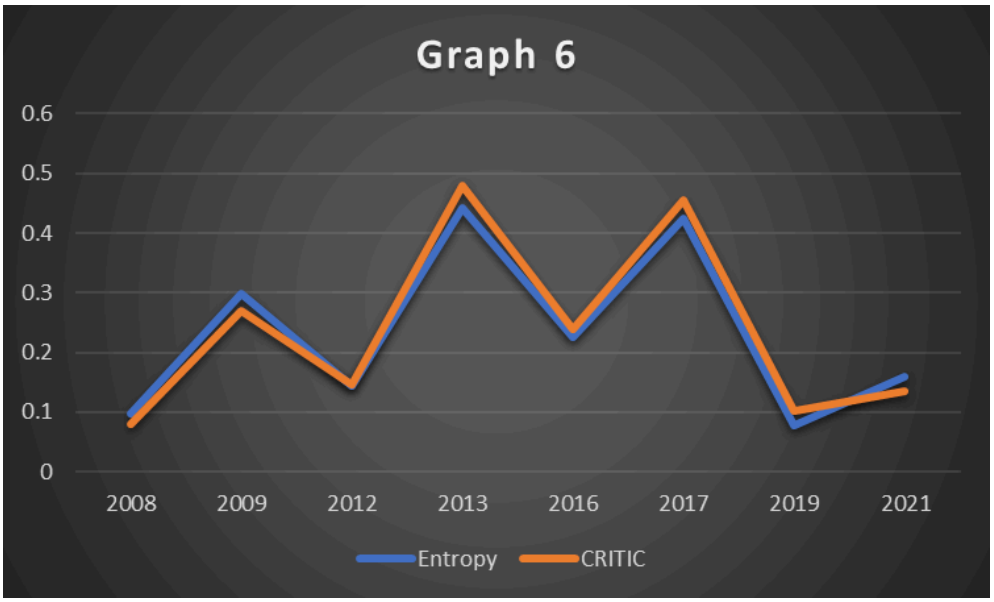


Figure 6: Synergy degree between BMCT and GDFCF ordering degrees (mechanism-to-mechanism comparison). Positive values indicate years when the two mechanisms' ordering degrees moved in the same direction; negative values indicate divergence.

The fundamentals and the objectives on which both BMCT and GDFCF have embarked are close as suggested from the positive synergy degrees (mostly in the mid-synergy zone) between the two mechanisms. However, they are two independent mechanisms operating in different habitats and continents, which signals a tacit possibility of information transfer, collaboration, and knowledge synergies in the future. Bwindi-Mgahinga's conservation outlook has been labelled as Good with some concerns, while the conservation outlook of Guanacaste region is in the Significant concerns level (IUCN World Heritage Outlook, 2020). Though BMCT is more inclined towards poverty alleviation and community development while GDFCF weighs more towards conservation efforts, both the setups' underlying responsibility is to conserve decimating habitats and the rich biodiversity that resides in these ecosystems. The largely positive synergies between the two mechanisms suggests that mechanisms geo-socially separated may leverage off each other. Both mechanisms have possibilities to strengthen knowledge synergies between them since both offer expertise in seemingly different but connected areas.

V.iv. Sensitivity and robustness

We conducted four checks (full details in Appendix B):

1. Weights. Re-computing ordering degrees with Entropy-only and CRITIC-only weights did not result in systematic sign flips of the annual synergy series within or across mechanisms.
2. Ecological scaling. Replacing forest-loss levels with the share of forest area lost yields the same qualitative patterns (alternation for Finance–Ecology at BMCT; irregular co-movement for GDFCF).
3. Baseline for temperature variability. Shifting the baseline year t_0 within the first three years of each sample leaves the sign patterns substantively unchanged.
4. Lag check (informal). Introducing a one-year lag of the ecological subsystem relative to finance does not materially alter the overall counts of positive vs. negative years, though individual annual signs can differ—as expected when re-aligning series.

V.v. Reading the figures

- A positive synergy value in any panel indicates that both subsystems moved in the same direction that year (improvement or deterioration relative to the previous year).
- A negative value indicates divergence.
- Magnitude reflects how strongly the ordering degrees moved that year after normalisation and weighting; the figures are intended to guide pattern recognition, not statistical inference.

VI. Conclusion, Limitations, and Future Avenues

This study examined how two long-standing conservation-finance mechanisms—the Bwindi–Mgahinga Conservation Trust (BMCT) and the Guanacaste Dry Forest Conservation Fund (GDFCF)—move in relation to selected ecological and macro-institutional indicators over time. Using a synergy-degree framework, we characterised co-movement, not causal relationships, between fund revenues, primary forest loss, temperature variability, and basic macro-stability measures. Across

both mechanisms, results highlighted periods of alignment and divergence rather than consistent directional patterns, reflecting the varied ecological pressures, institutional contexts, and funding environments in which the funds operate.

The comparative findings suggest that conservation-finance inflows interact with ecological and macro-institutional dynamics in non-linear and context-dependent ways. BMCT and GDFCF share some years of similar net movement at the system level, but the underlying drivers remain distinct. These patterns reinforce the idea that conservation-finance mechanisms need to be interpreted within their ecological setting and institutional constraints rather than as homogeneous instruments.

Despite offering a structured way to observe annual co-movement, the approach has several limitations. Data availability remains a central constraint: species-level biodiversity indicators are sparse, ecological monitoring can be intermittent, and long time-series of disaggregated financial allocations are uncommon. Measurement issues—particularly around temperature baselines, forest-loss geographies, and the timing of revenue recognition—also affect the precision of annual ordering degrees. The synergy-degree approach necessarily simplifies each subsystem into a single index, trading detail for comparability and interpretability. These choices mean that synergy values should not be interpreted as evidence of ecological impact or institutional influence.

Future work could extend this analysis in several directions. First, expanding ecological indicators (e.g., species abundance data, disturbance indices, or habitat-connectivity measures) would allow richer subsystem characterisation where monitoring permits. Second, linking revenue streams to categorised expenditures could clarify whether co-movements differ by programme type (e.g., community development, research, protected-area operations). Third, methodological extensions—such as transfer-entropy measures or non-parametric lag-structures—may help identify directional dependencies when longer data series are available. Finally, integrating field-level information from fund managers, park authorities, and partner communities could contextualise the statistical patterns identified here, grounding quantitative movements in concrete operational decisions.

Overall, the paper contributes a transparent framework for observing how conservation-finance flows relate to ecological and macro-institutional conditions across time, without making causal claims. The approach highlights the value of assembling longitudinal data for conservation funds and points to opportunities for strengthening monitoring, reporting, and evaluation practices across mechanisms.

Data Availability Statement

All data points that we use are available publicly. The following are the sources of our data used in the paper (with links attached):

Financial Information of Bwindi Mgahinga Conservation Trust is obtained from the official website: Annual Reports - Bwindi Mgahinga Conservation Trust (BMCT) (bwinditrust.org)

Financial Information of Guanacaste Dry Forest Conservation Fund is obtained from Non-Profit Explorer by Propublica: Guanacaste Dry Forest Conservation Fund - Nonprofit Explorer - ProPublica

Primary forest loss for the region covered by Bwindi Mgahinga Conservation Trust is obtained from Global Forest Watch: Kanungu, Uganda Deforestation Rates & Statistics | GFW (globalforestwatch.org)

Primary forest loss for the region covered by Guanacaste Dry Forest Conservation Fund is obtained from Global Forest Watch: Guanacaste, Costa Rica Deforestation Rates & Statistics | GFW (globalforestwatch.org)

Temperature data for the region covered by Bwindi Mgahinga Conservation Trust is obtained from Global Historical Weather and Climate Data and Meteoblue: Kanungu, UG Climate Zone, Monthly Weather Averages and Historical Data (tcktcktck.org) and Weather Archive Kanungu - meteoblue

Temperature data for the region covered by Guanacaste Dry Forest Conservation Fund is obtained from Global Historical Weather and Climate Data and Meteoblue: Guanacaste, CR Climate Zone, Monthly Weather Averages and Historical Data (tcktcktck.org) and Weather Archive Guanacaste - meteoblue

GDP Per Capita (in USD) for Uganda and Costa Rica has been obtained from World Bank: GDP per capita (current US$) - Uganda | Data (worldbank.org) and GDP per capita (current US$) - Costa Rica | Data (worldbank.org)

Fragile States Index for Uganda and Costa Rica: Fragile States Index | The Fund for Peace

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