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Agricultural Intensification and Biodiversity Loss in Rwanda: Assessing the Effects of Farming Practices, Landscape Change, and Environmental Governance
A case of four selected Districts: Gakenke, Kirehe, Nyamagabe and Bugesera

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ABSTRACT

Rwanda's agricultural transformation has raised productivity on small, fragmented, and often steep farms, but its biodiversity consequences are rarely quantified at district level. This study assesses how farming practices, landscape change, and environmental governance relate to biodiversity loss in Gakenke, Kirehe, Nyamagabe, and Bugesera districts between 2018 and 2025. A documentary, comparative multiple-case design was used. Official statistical, policy, conservation, and peer-reviewed sources were harmonised into an indicative district-by-period panel (four districts in 2018, 2022 and 2025; n = 12) and analysed with descriptive statistics, correlation, within-district (fixed-effects) regression, one-way ANOVA with Tukey tests, paired tests and a chi-square test, followed by robustness checks. Natural habitat cover fell in every district, most in relative terms in Gakenke (7% to 5%) and most in absolute terms in Bugesera (29% to 23%); the four-district mean fell by 3.75 percentage points (14.2%). Cropland share was the strongest correlate of habitat loss (within-district $r = -0.98$; -0.71 pp of habitat per percentage point of cropland). Fertiliser intensity was also negatively associated with habitat once district differences were removed ($r = -0.86$), but it is collinear with cropland expansion and with the common time trend, and its coefficient changes sign when cropland is controlled. Districts differed significantly in habitat cover ($F = 150.17$, $p < 0.001$; $\eta^2 = 0.98$). Adoption of conservation practices was not significantly associated with slower loss ($r = -0.69$, $p = 0.060$), and the sign reversed when loss was expressed in relative terms. Among seven species groups, amphibians were most exposed (44.4%) and vascular plants least (17.7%; $\chi^2 = 35.76$, $p < 0.001$). Four of five hypotheses were supported, but because the panel is small and indicative, the findings are directional. Biodiversity targets in Imihigo, no-net-loss safeguards for wetlands, and buffer-zone agroforestry are recommended.

KEYWORDS: Agricultural Intensification; Biodiversity Loss; Landscape Change; Environmental Governance; Natural Habitat Cover; Rwanda

1. INTRODUCTION

Rwanda is among the most densely populated countries in Africa, with 13,246,394 residents on 26,338 km² and a national density of 503 persons/km² (National Institute of Statistics of Rwanda [NISR], 2023). Agriculture remains the principal livelihood and export base. Successive strategies, from the National Strategy for Transformation (NST1) 2017–2024 and the Strategic Plan for Agriculture Transformation (PSTA 4) 2018–24 to NST2 2024–2029, treat agricultural intensification as a cornerstone of poverty reduction and food security (Ministry of Agriculture and Animal Resources [MINAGRI], 2018; Republic of Rwanda, 2017, 2020, 2024). Since 2007, the Crop Intensification Program (CIP), land use consolidation, subsidised fertiliser and improved seed, marshland reclamation and irrigation expansion have reshaped land use in every province (Cioffo et al., 2016; Kathiresan, 2011). Average landholdings are small, at roughly 0.5–0.6 ha per household (NISR, 2018), so growth in output has come from higher input use and from bringing marginal land, hillsides and wetlands into cultivation. The footprint is large: about 1.4 million hectares, or 59% of the national land area, were used for agriculture in Season A of 2025 (NISR, 2025b), and a 2015 land-cover map placed cropland at 56% of the country

(Karamage et al., 2016). Inorganic fertiliser was applied by 63.2% of farmers and pesticides by 41.9% in the same season (NISR, 2025b), against 26% and 15% in Season B of 2020 (NISR, 2020).

The same landscapes host exceptional biodiversity. Rwanda lies within the Albertine Rift, a global hotspot of vertebrate endemism (Plumptre et al., 2007), and holds Nyungwe National Park (about 1,019 km²), Akagera National Park (about 1,122 km²), Volcanoes National Park, Gishwati-Mukura National Park and extensive wetlands (Rwanda Environment Management Authority [REMA], 2018).

The 2008 wetland inventory recorded 860 marshlands covering 278,536 ha, or 10.6% of the territory, of which 53% were already under cropping (Rwanda Water Resources Board [RWB], n.d., citing REMA, 2008). Forest cover is officially reported at 30.4% (724,695 ha), but 53.5% of it is plantation; natural montane forest accounts for 18.1%, wooded savannah 22.3% and shrubs 6.1% (Ministry of Environment [MoE], 2019; REMA, n.d.-b). Natural habitat outside protected areas is therefore thin, fragmented and heavily used (REMA, 2016, 2018). Globally, agriculture is the leading driver of terrestrial biodiversity decline (Green et al., 2005; IPBES, 2019; Newbold et al., 2015; Leclère et al., 2020), through habitat conversion, agrochemical pollution, fragmentation, hydrological alteration and simplification of crop and landscape diversity (Tilman et al., 2002; Sánchez-Bayo & Wyckhuys, 2019).

The four study districts represent contrasting configurations of this tension. Gakenke, in the Northern Province, combines intensive cultivation with steep slopes and severe erosion risk (Kagabo et al., 2013; Karamage et al., 2016). Kirehe, in the Eastern Province, holds Akagera-basin wetlands and expanding irrigation schemes. Nyamagabe, a highland district in the Southern Province, adjoins Nyungwe Forest and its tea and potato belt (Masozera et al., 2006). Bugesera, a drier district, has lake and marsh systems (Lakes Cyohoha and Rweru, Nyabarongo floodplains) under pressure from rapid land-use change, urbanisation and infrastructure development; its population grew by about 52% between the 2012 and 2022 censuses.

Rwanda has strong environmental laws, including Law No. 48/2018 on Environment and Law No. 70/2013 governing biodiversity, and it has committed to the Kunming-Montreal Global Biodiversity Framework (Convention on Biological Diversity [CBD], 2022). Yet implementation gaps are visible in the physical evidence: of 1,080,168 ha of land at risk of erosion, only 282,352 ha (26%) are protected against it (RWB & IUCN Rwanda, 2022), and cropland, which carries a mean erosion rate of 421 t/ha/yr, generates about 95% of national soil loss (Karamage et al., 2016). Agricultural policy has been evaluated mainly on yield, food security and household income (Cioffo et al., 2016; Huggins, 2014), while its ecological costs are rarely measured at district scale, where planning and enforcement take place. Existing biodiversity assessments are national or protected-area specific, and they seldom connect farming practices, landscape change and governance in one frame. Without such evidence, districts cannot set biodiversity-sensitive targets in their imihigo (performance contracts), and short-term intensification gains risk being offset by erosion of the ecosystem services on which agriculture depends, including pollination, pest regulation, water regulation and soil fertility (Kremen & Merenlender, 2018; Dudley & Alexander, 2017; IPBES, 2024). This study addresses that gap for the period 2018–2025.

1.1 Objectives of the Study

1.1.1 General Objective

To assess the effects of farming practices, landscape change, and environmental governance on biodiversity loss in Gakenke, Kirehe, Nyamagabe, and Bugesera districts of Rwanda between 2018 and 2025.

1.1.2 Specific Objectives

SO1. To measure the change in natural habitat cover (forest, woodland, savanna, wetland and natural grassland) in each of the four districts between 2018 and 2025, and to compare the districts statistically.

SO2. To determine, using 2018, 2022 and 2025 observations, the strength and direction of the association between fertiliser application intensity (kg/ha) and natural habitat cover.

SO3. To quantify the relationship between cropland, share of district land (%) and natural habitat cover over 2018–2025, after controlling for stable district-specific conditions.

SO4. To evaluate whether household adoption of conservation practices (agroforestry, terracing, buffer planting), used as an indicator of environmental governance implementation, is associated with lower annual rates of habitat loss in 2018–2022 and 2022–2025.

SO5. To compare the exposure of seven species groups (mammals, birds, amphibians, reptiles, freshwater fishes, vascular plants and pollinating insects) to agriculture-related pressure and to identify priority groups in each district by 2025.

1.2 Hypotheses of the Study

Each hypothesis is stated in its alternative form; the corresponding null hypothesis is that no such association or difference exists. Table 1 maps every objective to its hypothesis, variables and statistical test.

H1. Higher fertiliser application intensity is significantly and negatively associated with natural habitat cover within districts over time.

H2. A larger cropland share of district land is significantly and negatively associated with natural habitat cover.

H3. Natural habitat cover (a) differs significantly among the four districts, and (b) declined significantly between 2018 and 2025.

H4. Higher adoption of conservation practices is significantly and negatively associated with the annual rate of habitat loss.

H5. Species groups differ significantly in their exposure to agriculture-related pressure.

Table 1. Specific objectives, hypotheses, variables and statistical tests

Objective	Hypothesis (alternative)	Variables	Statistical test(s)	Section
SO1	H3(a) districts differ; H3(b) cover declined	Y: natural habitat cover (%). Factors: district, year	One-way ANOVA with Tukey HSD; paired t-test with exact sign-flip test; within-district time trend	4.2
SO2	H1 fertiliser intensity lowers habitat cover	Y: habitat cover. X1: fertiliser (kg/ha)	Pearson and Spearman (pooled and within); fixed-effects regression; leave-one-district-out; two-predictor model	4.3
SO3	H2 cropland share lowers habitat cover	Y: habitat cover. X2: cropland share (%)	As SO2, plus pooled OLS and habitat loss per point of cropland gain	4.4
SO4	H4 adoption slows habitat loss	Y: annual loss rate (pp/yr; % of starting cover/yr). X3: adoption (%)	Pearson, Spearman, Kendall, permutation test, within-district and partial correlation	4.5
SO5	H5 exposure differs among species groups	Exposure (% of recorded species) in seven groups	Chi-square of homogeneity; adjusted residuals; Cramér's V; Wilson intervals; denominator sensitivity	4.6

Source: Author's design. pp = percentage points.

2. LITERATURE REVIEW

2.1 Conceptual Review

Agricultural intensification is the increase in output per unit of land, labour or time through higher inputs (fertiliser, pesticides, irrigation, improved seed), mechanisation, shorter fallows or land consolidation (Tilman et al., 2011). It differs from *extensification*, in which output rises through expansion of cultivated area. In Rwanda, both occur together: CIP intensifies existing plots while marshlands and steep slopes are added to the cultivated estate (Nabahungu & Visser, 2011; Karamage et al., 2016). Sustainable intensification seeks higher yields without additional environmental harm or land conversion (Garnett et al., 2013; Pretty et al., 2018), but critics note that it can become a label for input-heavy practice without ecological safeguards. Biodiversity encompasses genetic, species and ecosystem diversity, and biodiversity loss is understood as declines in population size, species richness, functional diversity or habitat extent (Sala et al., 2000). On farmland, relevant components include wild species in remnant habitats, agrobiodiversity and functionally important groups such as pollinators, natural enemies and soil organisms (Dudley & Alexander, 2017). Landscape change refers to alterations in the composition and configuration of land cover, including conversion, fragmentation and loss of connectivity (Tscharntke et al., 2012). Environmental governance is the set of laws, institutions, incentives and enforcement practices through which societies regulate resource use (Ostrom, 2009). In Rwanda, it includes the Law on Environment, the biodiversity and land laws, the National Land Use and Development Master Plan, wetland regulations, buffer-zone rules around protected areas, and district-level implementation through imihigo.

2.2 Theoretical Review

Land sparing and land sharing. Green et al. (2005) and Phalan et al. (2011) argue that when species show steep density-yield trade-offs, high-yield farming that spares natural habitat can conserve more biodiversity than wildlife-friendly farming over larger areas. Fischer et al. (2014) counter that in densely settled smallholder systems such as Rwanda's, sparing is rarely feasible without strong protection and that a landscape approach combining both is more realistic. This debate frames our test of whether intensification (fertiliser use, H1) or expansion (cropland share, H2) is more strongly related to habitat loss.

Landscape ecology and island biogeography. MacArthur and Wilson (1967) predicted that species richness in habitat patches falls as area shrinks and isolation rises. In agrarian landscapes, remnant forest, wetland and riparian patches behave as habitat islands, and matrix quality determines connectivity (Tscharntke et al., 2005). This supports the expectation that habitat cover (H3) and species exposure (H5) will be worst where remnants are smallest.

Drivers of land-use change and the DPSIR framework. Geist and Lambin (2002) distinguish proximate causes (agricultural expansion, infrastructure) from underlying drivers (demography, policy, markets), and Lambin and Meyfroidt (2011) show how land scarcity and markets push conversion. The Driver-Pressure-State-Impact-Response model (Smeets & Weterings, 1999) organises these into a causal chain suited to policy analysis and provides the backbone of the conceptual framework in Section 2.5.

Commons and social-ecological systems. Hardin (1968) warned of overuse of open-access resources, while Ostrom (1990, 2009) showed that well-designed local institutions can sustain them. Wetlands and forest margins in Rwanda are quasi-commons whose fate depends on clear rules, monitoring and graduated sanctions, which underpins hypothesis H4.

Environmental Kuznets Curve. Grossman and Krueger (1995) proposed that degradation initially rises with income and then falls. For biodiversity, the evidence for an automatic turning point is weak, and Leclère et al. (2020) argue that bending the curve requires integrated action on conversion, production and consumption, not growth alone.

2.3 Empirical Studies

A global meta-analysis found that conventional intensification reduces local species richness while raising production (Beckmann et al., 2019). In Europe, farmland biodiversity declined with land-use intensity, with the strongest effects from fertiliser and pesticide use (Kleijn et al., 2009; Geiger et al., 2010). Pesticide contamination was linked to reduced stream invertebrate diversity (Beketov et al., 2013), flying insect biomass in German protected areas fell by more than 75% in 27 years (Hallmann et al., 2017), and Sánchez-Bayo and Wyckhuys (2019) identified habitat conversion to intensive agriculture and agrochemicals as the main drivers of entomofauna decline. Newbold et al. (2015) estimated that land use has reduced local species richness by about 14% globally, and Maxwell et al. (2016) identified agriculture as threatening a majority of species classed as at risk. The IPBES (2019, 2024) assessments confirm food production as the dominant direct driver of loss.

Plumptre et al. (2007) documented the Albertine Rift's exceptional richness and its exposure to agricultural encroachment. Studies of Nyungwe show strong local dependence on forest resources and the importance of buffer-zone livelihoods for conservation outcomes (Masozera & Alavalapati, 2004; Masozera et al., 2006).

Cioffo et al. (2016) documented the top-down design and social costs of the CIP, while Ansoms (2009) and Huggins (2014) analysed how state-facilitated consolidation reshapes rural land control. Karamage et al. (2016) mapped cropland at 56% of national land, found that about 24% of it eroded faster than 300 t/ha/yr and was concentrated in the Congo-Nile Ridge, the Virunga range and the Buberuka highlands, and estimated that terracing could cut cropland erosion by about 79%. Kagabo et al. (2013) demonstrated soil and nutrient loss on terraced slopes in the Buberuka highlands, which include Gakenke. Nabahungu and Visser (2011) showed the livelihood importance of wetland agriculture, and Dixon and Wood (2003) explained how wetland cultivation alters hydrology in East Africa. REMA (2016, 2018) reports habitat degradation, invasive species, wetland conversion and pesticide risk as leading pressures, and Pretty et al. (2018) show that agroforestry and integrated pest management can improve yields without the same ecological costs. The RWB and IUCN Rwanda (2022) assessment adds that erosion-control coverage remains low relative to need, which bears directly on the governance objective of this study.

2.4 Research Gap

Most studies either quantify agricultural outcomes without ecological indicators or describe biodiversity at protected-area scale. Few integrate practices, landscape metrics and governance at district level for the post-2018 period, or compare species groups' exposure across contrasting agro-ecological settings. This study helps fill that gap by (i) assembling a transparent district panel, (ii) testing each objective with a matched statistical procedure, and (iii) subjecting each finding to explicit robustness checks.

2.5 Conceptual Framework

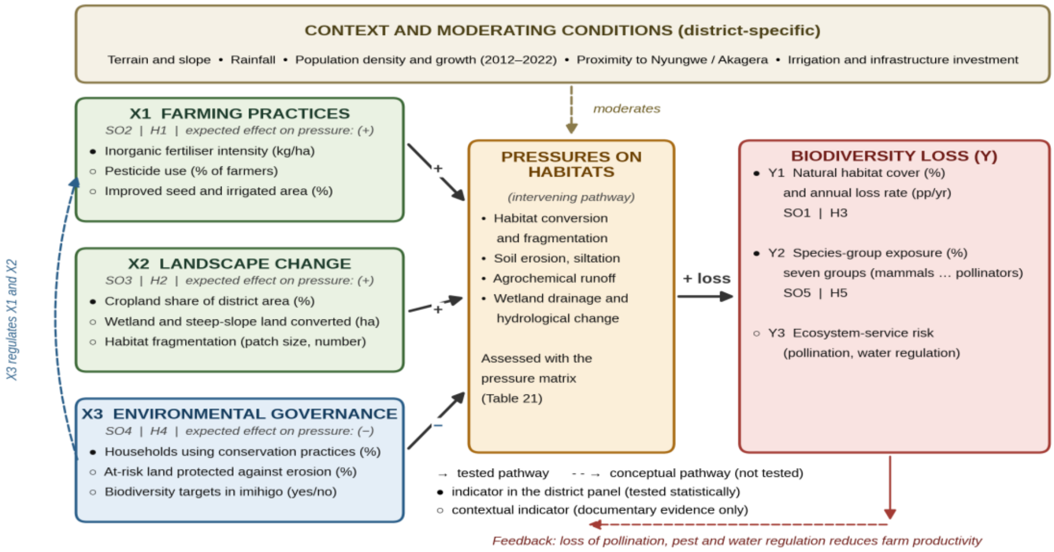

Figure 1. Conceptual framework: variables, indicators and hypothesised pathways

Source: Author's synthesis adapted from Smeets and Weterings (1999), Geist and Lambin (2002) and Ostrom (2009). SO = specific objective; H = hypothesis; pp = percentage points.

Table 2. Operationalisation of the conceptual framework: variables, indicators, sources and hypotheses

Component	Indicator (unit)	Operational definition	Main source(s)
X1 Farming practices	Inorganic fertiliser intensity (kg/ha)	Mean inorganic fertiliser applied per hectare of cropland in the district and year	NISR Seasonal Agricultural Surveys; MINAGRI (PSTA 4, CIP records); district plans
	Pesticide use (% of farmers)	Share of farmers applying pesticides or fungicides in the season	NISR Seasonal Agricultural Surveys (national and district tables)
	Improved seed and irrigated area (%)	Share of farmers using improved seed; share of cropland under irrigation	NISR; RAB irrigation records
X2 Landscape change	Cropland share (% of district area)	Area under seasonal and permanent crops divided by district area	Land-cover maps (Karamage et al., 2016; MoE); SAS land use; district plans
	Marshland and steep-slope conversion (ha)	Area of marshland developed for irrigated crops or slope land brought into cultivation	RWB and REMA wetland inventories; MINAGRI and RAB scheme records
	Habitat fragmentation	Number and mean size of natural habitat patches	Land-cover time series (to be derived)
X3 Environmental governance	Conservation-practice adoption (% of households)	Households using at least one of terracing, agroforestry or buffer planting	NISR; RAB and MINAGRI reports; district imihigo reports
	At-risk land protected against erosion (%)	Land under effective erosion control divided by land at erosion risk	RWB and IUCN Rwanda (2022)

Component	Indicator (unit)	Operational definition	Main source(s)
	Biodiversity targets in imihigo	Presence or absence of habitat, wetland or agroforestry targets in district contracts	Imihigo contracts (MINALOC)
Intervening pressures	Habitat pressure rating (H/M/L)	Qualitative rating of conversion, erosion, agrochemical runoff and hydrological change per species group	REMA (2016, 2018); Karamage et al. (2016); Nabahungu and Visser (2011)
Y1 Biodiversity loss: habitat	Natural habitat cover (%) and annual loss rate (pp/yr; % of starting cover/yr)	Forest, woodland, savanna, natural wetland and natural grassland divided by district area; loss rate = change ÷ years	MoE forest mapping; land-cover maps; REMA
Y2 Biodiversity loss: species	Species-group exposure (% of recorded species)	Species judged exposed to agriculture-related pressure divided by species recorded, for seven groups	REMA; IUCN Red List; Plumptre et al. (2007); IPBES
Context (moderators)	Population density and growth; terrain; rainfall; proximity to protected areas	Persons/km² (2012, 2022); slope class; annual rainfall (mm); distance to Nyungwe or Akagera	NISR censuses; district plans

Source: Author's design. ● = indicators in the district panel; other indicators are supported by documentary evidence only and are proposed for future data collection. RAB = Rwanda Agriculture and Animal Resources Development Board; MINALOC = Ministry of Local Governance.

3. METHODOLOGY

3.1 Research Design

The study used a documentary (desk-based) research design with a comparative multiple-case structure. Documentary designs are suited to district-scale questions where primary biodiversity surveys are unavailable, and the multiple-case structure allows contrasts among agro-ecological settings. The design is exploratory and hypothesis-testing at the same time: each objective is matched with a statistical test (Table 1), and each result is accompanied by robustness checks.

3.2 Data Sources and Documentary Search

Evidence was gathered from (i) government statistical reports (NISR Population and Housing Censuses 2012 and 2022, EICV5, Seasonal Agricultural Surveys (SAS) 2020–2025), (ii) policy documents (MINAGRI's PSTA 4; NST1 and NST2; district development plans), (iii) environmental reports (REMA's State of Environment and Outlook Reports and National Biodiversity Strategy and Action Plan (NBSAP); Ministry of Environment forest cover mapping; RWB and IUCN Rwanda soil-erosion assessment), (iv) legal instruments (Laws No. 48/2018, 70/2013 and 27/2021), (v) international assessments (IPBES, IUCN Red List, CBD) and (vi) peer-reviewed literature indexed in Scopus, Web of Science and Google Scholar (search terms: agricultural intensification, biodiversity, Rwanda, landscape change, wetlands, governance, soil erosion). Policy, statistical and empirical sources were restricted mainly to 2018–2025, complemented by foundational theoretical works. Documents were included if they were official, peer-reviewed or issued by recognised institutions and reported quantitative or spatial indicators relevant to the study variables; grey material without stated methodology was excluded. News reports were used only to document the extent of named marshland projects and are flagged as such.

3.3 Variables, Indicators and Data Harmonisation

Indicators were extracted into a district-by-period panel for 2018, 2022 and 2025 (four districts × three periods; n = 12) covering fertiliser intensity, cropland share, natural habitat cover and adoption of conservation practices (Table 2). Where districts lacked published series, values were triangulated from provincial and national reports and land-cover analyses, harmonised by rounding and cross-checking across sources, and are therefore *indicative estimates* that must be verified against primary datasets before policy use. Table 3 states, indicator by indicator, what the official sources publish, what the panel uses and what verification is still required. Species-group exposure was compiled from national inventories, IUCN assessments and REMA reporting and is likewise approximate. To guard against gross error, the panel was triangulated against independent national benchmarks (Section 4.1).

Two derived measures were computed. The **annual habitat loss rate** for interval *j* is (cover at start − cover at end)/years in percentage points per year, and, as a scale-free alternative, the **relative loss rate** is that quantity divided by starting cover (% of starting cover per year). Species **exposure** is the number of species judged exposed to agriculture-related pressure divided by the number of species recorded in the group.

3.5 Analytical Strategy by Objective

All analyses were run in Python (SciPy) at $\alpha = 0.05$, and results are reported with effect sizes and 95% confidence intervals.

- **SO1 (H3).** Descriptive change (absolute, relative and annualised); one-way ANOVA of habitat cover among districts with Levene's test, η^2 and ω^2, Tukey HSD post-hoc comparisons and a Kruskal-Wallis check; paired t-test of 2018 versus 2025 cover with a 95% confidence interval, Cohen's dz and an exact sign-flip permutation test; and a within-district linear time trend that uses all 12 observations.
- **SO2 and SO3 (H1, H2).** Pearson and Spearman correlations of habitat cover with each predictor, pooled and within district (values centred on district means); bivariate fixed-effects regressions, Habitat(it) = α(i) + β × X(it) + ε(it), where i indexes districts and t periods, with residual degrees of freedom $n - k - 1 = 7$; leave-one-district-out re-estimation; and a two-predictor within-district model with a variance-inflation factor to expose collinearity.
- **SO4 (H4).** Correlation of annual loss rate (eight district-interval observations) with adoption at the start of the interval: Pearson with a Fisher 95% interval and permutation p-value, Spearman, Kendall, within-district and between-district correlations, partial correlation controlling for starting cover, and the same tests on the relative loss rate.
- **SO5 (H5).** Chi-square test of homogeneity on exposed versus not-exposed species across seven groups; adjusted standardised residuals judged against a Bonferroni-corrected threshold ($|z| > 2.69$ for seven comparisons); Cramér's V; Wilson 95% intervals for each exposure rate; and a sensitivity analysis that re-bases exposure on alternative species-richness denominators.

3.6 Validity, Reliability and Limits of Inference

With twelve harmonised observations, three per district, the panel violates the independence assumption of classical tests (pseudo-replication), the districts are not a random sample, and the values are estimates rather than measurements. Inferential statistics are therefore used descriptively: they quantify how strong and how consistent the patterns in the panel are, not the probability of the same pattern in the wider population. Effect sizes are emphasised over p-values, conclusions are triangulated with the documentary evidence, and findings that depend on the analytical choice are flagged (for example, the metric used for habitat loss in SO4).

3.7 Ethical Considerations

The study used published secondary data only and involved no human participants, so no ethical clearance was required. All sources are cited, and estimates derived by the author are labelled as such.

Table 3. Data provenance and verification status of the panel indicators

Indicator	What official sources publish	What the panel uses	Verification still required
Natural habitat cover (%)	Ministry of Environment forest cover mapping (2019); wetland inventories; national land-cover maps	District values harmonised from provincial and national reports and land-cover analyses (indicative)	Classify one consistent land-cover series (2018, 2022, 2025) per district under a single legend and report map accuracy
Cropland share (%)	SAS national and district land use by season; 2015 land-cover map (56% national cropland)	Harmonised indicative district shares	Extract district land-use shares from SAS annual tables and cross-check against the land-cover series
Fertiliser intensity (kg/ha)	SAS publishes the share of farmers using inorganic fertiliser (63.2% nationally, 2025 Season A) and fertiliser type by district; kg/ha is not published as a district series	Indicative kg/ha harmonised from national roll-out and district information	Compute kg/ha from district distribution volumes divided by cropped area, or replace with the SAS share of farmers

Indicator	What official sources publish	What the panel uses	Verification still required
Conservation-practice adoption (%)	No single household series; area-based erosion-control data exist (RWB and IUCN Rwanda, 2022) and terrace statistics are national	Indicative household adoption shares	Replace with area-based indicators (ha terraced or agroforested per district) from RAB records
Species exposure (%)	REMA and IUCN species inventories; richness totals differ among sources	National expert synthesis (Table 18)	Reconcile richness denominators and use IUCN Red List categories by habitat and district

Source: Author's review of NISR (2023, 2025a, 2025b), MoE (2019), Karamage et al. (2016), RWB and IUCN Rwanda (2022) and REMA (2016, 2018).

4. RESULTS AND DISCUSSION

Results are presented in the order of the specific objectives. Section 4.1 first establishes the district and national context and checks the panel against independent benchmarks; Sections 4.2 to 4.6 then report the statistical evidence for SO1 to SO5, each closing with a hypothesis decision; Section 4.7 summarises all decisions, and Sections 4.8 and 4.9 discuss the findings and their limits.

4.1 District and National Context

Table 4. Profile of the four study districts

Indicator	Gakenke	Kirehe	Nyamagabe	Bugesera
Province	Northern	Eastern	Southern	Eastern
Area (km², approx.)	704	1,206	1,090	1,337
Population, 2012 census (approx.)	338,600	340,400	341,500	361,900
Population, 2022 census	365,292	460,860	371,501	551,103
Population change 2012–2022 (%)	+7.9	+35.4	+8.8	+52.3
Mean annual growth 2012–2022 (%)	0.76	3.08	0.85	4.30
Density 2012 (persons/km²)	481	282	313	271
Density 2022 (persons/km², NISR)	520	398	341	450
Urban share of population, 2022 (%)	4.0	6.3	10.9	40.1
Dominant terrain	Steep hills	Rolling hills, valley marshes	High plateau and ridges	Low undulating plains, lakes
Annual rainfall (mm, approx.)	1,200–1,400	1,000–1,100	1,300–1,500	850–1,000
Main crops	Maize, beans, Irish potato, cassava	Rice, maize, banana, beans	Irish potato, wheat, tea, maize	Cassava, banana, maize, horticulture
Key biodiversity assets	Small forest and riparian remnants	Akagera-basin wetlands, savanna fragments	Nyungwe buffer zone, Kitabi forest margin	Lakes Cyohoha and Rweru, Nyabarongo wetlands

Source: NISR (2014, 2023); REMA (2018); district development plans; author's calculations for growth rates (compound, 10 years). Areas are approximate, and NISR densities are computed on NISR's own land-area figures, so they can differ slightly from population divided by the areas shown.

Gakenke is the smallest district but remains the most densely settled, at 520 persons/km² in 2022, or 1.2 to 1.5 times the density of the other three. The gap has narrowed since 2012 (1.5 to 1.8 times) because Kirehe and Bugesera grew by 35% and 52% over the decade, partly through urbanisation in Bugesera (40.1% urban). Nyamagabe combines the highest rainfall with the only large natural-forest neighbour, while Bugesera is the driest and largest. Demographic pressure is thus now rising fastest exactly where the largest absolute habitat losses are recorded later in this section (Kirehe and Bugesera); across the four districts, 2012–2022 population growth and 2018–2025 habitat loss are almost perfectly correlated (r = 0.99), although with four points this is illustrative only. These contrasts justify treating the districts as distinct agro-ecological cases.

Table 5. National agriculture, land and biodiversity context indicators

Indicator	Value	Reference
Total area; population (2022 census)	26,338 km²; 13,246,394 residents (503 persons/km²)	NISR (2023)
Land used for agriculture, 2025 Season A	1.399 million ha, ≈ 59% of 2.376 million ha (58% in 2024 Season A)	NISR (2025a, 2025b)
Cropland extent, 2015 land-cover map	56% of national land area	Karamage et al. (2016)
Cropland erosion	Mean 421 t/ha/yr; ≈ 95% of national soil loss; 24% of cropland above 300 t/ha/yr	Karamage et al. (2016)
Land at erosion risk that is protected	282,352 ha of 1,080,168 ha (26%); 74% unprotected	RWB and IUCN Rwanda (2022)
Radical terraces	≈ 139,000 ha built by June 2023 (target 142,000 ha by 2024; potential ≈ 265,000 ha)	KT Press (2023)
Forest cover, 2019	724,695 ha (30.4%): plantations 53.5%, natural montane forest 18.1%, wooded savannah 22.3%, shrubs 6.1%	MoE (2019); REMA (n.d.-b)
Wetlands (2008 inventory)	860 marshlands, 278,536 ha (10.6% of territory); 53% cropped, 41% natural vegetation, 6% fallow	RWB (n.d.), citing REMA (2008)
Major national parks	Nyungwe ≈ 1,019 km²; Akagera ≈ 1,122 km²; Volcanoes ≈ 160 km²; Gishwati-Mukura ≈ 34 km²; together ≈ 9% of territory	REMA (2018); author's calculation
Nyungwe: primate species / bird species	13 / ≈ 320	Plumptre et al. (2007); REMA (2018)
Recorded species richness (2003 inventory used by REMA)	402 mammals; 1,061 birds; 293 reptiles and amphibians; 5,793 higher plants	REMA (n.d.-a)
Start of Crop Intensification Program	2007	Kathiresan (2011)

Source: As indicated in the last column. Park areas other than Nyungwe and Akagera are approximate.

Rwanda's very small holdings and high density mean that agricultural production and habitat share one narrow land base. Although forest cover is reported above the 30% national target, more than half of it is plantation, so natural habitat outside parks is far smaller than the headline suggests. The natural components of the 2019 forest map (natural forest, wooded savannah, shrubs and bamboo) total about 337,000 ha, or 14% of the land area. Erosion control lags behind need: only a quarter of at-risk land is protected. Nyungwe alone shelters 13 primate species and more than 300 birds, so farming pressure at its edges (Nyamagabe) carries outsized conservation risk.

Table 6. Triangulation of the district panel against independent national benchmarks

Benchmark	National value	Four-district panel	Reading
Natural forest, wooded savannah, shrubs and bamboo (2019)	≈ 14.1% of land (337,269 ha)	—	Component of natural habitat
Uncropped natural marsh vegetation (2008 inventory)	≈ 4.8% of land (41% of 278,536 ha)	—	Component of natural habitat
Indicative national natural habitat (sum; excludes natural grassland; mixes years)	≈ 18.9%	26.5% (2018); 22.75% (2025)	Panel is 4–8 points higher, consistent with inclusion of natural grassland and of Nyamagabe's forest edge
Agricultural or cropland share of land	56% (2015 map); 58% (2024 Season A); 59% (2025 Season A)	46.75% (2018); 52.25% (2025) cropland	Panel is 4–12 points lower, plausible for districts with forest, lakes and wetlands
Direction of change in inputs	Farmers using inorganic fertiliser 26% (2020 B) to 63.2% (2025 A)	Mean fertiliser 17 kg/ha (2018) to 31 kg/ha (2025)	Same direction and similar order of change

Source: Author's calculation from MoE (2019), REMA (n.d.-b), RWB (n.d.), Karamage et al. (2016), NISR (2020, 2025a, 2025b) and Table 7. National land area derived as 724,695 ha ÷ 0.304 ≈ 2.38 million ha. The comparison is an order-of-magnitude plausibility check only; the districts are not a representative sample.

The plausibility check (Table 6) does not validate the district values, but it shows that the panel is neither implausibly high nor low relative to national figures, and that its direction of change in inputs matches the national record. It therefore supports using the panel for exploratory comparison, provided the verification steps in Table 3 are completed before the values are used for policy.

4.2 Objective 1: Change in Natural Habitat Cover and Differences among Districts (H3)

Table 7. Harmonised district-by-period panel (2018, 2022, 2025)

District	Year	Cropland share (%)	Fertiliser (kg/ha)	Natural habitat cover (%)	Conservation-practice adoption (% households)
Gakenke	2018	66	24	7	55
Gakenke	2022	68	33	6	64
Gakenke	2025	70	40	5	70
Kirehe	2018	45	12	27	38
Kirehe	2022	49	19	24	50
Kirehe	2025	52	26	22	58
Nyamagabe	2018	36	22	43	46
Nyamagabe	2022	38	30	42	57
Nyamagabe	2025	40	36	41	64
Bugesera	2018	40	10	29	28
Bugesera	2022	44	16	26	41
Bugesera	2025	47	22	23	51
Four-district mean	**2018**	**46.75**	**17.0**	**26.50**	**41.75**
Four-district mean	**2025**	**52.25**	**31.0**	**22.75**	**60.75**

Source: Author's harmonisation from NISR (2018, 2023, 2025a), MINAGRI (2018), REMA (2016, 2018), district plans and land-cover assessments. Indicative estimates; see Section 3.4 and Table 3.

Between 2018 and 2025 fertiliser intensity rose in every district, by 16 kg/ha in Gakenke, 14 in Kirehe and Nyamagabe, and 12 in Bugesera, mirroring the national roll-out of subsidised inputs under CIP. Cropland share increased everywhere, fastest in Kirehe and Bugesera (+7 percentage points each), the districts with the most available marginal land and wetland margins. Natural habitat cover fell in all four districts, and conservation-practice adoption rose substantially in all of them without halting the decline.

Table 8. Descriptive summary of natural habitat cover by district

District	2018 (%)	2022 (%)	2025 (%)	Change (pp)	Relative change (%)	Annualised (pp/yr)	Compound rate (%/yr)	Mean (%)	SD
Gakenke	7	6	5	−2	−28.6	−0.29	−4.7	6.0	1.00
Kirehe	27	24	22	−5	−18.5	−0.71	−2.9	24.3	2.52
Nyamagabe	43	42	41	−2	−4.7	−0.29	−0.7	42.0	1.00
Bugesera	29	26	23	−6	−20.7	−0.86	−3.3	26.0	3.00
Four-district mean	**26.50**	**24.50**	**22.75**	**−3.75**	**−14.2**	**−0.54**	**−2.2**	**24.6**	**13.44**

Source: Computed from Table 7. pp = percentage points. SD is the sample standard deviation over the three periods (last row: over all 12 observations, which reflects differences among districts rather than change over time).

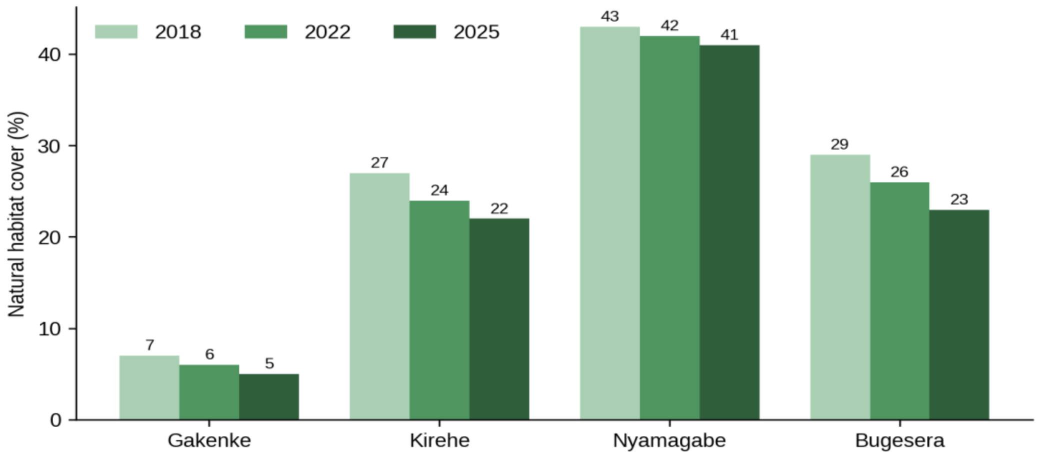

Figure 2. Natural habitat cover (%) by district, 2018, 2022 and 2025

Source: Table 7.

The four-district mean habitat cover fell from 26.5% to 22.75%, a relative loss of about one-seventh in seven years, or 0.54 percentage points a year. In absolute terms, Bugesera (−6 pp) and Kirehe (−5 pp) lost the most, consistent with wetland and savanna-margin conversion. In relative terms, Gakenke lost more than a quarter of what little it had (−4.7% a year, compounded), leaving 5% in scattered patches unlikely to sustain area-sensitive species. Nyamagabe lost least (−4.7% in total, −0.7% a year) because its forest edge is legally protected and buffer-zone rules constrain clearing.

Table 9. One-way ANOVA of habitat cover among districts (H3a)

Source	SS	df	MS	F	p
Between districts	1,952.25	3	650.75	150.17	< 0.001
Within districts	34.67	8	4.33		
Total	1,986.92	11			

Source: Author's computation from Table 7. Effect sizes: $\eta^2 = 0.983$; $\omega^2 = 0.974$. Levene's test of equal variances: $W = 0.94$, $p = 0.46$. Kruskal-Wallis check: $H = 9.46$, $p = 0.024$.

Table 10. Tukey HSD pairwise comparisons of mean habitat cover (percentage points)

Comparison	Mean difference	95% confidence interval	Adjusted p
Gakenke − Kirehe	−18.33	−23.78 to −12.89	< 0.001
Gakenke − Nyamagabe	−36.00	−41.44 to −30.56	< 0.001
Gakenke − Bugesera	−20.00	−25.44 to −14.56	< 0.001
Kirehe − Nyamagabe	−17.67	−23.11 to −12.22	< 0.001
Kirehe − Bugesera	−1.67	−7.11 to 3.78	0.764
Nyamagabe − Bugesera	+16.00	+10.56 to +21.44	< 0.001

Source: Author's computation. Differences are first district minus second.

District identity explains 98% of the variance in habitat cover ($\eta^2 = 0.98$), the variances are homogeneous (Levene p = 0.46), and the non-parametric Kruskal-Wallis test agrees (p = 0.024). Tukey comparisons show that Nyamagabe (mean 42%) stands 16 to 36 points above every other district, that Gakenke (mean 6%) is far below all others, and that Kirehe (24%) and Bugesera (26%) do not differ from each other (difference 1.7 points, p = 0.76). Hypothesis H3(a) is supported. Because each district contributes three non-independent observations, this result should be read as a description of very large, stable between-district gaps rather than as a sampling inference.

Table 11. Tests of change in habitat cover, 2018 to 2025 (H3b)

Test	Statistic	Estimate (95% CI)	p	Effect size or note
Paired t-test, 2018 vs 2025 (four district pairs)	t(3) = 3.64	3.75 pp decline (0.47 to 7.03)	0.036	Cohen's dz = 1.82
Exact sign-flip permutation test (four pairs)	—	—	0.125	Smallest p attainable with n = 4
Within-district linear time trend (12 observations)	t(7) = −5.48	−0.53 pp/yr (−0.76 to −0.30)	< 0.001	Uses all periods; district effects removed
Successive intervals with a decline	8 of 8	—	0.008	Binomial test; intervals are nested in districts, so indicative

Source: Author's computation from Table 7. All four districts declined (range 2–6 pp), so the result is not driven by one outlier.

The parametric paired test gives a significant 3.75-point decline (p = 0.036), but with only four pairs an exact permutation test cannot fall below p = 0.125, so the t-test result depends on the normality assumption. Two further checks support the direction of change: the within-district time trend that uses all twelve observations is −0.53 points a year (95% CI −0.76 to −0.30, p < 0.001), and all eight successive intervals show a decline. Hypothesis H3(b) is therefore supported, with the caveat that formal significance rests on parametric assumptions and a very small sample.

4.3 Objective 2: Fertiliser Intensity and Natural Habitat Cover (H1)

National survey data confirm that the input intensification captured in the panel is real (Table 12). The share of farmers applying inorganic fertiliser rose from 26% in Season B of 2020 to 38.6% in Season A of 2022 and to 59.6%, 64.5% and 63.2% in Season A of 2023, 2024 and 2025, and pesticide use rose from 34.5% to 41.9% between Season A of 2023 and 2025. The surveys report the share of farmers rather than kg/ha, so the panel's district kg/ha series remains an indicative construct (Table 3). Comparisons across surveys should also be made within the same season, and part of the jump between 2022 and 2023 may reflect survey design as well as behaviour.

Table 12. National use of agricultural inputs by Seasonal Agricultural Survey (% of farmers)

Survey and season	Inorganic fertiliser (%)	Pesticides or fungicides (%)	Improved seed (%)	Source
2020, Season B	26.0	15.0	—	NISR (2020)
2022, Season A	38.6	—	—	NISR (2022a)
2022, Season B	27.5	—	8.6	NISR (2022b)
2023, Season A	59.6	34.5	37.1	NISR (2024)
2024, Season A	64.5	39.8	39.7	NISR (2025a)
2025, Season A	63.2	41.9	37.3	NISR (2025b)

Source: NISR Seasonal Agricultural Surveys as listed. — = not available in the sources consulted. Seasons differ in coverage, so like-for-like comparison requires the same season.

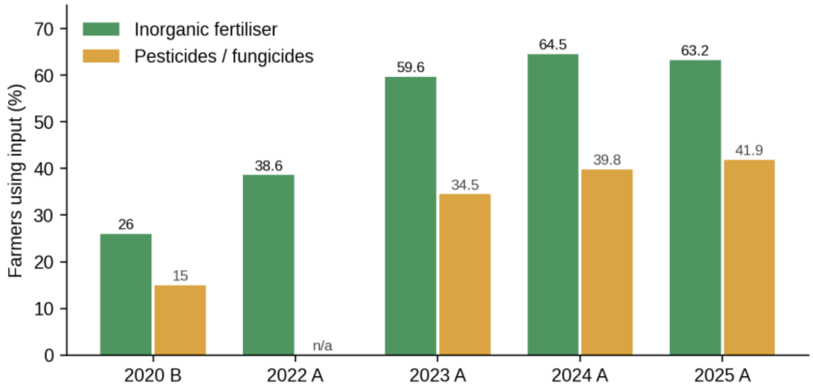

Figure 3. Share of farmers using inorganic fertiliser and pesticides, selected survey seasons

Source: Table 12.

Table 13. Association between fertiliser intensity and natural habitat cover (n = 12)

Statistic	Value	Reading
Pooled Pearson r	−0.230 (p = 0.472)	Weak and not significant; masked by large differences in baseline habitat
Pooled Spearman ρ	−0.347 (p = 0.269)	Same conclusion with a rank-based measure
Within-district Pearson r	−0.861 (p = 0.003)	Strong once stable district differences are removed
Within-district Spearman ρ	−0.839	Consistent with the Pearson result
Fixed-effects slope (pp per kg/ha)	−0.254; SE 0.057; 95% CI −0.389 to −0.120; t(7) = −4.47; p = 0.003	10 kg/ha more fertiliser goes with about 2.5 pp less habitat within a district
Within-district R^2	0.74	Fertiliser accounts for about three-quarters of within-district variation
Leave-one-district-out slopes	−0.316 to −0.200; all p ≤ 0.026	Not driven by any single district
Two-predictor model, fertiliser coefficient (with cropland)	+0.142 (SE 0.035)	Sign reverses once cropland share is controlled
Two-predictor model, cropland coefficient	−1.042 (SE 0.087)	Cropland absorbs the association
Collinearity: within-district r (fertiliser, cropland); VIF	0.94 (pooled 0.47); VIF 8.2	Predictors move together within districts

Source: Author's computation from Table 7. Within-district statistics use district-mean-centred values; residual degrees of freedom are 7, so p-values are indicative.

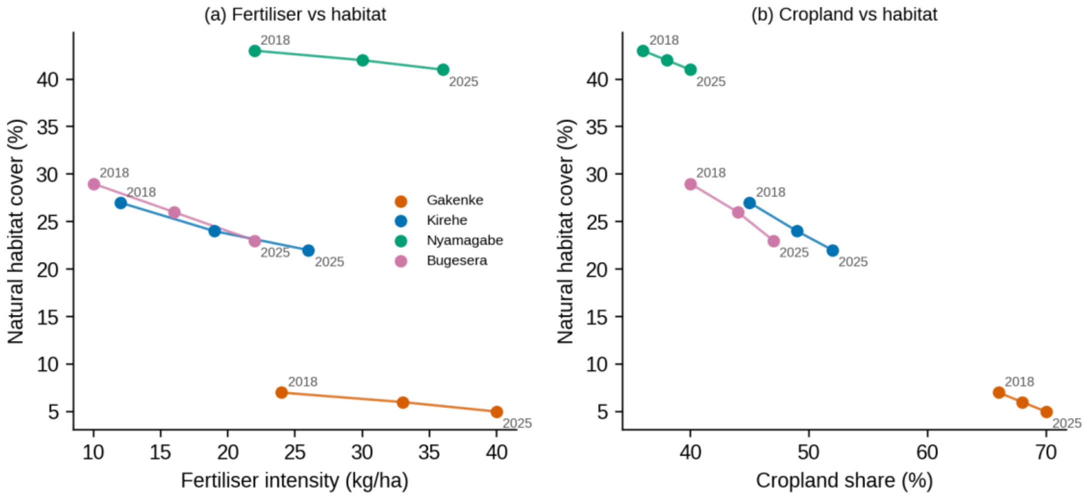

Figure 4. Natural habitat cover against (a) fertiliser intensity and (b) cropland share, by district and year
Source: Table 7. Lines join the 2018, 2022 and 2025 observations of each district.

Pooled across districts, fertiliser shows only a weak, non-significant link with habitat cover (r = −0.23) because baseline habitat differs enormously: Nyamagabe has high fertiliser use and high habitat, which masks the trend. Once stable district differences are removed, fertiliser is strongly negative (within r = −0.86; slope −0.25 points per kg/ha, 95% CI −0.39 to −0.12), and this holds when any one district is dropped. The interpretation, however, needs care. Within districts, fertiliser is almost collinear with cropland share (r = 0.94, not the 0.47 obtained from pooled data), and when both are entered together the fertiliser coefficient turns positive while cropland remains strongly negative. The negative fertiliser association therefore travels with cropland expansion and the common time trend rather than establishing an independent effect of input intensity. Hypothesis H1 is supported conditional on district effects.

4.4 Objective 3: Cropland Share and Natural Habitat Cover (H2)

Table 14. Association between cropland share and natural habitat cover (n = 12)

Statistic	Value	Reading
Pooled Pearson r	−0.957 ($p < 0.001$)	Very strong negative association across all observations
Pooled Spearman ρ	−0.984 ($p < 0.001$)	Confirmed by ranks
Within-district Pearson r	−0.981 ($p < 0.001$)	Strongest of all predictors
Fixed-effects slope (pp per pp of cropland)	−0.714; SE 0.054; 95% CI −0.842 to −0.587; t(7) = −13.23; $p < 0.001$	Each extra point of cropland goes with about 0.7 points less natural habitat
Within-district R^2	0.96	Cropland accounts for almost all within-district variation
Pooled OLS slope; R^2	−1.07 (SE 0.10); $R^2 = 0.916$	Larger slope because it mixes between-district differences
Leave-one-district-out slopes	−0.744 to −0.631; all $p \leq 0.0003$	Robust to dropping any district
Habitat lost per point of cropland gained, 2018–2025	Gakenke 0.50; Kirehe 0.71; Nyamagabe 0.50; Bugesera 0.86	Conversion is most habitat-costly in the wetland and savanna districts

Source: Author's computation from Table 7. Habitat lost per point of cropland gained = change in habitat ÷ change in cropland share, 2018–2025.

Cropland share is the strongest correlate of habitat loss in both the pooled and the within-district view, so habitat loss tracks the physical expansion of farmland. Each additional percentage point of cropland is associated with about 0.7 points less natural habitat within a district, and the estimate is stable when districts are dropped one at a time. The loss of habitat per point of cropland gained is highest in Bugesera (0.86) and Kirehe (0.71), where farmland has advanced into marsh and savanna margins, and lowest in Gakenke and Nyamagabe (0.50 each), where new cropland comes partly from other cover types or, in Gakenke, from land already almost stripped of natural habitat. Hypothesis H2 is supported.

Documented marshland development helps explain why the wetland districts show the steepest conversion (Table 15). In Bugesera the Gashora marshland scheme (750 ha) has been under rice and horticulture since 2017, while schemes at Cyohoha (3,000 ha, Bugesera) and Nasho (700 ha, Kirehe) were at tender stage in 2026; together they represent about 30% of the 12,544 ha of wetland rehabilitation planned under the Commercialisation and De-Risking for Agricultural Transformation (CDAT) project. National assessments also show that 53% of inventoried marshland was already cropped by 2008, so further development will fall increasingly on the remaining natural fraction.

Table 15. Documented marshland and irrigation developments in Kirehe and Bugesera

Scheme	District	Area (ha)	Status and use	Source
Gashora marshland	Bugesera (with Ngoma)	750 developed; rice on 400; 260 planned for horticulture	Farming launched in March 2017	MINAGRI (2017)
Cyohoha scheme	Bugesera	3,000	Tender stage under CDAT (2026)	The New Times (2026)
Nasho scheme	Kirehe	700	Tender stage under CDAT (2026)	The New Times (2026)
Kibaya–Cyunuzi wetland	Kirehe and Ngoma	490 cultivated by one cooperative; 153 more planned	Rice, about 5 t/ha	Top Africa News (2025)
Rice cultivation in Kirehe	Kirehe	> 800	In production	Top Africa News (2025)
CDAT wetland programme (national)	Sixteen districts	12,544 in total; Nasho plus Cyohoha = 3,700 (29.5%)	Rehabilitation and development	The New Times (2026)

Source: As listed. News-based sources are used only to document the extent of named projects. Percentage share is the author's calculation.

4.5 Objective 4: Conservation-Practice Adoption and the Rate of Habitat Loss (H4)

Table 16. Annual habitat loss and conservation-practice adoption at the start of each interval

District	Interval	Years	Adoption at start (%)	Habitat at start (%)	Loss (pp)	Loss rate (pp/yr)	Relative loss rate (% of start cover/yr)
Gakenke	2018–2022	4	55	7	1	0.25	3.57
Gakenke	2022–2025	3	64	6	1	0.33	5.56
Kirehe	2018–2022	4	38	27	3	0.75	2.78
Kirehe	2022–2025	3	50	24	2	0.67	2.78
Nyamagabe	2018–2022	4	46	43	1	0.25	0.58
Nyamagabe	2022–2025	3	57	42	1	0.33	0.79
Bugesera	2018–2022	4	28	29	3	0.75	2.59
Bugesera	2022–2025	3	41	26	3	1.00	3.85

Source: Derived from Table 7. The relative loss rate divides the annual loss by cover at the start of the interval.

Measured in percentage points a year, the districts with the highest adoption (Gakenke and Nyamagabe) show the slowest loss (0.25–0.33 pp/yr), while Bugesera, with the lowest adoption, shows the fastest and accelerating loss (1.00 pp/yr in 2022–2025). Kirehe's rate barely changed despite rising adoption. Measured relative to the habitat each district had left, however, Gakenke has the fastest loss (3.6 to 5.6% of its remaining cover a year) and Nyamagabe the slowest (0.6 to 0.8%). The choice of metric therefore matters, and both are tested (Table 17).

Table 17. Tests of the association between adoption and habitat loss rate (eight district-intervals)

Test	Absolute loss rate (pp/yr)	Relative loss rate (% of start cover/yr)
Pearson r (95% CI)	−0.686 (−0.94 to +0.04); p = 0.060	+0.252 (−0.55 to +0.81); p = 0.547
Permutation p-value for Pearson r	0.065	0.549
Spearman ρ	−0.630; p = 0.094	+0.275; p = 0.509
Kendall τ	−0.416; p = 0.164	+0.255; p = 0.383
Within-district r (change in adoption vs change in loss rate)	+0.60	+0.68
Between-district correlation of district means (n = 4)	−0.94; p = 0.060	+0.14; p = 0.856
Partial r controlling for starting habitat cover (df = 5)	−0.71; p = 0.072	−0.22; p = 0.633

Source: Author's computation from Table 16. Within-district r removes district means and asks whether loss slowed in a district as its own adoption rose.

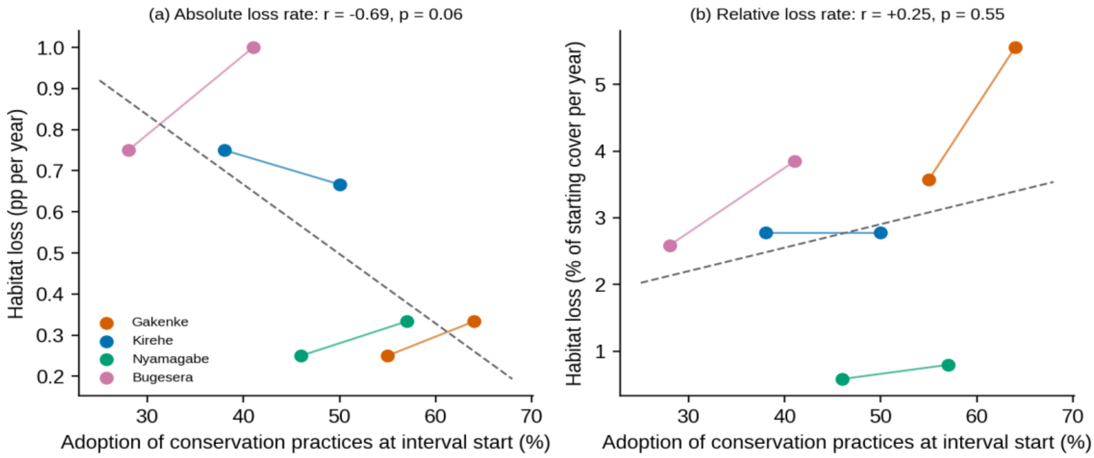

Figure 5. Conservation-practice adoption and habitat loss rate, by district (points join the two intervals), ***Source: Table 16.***

The negative association in absolute terms (r = −0.69) is moderate to strong but does not reach the 5% level under Pearson (p = 0.060), permutation (p = 0.065), Spearman or Kendall tests, and its confidence interval spans zero. Three further checks weaken the case that adoption slows loss. First, within districts the relationship is positive: loss accelerated as adoption rose in Gakenke, Nyamagabe and Bugesera and fell slightly only in Kirehe, so the negative pooled association arises between districts, not as adoption grows. Second, when loss is expressed relative to remaining habitat the sign reverses (r = +0.25). Third, the explanation that Gakenke's low rate reflects a simple floor effect is not supported, since starting cover and the absolute loss rate are uncorrelated (r = 0.07); the pattern instead reflects three different situations, namely a large protected stock (Nyamagabe), a nearly exhausted stock (Gakenke) and mid-sized wetland and savanna stocks under irrigation pressure (Kirehe and Bugesera). Hypothesis H4 is not supported. These results should be read alongside the physical evidence on governance. Household adoption rates of 28–70% in the panel contrast with the finding that only 26% of at-risk land nationally is protected against erosion (RWB & IUCN Rwanda, 2022), and radical terraces, though close to the 2024 target (about 139,000 of 142,000 ha), cover roughly half of the estimated potential (265,000 ha) (KT Press, 2023). Household counts measure effort, not the area effectively protected or the habitat retained, which may explain why higher adoption is not accompanied by slower loss.

4.6 Objective 5: Exposure of Species Groups to Agriculture-Related Pressure (H5)

Table 18. Approximate species groups and estimated exposure to agriculture-related pressure in Rwanda

Species group	Recorded species	Species exposed	Exposure (%)	Wilson 95% CI (%)	Adjusted residual	Main agricultural pathways
Mammals	150	38	25.3	19.0–32.8	+1.62	Forest and savanna conversion, human-wildlife conflict, snares
Birds	700	150	21.4	18.5–24.6	+0.95	Wetland drainage, papyrus loss, pesticides, habitat loss
Amphibians	45	20	44.4	30.9–58.8	+4.09*	Wetland reclamation, agrochemical runoff, water-table change
Reptiles	90	25	27.8	19.6–37.8	+1.83	Habitat clearing, burning, direct persecution
Freshwater fishes	130	35	26.9	20.0–35.1	+1.97	Siltation, nutrient loading, pesticide runoff, wetland loss
Vascular plants	2,150	380	17.7	16.1–19.3	−4.26*	Clearing, slope cultivation, fire, invasive competitors
Pollinating insects (bees, butterflies)	600	130	21.7	18.6–25.1	+1.02	Pesticides, monocropping, loss of flowering margins
Total	**3,865**	**778**	**20.1**	**18.9–21.4**		

*Source: Compiled from REMA (2016, 2018), Plumptre et al. (2007), IUCN (2024) and IPBES (2019, 2024); statistics are the author's computation. Counts are rounded approximations; exposure is an expert-synthesis estimate rather than an IUCN category. * = exceeds the Bonferroni threshold of |z| > 2.69.*

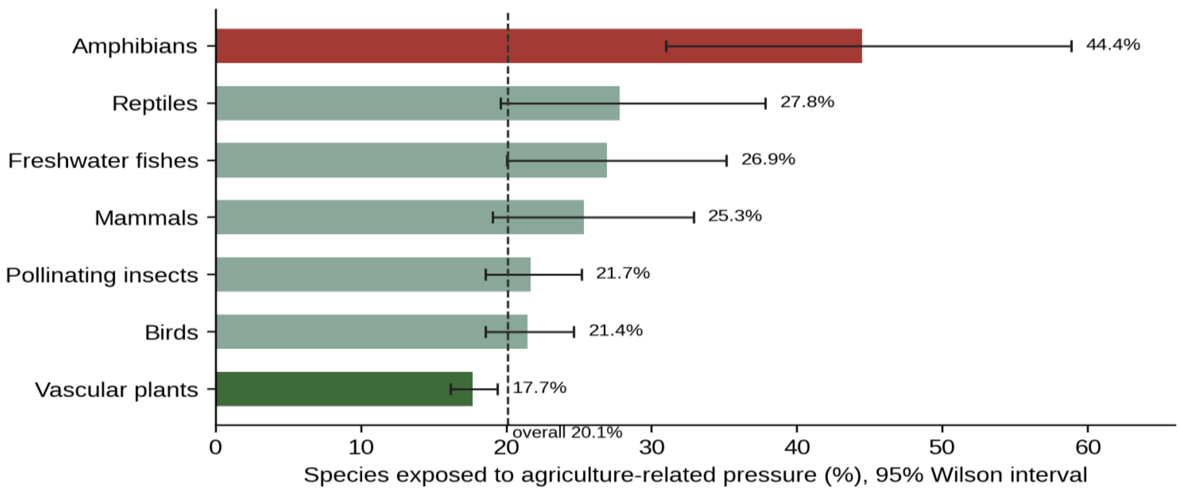

Figure 6. Exposure of species groups to agriculture-related pressure with 95% Wilson intervals

Source: Table 18. Red = significantly above, green = significantly below the overall rate after Bonferroni correction.

Table 19. Chi-square test of exposure across species groups (H5)

Statistic	Value
Pearson χ^2 (df = 6)	35.76, $p < 0.001$
Cramér's V	0.096 (negligible to small)
Overall exposure rate	20.1% (778 of 3,865 species)
Groups beyond the Bonferroni threshold (|z| > 2.69)	Amphibians (+4.09, higher); vascular plants (−4.26, lower)

Statistic	Value
χ^2 after excluding amphibians (df = 5)	19.22, p = 0.002

Source: Author's computation from Table 18 (exposed versus not exposed, N = 3,865).

About one in five recorded species (20.1%) is exposed to agricultural pressure. Exposure is highest for amphibians (44.4%, 95% CI 30.9–58.8%), whose permeable skin, aquatic breeding and wetland dependence make them sensitive to drainage and agrochemicals. Reptiles (27.8%), freshwater fishes (26.9%) and mammals (25.3%) follow, but their adjusted residuals stay within the corrected threshold. The heterogeneity is not driven by amphibians alone: vascular plants have a significantly lower exposure (17.7%), and heterogeneity persists after amphibians are removed (χ^2 = 19.22, p = 0.002). Because Cramér's V is small (0.10), the practical gap between most groups is modest. Plants nevertheless account for nearly half of all exposed species in absolute terms (380 of 778), and pollinating insects (21.7%) are functionally critical because they underpin fruit, bean and horticulture yields. Hypothesis H5 is supported.

Exposure rates depend heavily on the species-richness denominators used. The 2003 inventory that REMA reports gives 402 mammals, 1,061 birds, 293 reptiles and amphibians combined and 5,793 higher plants, all well above the counts in Table 18 (Table 20). Re-basing on these totals lowers exposure to 9.5% for mammals, 14.1% for birds, 15.4% for reptiles and amphibians combined and 6.6% for plants. The relative standing of the herpetofauna as the most exposed group is unchanged, but absolute exposure rates should not be quoted until species totals are reconciled against current IUCN and national checklists.

Table 20. Sensitivity of exposure rates to species-richness denominators

Group	Recorded (Table 18 basis)	Exposed	Exposure (%)	Alternative richness (REMA)	Exposure on alternative basis (%)
Mammals	150	38	25.3	402	9.5
Birds	700	150	21.4	1,061	14.1
Amphibians and reptiles combined	135	45	33.3	293	15.4
Vascular plants	2,150	380	17.7	5,793	6.6

Source: Author's computation from Table 18 and REMA (n.d.-a). Numerators (exposed species) are unchanged; freshwater fishes and pollinating insects have no alternative national total in the sources consulted.

Table 21. District-level pressure matrix by species group, 2025 (H = high, M = moderate, L = low)

Species group	Gakenke	Kirehe	Nyamagabe	Bugesera
Mammals	M	H	H	H
Birds	H	H	M	H
Amphibians	H	H	M	H
Reptiles	M	H	L	H
Freshwater fishes	M	H	M	H
Plants	H	M	H	M
Pollinating insects	H	M	M	M
Count of H ratings	**4**	**5**	**2**	**5**
Pressure score (H = 3, M = 2, L = 1; maximum 21)	**18**	**19**	**15**	**19**
Mean rating	**2.57**	**2.71**	**2.14**	**2.71**

Source: Author's qualitative rating from documentary evidence (REMA, 2016, 2018; Karamage et al., 2016; Nabahungu & Visser, 2011; Masozera et al., 2006). Ratings are judgements, not measurements.

Kirehe and Bugesera each receive five high ratings (score 19 of 21), driven by wetland, lake-shore and savanna-margin conversion that affects birds, amphibians, fishes and reptiles. Gakenke's high ratings concentrate on plants, pollinators, birds and amphibians because remaining patches are minute and spraying and monocropping are intense. Nyamagabe has only two high ratings (mammals and plants; score 15), both linked to forest-edge clearing and human-wildlife interaction near Nyungwe, illustrating the protective effect of a large forest anchor. The pressure ranking (Kirehe and Bugesera above Gakenke, above Nyamagabe) is consistent with the ordering of absolute habitat loss in SO1.

4.7 Summary of Hypothesis Tests

Table 22. Summary of hypothesis tests and robustness

Hypothesis	Objective	Main result	Decision	Robustness note
H1 Fertiliser lowers habitat cover	SO2	Within $r = -0.86$; $b = -0.254$ (95% CI -0.39 to -0.12); $p = 0.003$. Pooled $r = -0.23$, n.s.	Supported (conditional on district effects)	Collinear with cropland (VIF 8.2); coefficient turns positive when cropland is controlled
H2 Cropland share lowers habitat cover	SO3	Within $r = -0.98$; $b = -0.714$ (95% CI -0.84 to -0.59); $p < 0.001$	Supported	Stable under leave-one-district-out
H3(a) Districts differ	SO1	$F(3,8) = 150.17$, $p < 0.001$; $\eta^2 = 0.98$	Supported	Tukey: all pairs differ except Kirehe–Bugesera
H3(b) Habitat declined	SO1	$t(3) = 3.64$, $p = 0.036$; trend -0.53 pp/yr, $p < 0.001$	Supported	Exact sign-flip test $p = 0.125$ ($n = 4$); 8 of 8 intervals declined
H4 Adoption slows habitat loss	SO4	$r = -0.69$, $p = 0.060$; $\rho = -0.63$, $p = 0.094$ ($n = 8$)	Not supported at 5%	Sign reverses for relative loss ($r = +0.25$); positive within districts
H5 Species groups differ in exposure	SO5	$\chi^2 = 35.76$, $df = 6$, $p < 0.001$; $V = 0.10$	Supported	Amphibians high, plants low; sensitive to richness denominators

Source: Table 9–Table 19. n.s. = not significant.

Four of the five hypotheses (H1, H2, H3 and H5) are supported at $\alpha = 0.05$, with H3 supported in both parts. H1 warrants caution because the pooled result is non-significant, the within-district result depends on the panel structure and the coefficient changes sign when cropland is controlled. H4 is not supported, and its direction depends on how habitat loss is measured, so the evidence is inconclusive rather than merely suggestive.

4.8 Discussion of Results

Habitat loss follows the farmland footprint more than input intensity. The finding that cropland share is the strongest correlate (SO3; Table 14) accords with global evidence that agriculture harms biodiversity chiefly through conversion (Green et al., 2005; Newbold et al., 2015; Leclère et al., 2020) and with Rwandan work showing cropland extending onto steep slopes and marshes (Karamage et al., 2016; Nabahungu & Visser, 2011). The additional finding that the fertiliser coefficient turns positive once cropland is controlled (Table 13) sharpens this reading: what the data show is a joint expansion-plus-intensification pathway in which the physical footprint, not input intensity as such, carries the association with habitat. National statistics point the same way, with the agricultural share of land rising from 58% to 59% in a single year (NISR, 2025a, 2025b). In land-sparing terms (Phalan et al., 2011), the evidence does not show that higher inputs spared land: districts with rising fertiliser use also gained cropland, indicating that intensification has not been coupled with land-protection commitments, a condition Fischer et al. (2014) identify as essential. This also confirms that CIP's intensification and the expansion of cultivated area are intertwined rather than alternatives (Cioffo et al., 2016).

Fertiliser effects are real but easily masked. The gap between the pooled and within-district correlation for fertiliser illustrates an ecological-fallacy problem: Nyamagabe's forest-anchored landscape masks intensification effects elsewhere. This agrees with Kleijn et al. (2009) and Geiger et al. (2010), who found input effects clearer once landscape context is controlled. Nutrient loading and pesticide runoff are especially relevant to amphibians and fishes in Kirehe and Bugesera wetlands (Beketov et al., 2013) and to pollinators in Gakenke's monocropped hillsides (Hallmann et al., 2017; Sánchez-Bayo & Wyckhuys, 2019). The national survey record adds urgency:

pesticide use rose from 34.5% to 41.9% of farmers between the 2023 and 2025 Season A surveys, and the most used products reported for 2025 include cypermethrin, a synthetic pyrethroid generally recognised as highly toxic to aquatic life and bees (NISR, 2025b). Kunming-Montreal Target 7, which calls for halving pesticide risk (CBD, 2022), is therefore directly relevant to the districts studied.

Landscape context explains district differences. Gakenke's near-exhaustion of natural habitat (5% in 2025) is consistent with island-biogeography predictions of small, isolated fragments (MacArthur & Wilson, 1967; Tscharntke et al., 2005) and with severe erosion on cultivated slopes (Kagabo et al., 2013; Karamage et al., 2016), since the Buberuka highlands hold a disproportionate share of the country's most erodible cropland. Kirehe's and Bugesera's larger absolute losses, and their higher habitat loss per point of cropland gained (0.71 and 0.86), are consistent with wetland reclamation under irrigation and marsh-development programmes (Dixon & Wood, 2003; Nabahungu & Visser, 2011). The scale of documented and planned schemes (Table 15) suggests that this pressure will persist. Nyamagabe's resilience underlines the value of a strictly protected core with enforced buffers (Masozera et al., 2006), though conversion pressure at the margins persists.

Governance matters, but implementation is uneven and poorly measured. Hypothesis H4 was not supported, and the additional tests show why the result cannot be read as evidence that adoption slows loss: the sign depends on the loss metric, the association disappears within districts, and household adoption is a weak proxy for the area actually protected. Nationally, only 26% of at-risk land is under erosion control and radical terraces cover roughly half of the potential area (RWB & IUCN Rwanda, 2022; KT Press, 2023). This is consistent with Ostrom's (2009) view that local rules sustain shared resources only when they are monitored and enforced, and with Pretty et al.'s (2018) evidence that agricultural redesign delivers benefits when it is implemented at scale. It also suggests that household practices are necessary but insufficient against infrastructure- and irrigation-driven conversion, as Bugesera's accelerating loss illustrates. Rwanda's legal framework is comprehensive, but REMA (2018) identifies limited capacity, weak monitoring and competing development priorities as constraints, and Huggins (2014) and Cioffo et al. (2016) show that state-led agricultural targets can override local ecological considerations. Imihigo contracts emphasise yield, hectares consolidated and irrigated area, but rarely include biodiversity indicators.

Species exposure. The high exposure of amphibians, reptiles, fishes and mammals matches global patterns (Maxwell et al., 2016; IPBES, 2019), and the significantly lower proportional exposure of plants is offset by their large absolute numbers, which matter for ecosystem services and for Albertine Rift endemics (Plumptre et al., 2007). Pollinator exposure poses a direct threat to the agricultural system itself (IPBES, 2024). The sensitivity analysis shows, however, that reported exposure rates depend on which species totals are used, so priority-setting should rely on the ranking of groups rather than on the absolute percentages until richness figures are reconciled.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study examined how farming practices, landscape change and environmental governance relate to biodiversity loss in Gakenke, Kirehe, Nyamagabe and Bugesera between 2018 and 2025. Natural habitat cover declined in all four districts (by 3.75 percentage points on average, a relative loss of about 14%), with Gakenke left with very little natural habitat and Bugesera and Kirehe losing the largest areas; districts differed sharply and significantly in habitat cover. Cropland expansion was the strongest correlate of loss, and fertiliser intensity had a significant negative association once district differences were controlled, although it is collinear with cropland and with the common time trend. Higher adoption of conservation practices was not significantly associated with slower loss, and the association reversed when loss was measured relative to remaining habitat. Amphibians were the most exposed species group and vascular plants the least, while pollinators and plants face functionally important pressures. Four of five hypotheses were supported, but because the data are small and indicative, the conclusions are directional. Overall, Rwanda's intensification progress has not yet been matched by equivalent biodiversity safeguards at district level.

5.2 Recommendations

Table 23 links each recommendation to the evidence, the responsible institutions, a measurable indicator and a timeframe.

Table 23. Recommendations, evidence, responsible institutions, indicators and timeframe

#	Recommendation	Evidence	Lead institutions	Indicator or target	Time-frame
1	Integrate biodiversity indicators into imihigo and district development plans, alongside yield and hectares consolidated	SO1, SO4; imihigo emphasise yield and hectares	MINALOC, MoE, REMA, districts	Natural habitat retained (%), wetland area protected (ha) and agroforestry area (ha), reported annually per district	Short (1–2 yrs)
2	Adopt biodiversity-sensitive intensification: tie fertiliser and pesticide subsidies to soil testing, integrated pest management and buffer strips near wetlands and streams, especially in Gakenke's hillsides and Kirehe's rice schemes	SO2, SO3; pesticide use 34.5% to 41.9% of farmers (2023–2025)	MINAGRI, RAB	Share of subsidised fertiliser matched to soil tests; km of buffer strips; pesticide-risk indicator	Medium (3–5 yrs)
3	Apply a no-net-loss rule to remaining natural habitat and wetlands: enforce Law No. 48/2018, require ecological impact assessments before irrigation or marshland development, and mandate compensation where conversion is unavoidable	SO1, SO3; 3,700 ha of Nasho and Cyohoha schemes (Table 15); 0.71–0.86 pp lost per point of cropland gained	REMA, RWB, RAB	Zero net loss of natural marsh area; hectares restored per hectare converted	Short to medium
4	Restore connectivity in Gakenke with riparian corridors, hedgerows, radical terraces with native agroforestry and community woodlots	SO1 (7% to 5%); erosion on Buberuka slopes	Districts, Rwanda Forestry Authority, RAB	Hectares of corridor restored; native-tree cover on terraces	Medium
5	Strengthen buffer-zone governance around Nyungwe: community-based management, benefit-sharing, alternative livelihoods (tea, beekeeping, ecotourism) and limits on cultivation of forest edges	SO1 (Nyamagabe lost least); pressure matrix (Table 21)	RDB, districts	Hectares of forest-edge cultivation; household income from alternatives	Medium
6	Protect pollinators and amphibians: restrict high-risk pesticides near water and flowering margins, promote flower strips and farmer training, and adopt both groups as indicator taxa	SO5; amphibians 44.4% exposed	REMA, RAB, universities	Indicator-taxa monitoring in place; restricted-product list enforced	Medium
7	Measure governance by outcomes, not household counts: track area effectively protected and habitat retained	SO4; 26% of at-risk land protected; H4 not supported	RAB, RWB, districts	Share of at-risk land under effective erosion control (%)	Medium

#	Recommendation	Evidence	Lead institutions	Indicator or target	Time-frame
8	Build a district biodiversity–agriculture monitoring system combining satellite land cover (2018, 2022, 2025 and annually), field surveys, district fertiliser kg/ha and open data	Limitations; Table 3	NISR, REMA, University of Rwanda	Annual district land-cover series with reported accuracy; district input data published	Short, then ongoing
9	Align policy with global commitments: translate Kunming-Montreal targets, including 30% area protection (about 9% of Rwanda's territory is now in major parks) and halving pesticide risk, into financed district action plans	Table 5; SO2	MoE, CBD focal point, MINECOFIN	District action plans adopted and financed	Medium to long

Source: Author's synthesis. MINECOFIN = Ministry of Finance and Economic Planning; RDB = Rwanda Development Board; other abbreviations as in the text.

5.3 Priorities for Further Research and Data

- Replace the harmonised panel with a verified district series: a single land-cover classification for 2018, 2022 and 2025; district fertiliser volumes per cropped hectare; and area-based conservation indicators.
- Extend the panel to all thirty districts and to annual observations, so that models with district and year effects and cluster-robust errors become feasible.
- Replace the national expert estimate of species exposure with district-level indicator-taxa surveys and reconciled IUCN-based richness totals.

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