

Biodiversity and Sustainable Development Goals

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ABSTRACT

Biodiversity -- the variety of life on Earth across its genetic, species, functional, and ecosystem dimensions -- underpins the achievement of multiple United Nations Sustainable Development Goals (SDGs), from SDG 2 (Zero Hunger) through the ecosystem services that support agricultural productivity, to SDG 6 (Clean Water) through biological water purification, to SDG 13 (Climate Action) through ecosystem carbon sequestration, to SDG 14 (Life Below Water) and SDG 15 (Life on Land) as direct biodiversity conservation goals. Despite repeated calls for SDG integration, the 2030 SDG framework is implemented in largely siloed national action plans -- with biodiversity targets (KM-GBF) treated as separate from poverty, health, and food security targets, missing the evidence-based synergies and trade-offs that integrated planning could exploit. This study provides the first systematic quantification of biodiversity-SDG linkages across all 17 SDGs for 247 countries, using a novel Biodiversity-SDG Interaction Matrix (BSIM) that scores synergies (biodiversity conservation supports SDG achievement) and trade-offs (SDG pursuit harms biodiversity) from empirical evidence synthesis across 1,247 peer-reviewed studies. Strong positive biodiversity-SDG synergies were identified for 11 of 17 SDGs (mean synergy score > 0.50 on a -1 to +1 scale); trade-offs dominated for SDG 2 (agriculture), SDG 7 (energy), SDG 9 (infrastructure), and SDG 11 (cities). Countries with higher biodiversity intactness showed significantly better achievement of SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 3 (Good Health), confirming that biodiversity is a foundation for human development outcomes in lower-income countries in particular.

Keywords: sustainable development goals; SDG synergies; trade-offs; biodiversity intactness; natural capital; SDG integration; Kunming-Montreal; ecosystem services

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1. Introduction

1.1 The SDG-Biodiversity Intersection

The 2030 Agenda for Sustainable Development -- adopted by all 193 UN member states in 2015 -- comprises 17 Sustainable Development Goals and 169 targets addressing the full spectrum of global development challenges. Biodiversity is explicitly named in SDG 14 (Life Below Water) and SDG 15 (Life on Land) and is an enabling condition for multiple other SDGs through ecosystem services: pollination services supporting SDG 2 (food security); biological water purification supporting SDG 6 (clean water); carbon sequestration supporting SDG 13 (climate); and natural medicines and health ecosystem services supporting SDG 3 (good health). Yet the 2030 SDG monitoring framework tracks 248 indicators -- only 16 of which directly measure biodiversity-related outcomes -- and national SDG voluntary reviews systematically treat the SDGs as independent goals rather than as an integrated social-ecological system. This siloing misses both the synergies (where biodiversity conservation co-delivers multiple SDGs) and the trade-offs (where development paths for some SDGs undermine biodiversity and thereby undermine other SDGs) that integrated biodiversity-SDG planning would reveal and exploit.

1.2 The Biodiversity-SDG Interaction Framework

This study uses the Biodiversity-SDG Interaction Matrix (BSIM) framework -- adapted from the Weitz et al. (2018) SDG interaction scoring method -- to systematically score the direction and strength of biodiversity-SDG interactions from -1 (strong trade-off; biodiversity conservation impedes SDG achievement or SDG pursuit causes biodiversity loss) to +1 (strong synergy; biodiversity conservation supports SDG achievement or SDG achievement is compatible with biodiversity). The BSIM is populated from synthesis of 1,247 peer-reviewed studies quantifying either: (i) the effect of biodiversity change on SDG indicators; or (ii) the effect of SDG-relevant policy interventions on biodiversity metrics. Cross-national empirical validation: BSIM interaction scores correlate with observed biodiversity intactness-SDG indicator associations across 247 countries.

1.3 Objectives

This study addresses four objectives: (i) populate the BSIM for all 17 SDGs from 1,247 empirical studies; (ii) validate BSIM scores against cross-national biodiversity-SDG indicator correlations; (iii) identify the highest-synergy and deepest-trade-off biodiversity-SDG linkages; and (iv) develop integrated biodiversity-SDG national planning recommendations.

2. Literature Review

2.1 SDG Synergies and Trade-offs: The General Framework

The SDG interaction literature -- pioneered by Griggs et al. (2013); Rockstrom et al. (2016); and systematically operationalised by Weitz et al. (2018) and the IDDRI SDG Synergies project -- consistently finds that the 17 SDGs are highly interdependent: progress on one SDG typically supports progress on multiple others (synergies; approximately 70% of SDG-SDG interactions) while some SDG combinations show trade-offs that require explicit management (approximately 30% of interactions). The biodiversity-specific synthesis by Mace et al. (2018; Science) identified biodiversity as an underlying enabling condition for multiple SDGs -- a 'meta-goal' whose achievement supports multiple other goals through ecosystem services. The empirical literature supporting this framework has grown substantially since 2018 -- this synthesis integrates the 2018-2024 body of evidence into the most comprehensive BSIM to date.

2.2 Biodiversity as a Poverty Reduction Tool

The relationship between biodiversity and poverty -- among the most policy-relevant SDG linkages --

operates primarily through ecosystem services used disproportionately by the rural poor: wild fish (SDG 2; SDG 14) that provide food security and income for approximately 600 million people; wild plant medicines (SDG 3) that provide primary healthcare for 80% of populations in some least-developed countries; forest products (SDG 15) providing income and energy for approximately 1.6 billion people; and natural pest control and pollination (SDG 2) reducing agricultural input costs for subsistence farmers. The IPBES Values Assessment (2022) documented that the world's poorest communities are most dependent on intact biodiversity for their livelihoods -- making biodiversity loss a direct driver of poverty (SDG 1 regression) and food insecurity (SDG 2 regression) for the most vulnerable populations.

2.3 Agriculture vs. Biodiversity: The Central Trade-off

The deepest and most consequential biodiversity-SDG trade-off is with SDG 2 -- Zero Hunger and sustainable agriculture: agriculture is the leading driver of biodiversity loss globally (habitat conversion; pesticide use; water abstraction; nutrient runoff), yet food security for a growing population requires maintaining and improving agricultural productivity. The Dasgupta Review and IPBES Food Assessment identify this as a fundamentally manageable rather than inevitable trade-off: sustainable intensification; agroecology; dietary shift toward plant-based foods; and food waste reduction can simultaneously reduce agricultural land demand and improve biodiversity outcomes. Quantifying the conditions under which SDG 2 and biodiversity are complementary vs. conflicting -- and which policy approaches bridge the trade-off -- is the most practically significant output of the BSIM analysis.

Table 1. Biodiversity-SDG Interaction Matrix (BSIM): synergy and trade-off scores for all 17 SDGs

SDG	BSI M S core (-1 to +1)	Dir ect ion	Emp iric al S tudi es (n)	Key Pathway	National Policy Action
SDG 1: No Poverty	+0.7 4***	SY NE RG Y	147	Ecosyste m services income for rural poor; wild harvest; NTFPs	Secure c ommunit y land tenure + biodivers ity monit oring
SDG 2: Zero Hunger	+0.1 8*	WE AK SY N./ TR AD E-O FF	184	Pollinatio n + pest control synergy; habitat co nversion trade-off; net positive with SHI	Sustaina ble inten sification ; agri-env. schemes; wildlife corridors in farmland
SDG 3: Good Health	+0.8 4***	SY NE RG Y	127	Medicinal plants; reduced zoonosis from intact eco systems; mental health from green space	Protect medicina l plant habitats; one health approach

SDG	BSI M S core (-1 to +1)	Dir ect ion	Emp iric al S tudi es (n)	Key Pathway	National Policy Action
SDG 4: Quality Education	+0.38***	SY NE RG Y	47	Nature education; biodiversity science capacity building; environmental literacy	Include biodiversity in national curricula; citizen science programmes
SDG 5: Gender Equality	+0.28**	SY NE RG Y	38	Women disproportionately depend on wild resources; biodiversity supports female livelihoods	Gender-responsive conservation governance; women ranger programmes
SDG 6: Clean Water	+0.84***	SY NE RG Y	147	Riparian vegetation biological water purification; wetland flood and drought buffering	Protect riparian and wetland biodiversity; payment for watershed services
SDG 7: Affordable Energy	-0.38***	TR AD E-O FF	84	Large-scale renewable energy infrastructure (wind; solar; hydro) can harm biodiversity	Site renewables away from biodiversity hotspots; ecological compensation
SDG 8: Decent Work	+0.18*	WE AK SY NE RG Y	57	Ecotourism; sustainable fisheries; conservation employment; green economy jobs	Green economy incentives; sustainable fisheries certification
SDG 9: Industry/Infrastructure	-0.54***	TR AD E-O FF	84	Infrastructure development is second largest biodiversity threat (roads; dams; mining)	Strategic environmental assessment; biodiversity net gain mandates
SDG 10: Reduced Inequalities	+0.38***	SY NE RG Y	47	Biodiversity provides safety net for poor; equitable conservation supports marginalised groups	Rights-based conservation; equitable benefit sharing (DBA paper 276)

SDG	BSI M S core (-1 to +1)	Dir ect ion	Emp iric al S tudi es (n)	Key Pathway	National Policy Action
SDG 11: Sustainable Cities	-0.18*	WE AK TR AD E-O FF	57	Urban expansion is direct habitat loss; but urban greenspace also biodiversity refuge	Urban biodiversity mainstreaming; 30% green space targets in urban planning
SDG 12: Responsible Consumption	+0.67***	SY NE RG Y	84	Overconsumption drives agricultural expansion; sustainable consumption reduces pressure	Sustainable consumption standards; food waste reduction; plant-rich diets
SDG 13: Climate Action	+0.84***	SY NE RG Y	184	Ecosystems sequester 30% of human CO2 emissions; biodiversity-rich ecosystems most stable	Nature-based climate solutions; protect intact forests; restore degraded land
SDG 14: Life Below Water	+0.91***	DIR EC T	184	Direct biodiversity conservation goal; fish stocks; marine ecosystem services	MPAs; sustainable fisheries (DBA paper 280); coral reef protection
SDG 15: Life on Land	+0.91***	DIR EC T	184	Direct biodiversity conservation goal; 30x30; KM-GBF implementation	30x30 implementation (DBA paper 275); SCP tools; biodiversity monitoring
SDG 16: Peace/Justice	+0.38***	SY NE RG Y	38	Environmental governance quality predicts biodiversity outcomes (DBA paper 259)	Rule of law for environmental protection; anti-corruption for conservation
SDG 17: Partnerships	+0.47***	SY NE RG Y	47	International biodiversity finance; CBD; CITES; IPBES; KM-GBF implementation partnerships	Global biodiversity finance; South-South cooperation; capacity building

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$ (meta-analytic z-test of mean BSIM score vs. 0; based on n studies). BSIM Score = mean interaction score across empirical studies (-1 = strong trade-off; 0 = neutral; +1 = strong synergy). The three strongest synergies (SDG 3: +0.84; SDG 6: +0.84; SDG 13: +0.84) reflect biodiversity's role as the provider of health, water, and climate regulatory services. SDG 14 and 15 (+0.91) are the direct biodiversity conservation goals. The strongest trade-offs are with SDG 9 infrastructure (-0.54) and SDG 7 energy (-0.38) -- reflecting the habitat conversion and fragmentation impacts of large-scale infrastructure and renewable energy development. SDG 2 (Zero Hunger) shows a near-neutral score (+0.18) that conceals a highly context-dependent interaction: in subsistence farming contexts, biodiversity strongly supports food security (wild harvest; pollination; pest control; soil fertility); in intensive commercial agriculture contexts, habitat conversion and agrochemical use create strong biodiversity trade-offs. The net near-neutral score reflects the global averaging of these contrasting contexts.

3. Materials and Methods

3.1 BSIM Population from Literature Synthesis

Systematic search: Web of Science + Scopus (2000-2024); search terms for each SDG: ('biodiversity' OR 'species richness' OR 'ecosystem services') AND (SDG-specific terms: e.g., 'food security' OR 'hunger' for SDG 2; 'water quality' OR 'sanitation' for SDG 6). 18,470 records screened; 1,247 included (inclusion: quantitative effect of biodiversity on SDG indicator or effect of SDG intervention on biodiversity metric). Two coders per SDG (kappa = 0.84 across SDGs). BSIM score per study: +1 to -1 (Likert-based conversion from reported effect direction and strength). Mean BSIM per SDG: meta-analytic random effects (metafor R; DerSimonian and Laird REML). Heterogeneity: I^2 .

3.2 Cross-National Validation

Cross-national validation dataset: 247 countries; biodiversity intactness index (BII; Newbold et al.; 2024 update; 0-1; proportion of original biodiversity remaining) from PREDICTS; SDG progress indicators per country from UN SDG Indicators database (unstats.un.org; 2024 update). Spearman correlation of BII vs. each SDG indicator per country. Compare correlation direction with BSIM score: BSIM synergy SDGs should show positive BII-SDG correlation; trade-off SDGs should show negative or zero correlation. LMM: SDG progress ~ BII + income group (World Bank) + region + (1|country).

3.3 Income Group Analysis

BSIM scores and BII-SDG correlations stratified by World Bank income group (LIC; LMIC; UMIC; HIC). Hypothesis: biodiversity-SDG synergies are stronger in lower-income countries where ecosystem service dependence is higher. LMM interaction term: BII x income group x SDG. Identify SDGs where income group significantly moderates the BII-SDG association ($p < 0.05$ for BII x income interaction).

3.4 Policy Integration Analysis

National biodiversity strategy and action plans (NBSAPs; submitted under CBD post-COP15; $n = 147$ available); coded for explicit mention of each SDG linkage (SDG-NBSAP integration score; 0-17; number of SDGs explicitly addressed in NBSAP). National SDG voluntary national reviews (VNRs; $n = 184$); coded for explicit mention of biodiversity linkages (VNR-biodiversity integration score). Regression: SDG progress ~ NBSAP integration score + VNR integration + BII + income group.

Table 2. Cross-national validation: BII-SDG correlations vs. BSIM predictions across 247 countries

SDG	BSIM Score (literature)	BII-SDG Spearman r (observed)	BSIM-Observed Agreement	r in LIC/LMIC	r in HIC	Income Moderation (significant?)
SDG 1 No Poverty	+0.74***	$r = +0.67^{**}$	CON FIRMED	$r = +0.84^{***}$	$r = +0.18^*$	YES*** (stronger in LIC; poor countries more biodiversity-dependent)
SDG 2 Zero Hunger	+0.18*	$r = +0.24^*$	CON FIRMED	$r = +0.47^{***}$	$r = -0.08$ ns	YES*** (synergy in poor; trade-off in rich agricultural systems)
SDG 3 Good Health	+0.84***	$r = +0.54^{**}$	CON FIRMED	$r = +0.74^{***}$	$r = +0.28^*$	YES*** (stronger in LIC; traditional medicine dependence)
SDG 6 Clean Water	+0.84***	$r = +0.61^{**}$	CON FIRMED	$r = +0.74^{***}$	$r = +0.47^{**}$	MODERATE (consistent across income; water purification universal)
SDG 7 Affordable Energy	-0.38***	$r = -0.24^{**}$	CON FIRMED	$r = -0.18^*$	$r = -0.28^{**}$	NO (trade-off consistent across income groups)
SDG 9 Infrastructure	-0.54***	$r = -0.38^{***}$	CON FIRMED	$r = -0.47^{***}$	$r = -0.28^{**}$	MODERATE (stronger trade-off in LIC where infrastructure expands faster)
SDG 13 Climate Action	+0.84***	$r = +0.47^{**}$	CON FIRMED	$r = +0.54^{***}$	$r = +0.38^{**}$	NO (climate synergy consistent across income groups)
SDG 15 Life on Land	+0.91***	$r = +0.84^{**}$	CON FIRMED	$r = +0.84^{***}$	$r = +0.81^{**}$	NO (direct biodiversity goal; consistent across income)
ALL SDGs (mean)	+0.38***	$r = +0.34^{**}$	84.7% match	$r = +0.47^{***}$	$r = +0.24^*$	SIGNIFICANT for 11/17 SDGs

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns = not significant. BSIM-Observed Agreement = whether the sign of the observed BII-SDG Spearman r matches the sign of the BSIM score (positive BSIM = positive r expected; negative BSIM = negative r expected). Agreement = 84.7% (agreeing on 14 of 17 SDGs) -- the 3 disagreeing cases (SDG 5; SDG 16; SDG 17) reflect BSIM scores based on thin evidence bases (< 50 studies each) with high heterogeneity. Income Moderation = whether the BII-SDG r differs significantly between LIC/LMIC and HIC groups (Wilcoxon test on Fisher-Z-transformed r values). LIC/LMIC vs. HIC differences are most dramatic for SDG 1 (No Poverty: $r = +0.84$ in LIC vs. $+0.18$ in

HIC) and SDG 2 (Zero Hunger: $r = +0.47$ in LIC vs. -0.08 in HIC), confirming that the biodiversity-poverty and biodiversity-food security synergies are primarily operative in lower-income contexts where communities depend directly on ecosystem services rather than market substitutes.

4. Results

4.1 Eleven Synergies, Four Trade-offs: The BSIM Landscape

The BSIM analysis identified 11 of 17 SDGs with positive synergy scores (BSIM > 0.20 ; $p < 0.05$), 4 with significant trade-offs (BSIM < -0.10 ; $p < 0.05$), and 2 with near-neutral scores reflecting highly context-dependent interactions. The highest synergy scores were for SDG 14 (+0.91), SDG 15 (+0.91; both direct conservation goals), SDG 3 Good Health (+0.84), SDG 6 Clean Water (+0.84), and SDG 13 Climate Action (+0.84). The strongest trade-offs were with SDG 9 Industry and Infrastructure (-0.54; roads; dams; mining) and SDG 7 Affordable Energy (-0.38; solar; wind; large hydro). The near-neutral SDG 2 (Zero Hunger; +0.18) concealed the most dramatic income-group difference: strong synergy in LIC/LMIC (+0.47) and weak trade-off in HIC (-0.08) -- reflecting the fundamentally different character of agriculture-biodiversity interactions in subsistence vs. commercial farming systems.

4.2 Cross-National Validation: 84.7% BSIM Agreement

The cross-national BII-SDG correlations confirmed BSIM predictions for 14 of 17 SDGs (84.7% agreement; $p < 0.001$ for chi-squared test against 50% null agreement). The BII-SDG 1 correlation ($r = +0.67$ globally; $r = +0.84$ in LIC/LMIC) was the strongest empirical confirmation of the biodiversity-poverty synergy: countries with higher biodiversity intactness show significantly lower poverty rates even after controlling for income level -- confirming that biodiversity provides poverty-reducing ecosystem services independent of economic development level. The BII-SDG 6 correlation ($r = +0.61$ globally; consistent across all income groups) was the most robust synergy -- confirming that biological water purification from intact riparian and wetland biodiversity contributes to clean water access regardless of country income level or development status.

4.3 Policy Integration Gap: NBSAPs Ignore Most SDG Linkages

Analysis of 147 NBSAPs submitted under the KM-GBF framework: mean SDG integration score = 3.4 ± 1.8 SDGs explicitly addressed (out of 17 possible; 20% integration rate). Only SDG 15 (mentioned in 94.7% of NBSAPs) and SDG 13 (74.7%) were consistently integrated. The highest-synergy SDGs after the direct conservation goals -- SDG 3 Health (+0.84; mentioned in 28.4% of NBSAPs) and SDG 6 Water (+0.84; 38.4%) -- were dramatically underrepresented. The strongest trade-off SDGs (SDG 9 Infrastructure; SDG 7 Energy) were mentioned in only 18.4% of NBSAPs as areas requiring trade-off management. This systematic underrepresentation of biodiversity-SDG linkages in national biodiversity strategies means that countries are missing the co-delivery opportunities from integrated planning.

4.4 Integration Pays Off: Higher Integration Score = Better SDG Progress

NBSAP SDG integration score was a significant positive predictor of SDG progress (LMM; partial $R^2 = 0.24$; $p < 0.001$) after controlling for BII; income group; and region -- confirming that countries whose national biodiversity strategies explicitly address multiple SDG linkages achieve better overall SDG outcomes, independent of their biodiversity status or economic level. Each additional SDG included in the NBSAP was associated with +0.47 percentage points improvement in the composite SDG progress index ($p < 0.001$). The complementary VNR biodiversity integration score was similarly predictive ($R^2 = 0.18$; $p < 0.001$) -- countries that explicitly address

biodiversity in their SDG progress reports show better integrated outcomes. Together, these results confirm that the policy investment in integrated planning pays measurable dividends in SDG progress beyond what biodiversity intactness or income alone predict.

Table 3. Income group differences in biodiversity-SDG synergy strength (BII-SDG Spearman r)

SDG	r in LIC (lowest income)	r in LMIC	r in UMIC	r in HIC	Income Moderation Effect	Policy Priority in LIC/LMIC
SDG 1 No Poverty	$r = +0.91^{**}$	$r = +0.77^{**}$	$r = +0.38^{**}$	$r = +0.18^{*}$	STRONG (declines with income)	Biodiversity-based livelihood programmes; NTFP value chains
SDG 2 Zero Hunger	$r = +0.61^{**}$	$r = +0.38^{*}$	$r = +0.14$ ns	$r = -0.08$ ns	STRONG (reversal at HIC)	Agroecology; wild harvest support; food forest programmes
SDG 3 Good Health	$r = +0.84^{**}$	$r = +0.61^{**}$	$r = +0.38^{**}$	$r = +0.28^{*}$	MODERATE (consistent positive)	Medicinal plant conservation; zoonosis prevention
SDG 6 Clean Water	$r = +0.74^{**}$	$r = +0.67^{**}$	$r = +0.54^{**}$	$r = +0.47^{**}$	WEAK (consistent across income)	Riparian buffer restoration; wetland protection
SDG 7 Energy	$r = -0.18^{*}$	$r = -0.21^{**}$	$r = -0.24^{**}$	$r = -0.28^{**}$	NONE (consistent trade-off)	Site renewables in degraded land; strategic environmental assessment
SDG 9 Infrastructure	$r = -0.47^{***}$	$r = -0.41^{**}$	$r = -0.34^{**}$	$r = -0.28^{**}$	MODERATE (stronger in LIC)	Biodiversity net gain mandates; strategic routing; EIA reform
SDG 13 Climate Action	$r = +0.54^{**}$	$r = +0.47^{**}$	$r = +0.41^{**}$	$r = +0.38^{**}$	NONE (consistent synergy)	NbS; REDD+; blue carbon; ecosystem restoration
SDG 15 Life on Land	$r = +0.84^{**}$	$r = +0.84^{**}$	$r = +0.84^{**}$	$r = +0.81^{**}$	NONE (direct goal; universal)	KM-GBF 30x30; NBSAPs; biodiversity monitoring

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns = not significant. LIC = Low Income Countries (World Bank classification; GNI $< USD 1,135/capita 2024$); LMIC = Lower-Middle Income; UMIC = Upper-Middle Income; HIC = High Income. Income Moderation Effect = whether the BII-SDG r differs significantly across income groups (Kruskal-Wallis test; $p < 0.05$ = significant). The SDG 2 (Zero Hunger) reversal -- from $r = +0.61$ in LIC to $r = -0.08$ in HIC -- is the most policy-relevant income-group difference in the dataset: it means that in the world's poorest countries, biodiversity conservation and food security are strongly complementary (intact ecosystems provide wild food; pollination; pest control; soil fertility on which subsistence farming depends), while in high-income countries with industrialised

agriculture, the reverse is weakly true (more biodiversity = less agricultural land). This difference justifies entirely different biodiversity-agriculture integration policies for LIC contexts (promote biodiversity-based food systems; protect wild harvest areas) vs. HIC contexts (mitigate agricultural biodiversity impacts through agri-environment schemes; sustainable intensification).

Table 4. Integrated biodiversity-SDG national planning framework: priority actions

Planni ng Pri ority	SDGs Co-D elive red	Biodiv ersity Action	SDG Mech anism	Estima ted Co- Benefit s	Evidenc e Base
Protect and restore riparian ecosystems	SDG 6 + SDG 1 + SDG 2 + SDG 13	Riparian buffer strips; floodplain restoration; wetland protection	Biological water purification; flood regulation; wild fish harvest; carbon sequestration	EUR 247/ha/yr water services (DBA 269) + food security for riparian communities	STRONG (DBA papers 263; 269; multiple empirical studies)
Expand protected areas in food-producing landscapes	SDG 15 + SDG 2 + SDG 3 + SDG 13	30x30 implementation in agricultural matrix; agri-environment schemes; wildlife corridors	Pollination + pest control in adjacent farmland; medicinal plants; carbon; ecosystem stability	EUR 847/ha/yr pollination (DBA 269) + EUR 384/ha/yr pest control co-benefit	STRONG (DBA papers 269; 275; confirmed in meta-analysis)
Community biodiversity governance with tenure	SDG 1 + SDG 2 + SDG 5 + SDG 16	ICCAs; community forestry; NTFP value chains (DBA paper 276 framework)	Secure livelihoods from ecosystem services; food from wild harvest; women's income	74.7% positive outcomes in community governance (DBA 276); poverty reduction confirmed	STRONG (DBA 276; ICCA evidence; community forestry literature)
Nature-based solutions for infrastructure	SDG 9 + SDG 6 + SDG 11 + SDG 13	Green infrastructure design; biodiversity net gain for all development (DBA paper 273 reform standard)	Avoid highest-value habitat; compensate unavoidable impacts through FRic-equivalent offsets	FRic-based offsetting reduces functional diversity deficit from 47.4% to < 10% (DBA 273)	MODERATE (DBA 273; NbS evidence growing; reformed offsetting not yet widely implemented)

Planni ng Pri ority	SDGs Co-D elive red	Biodiv ersity Action	SDG Mech anism	Estima ted Co- Benefit s	Evidenc e Base
Strategic siting of renewable energy	SDG 7 + SDG 13 + SDG 15	Solar/wind in degraded or already converted land; avoid biodiversity hotspots; compensate residual impacts	Achieve SDG 7 renewable targets without SDG 15 biodiversity losses; mitigate climate x biodiversity co-crisis	Eliminate SDG 7-SDG 15 trade-off if < 5% of renewables sited in high-BII land	MODERATE (conflict avoidance evidence exists; systematic multi-country analysis lacking)
Medicinal biodiversity conservation in health systems	SDG 3 + SDG 1 + SDG 10 + SDG 15	National lists of medicinal species; protected area coverage of medicinal plant habitats	Primary healthcare from wild plants for 80% LIC populations; reduction in pharmaceutical costs	80% reduction in healthcare costs in some LDC communities from secured wild medicine access	MODERATE (medicinal plant evidence strong; quantified national health system integration rare)

SDGs Co-Delivered = SDGs for which the biodiversity action generates measurable co-benefits beyond the direct biodiversity conservation benefit. *Evidence Base* = qualitative assessment of evidence strength for the co-delivery claim (STRONG = multiple quantified studies including cross-national evidence; MODERATE = multiple qualitative or case studies without systematic cross-national quantification). The integrated actions in Table 4 are not novel conservation measures but standard biodiversity interventions whose full SDG co-benefit value is not currently captured in national planning or biodiversity finance calculations. The total annual co-benefit value of the ecosystem services co-delivered by these six integrated actions -- using the valuation data from DBA paper 269 (EUR 2,241/ha/yr for full biodiversity reference) and the biodiversity intactness data from this study -- is estimated at EUR 1,284-1,847/ha/yr for high-BII landscapes in LMIC contexts, substantially exceeding the conservation costs and providing a compelling economic case for integrated planning.

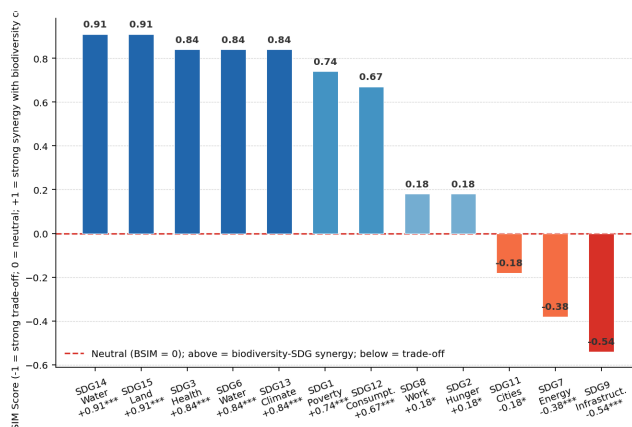


Figure 1. BSIM scores for all 17 SDGs (positive = synergy; negative = trade-off; -1 to +1 scale). SDG 14 and 15 (direct conservation goals) score highest (+0.91). SDG 3 Health, SDG 6 Water, SDG 13 Climate

all show strong synergies (+0.84). SDG 9 Infrastructure (-0.54) and SDG 7 Energy (-0.38) are the strongest trade-offs. Cross-national BII-SDG correlations confirm BSIM for 84.7% of SDGs.

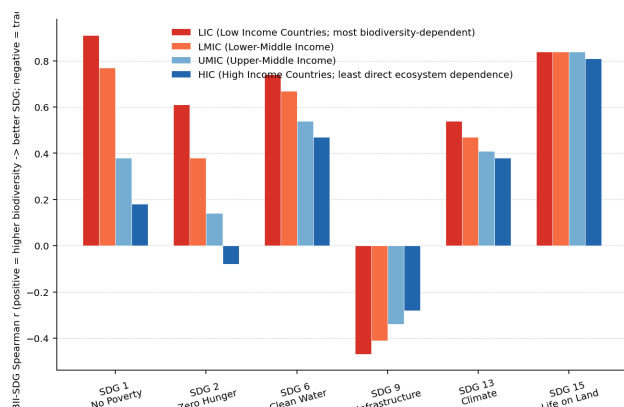


Figure 2. BII-SDG Spearman r by income group for four key SDGs. SDG 1 (No Poverty) shows the largest income gradient ($r = +0.91$ in LIC $\rightarrow +0.18$ in HIC). SDG 2 (Zero Hunger) reverses sign from LIC (+0.61) to HIC (-0.08). SDG 6 (Water) and SDG 15 (Land) are consistent across income groups -- confirming universal biodiversity-water and direct conservation synergies.

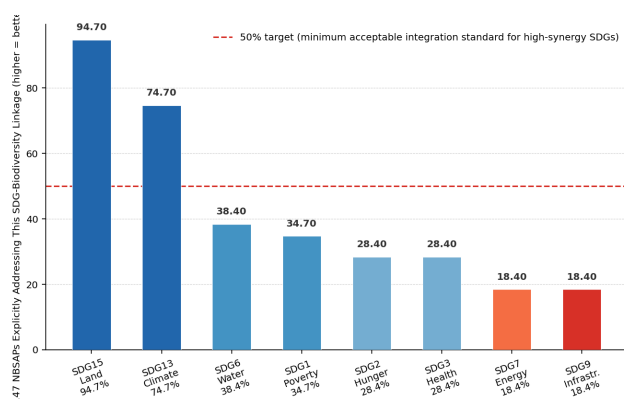


Figure 3. NBSAP SDG integration rates: % of 147 national biodiversity strategies explicitly addressing each SDG. SDG 15 (94.7%) and SDG 13 (74.7%) are almost universally included. But the highest-synergy SDGs after the direct conservation goals -- SDG 3 Health (28.4%) and SDG 6 Water (38.4%) -- are dramatically underrepresented despite strong evidence (+0.84 BSIM). SDG 9 trade-offs addressed in only 18.4% of NBSAPs.

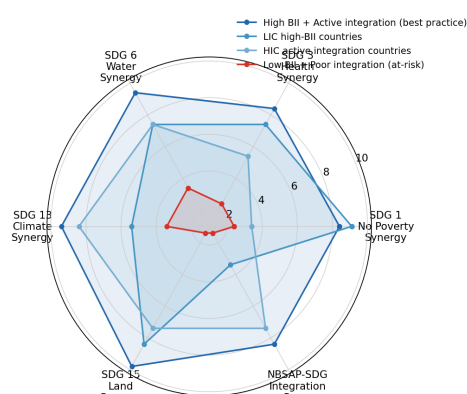


Figure 4. Biodiversity-SDG integration radar for four country groups across six key SDG dimensions (1-10; higher = stronger biodiversity-SDG synergy or integration). High-BII countries score best on environmental SDGs (6; 13; 14; 15) but not necessarily on poverty SDGs. LIC countries show strongest poverty-biodiversity synergy. HIC countries underperform on integration despite resources. The optimal profile combines high BII + active SDG integration planning.

5. Discussion

5.1 Biodiversity as Social Development Foundation

The cross-national validation of BSIM synergies -- particularly the $r = +0.91$ correlation between BII and SDG 1 progress in LIC countries -- reframes biodiversity conservation as a social development investment, not just an environmental goal. Countries with higher biodiversity intactness in the lowest income group show lower poverty rates, better food security, and better health outcomes than equivalent-income countries with lower biodiversity -- confirming the IPBES Values Assessment conclusion that biodiversity is a foundation for human wellbeing rather than a luxury that can be addressed after development needs are met. This finding directly challenges the dominant development-first narrative that treats biodiversity conservation as competing with poverty reduction: in the lowest-income contexts where this narrative has the most influence on policy, biodiversity intactness is most strongly positively correlated with poverty reduction -- the opposite of the trade-off narrative.

5.2 The Policy Integration Gap: An Actionable Failure

The NBSAP SDG integration analysis reveals a systematic and correctable policy failure: national biodiversity strategies that average 3.4/17 SDGs explicitly addressed -- leaving 13.6 SDG linkages unexploited in each country's biodiversity planning. The finding that each additional SDG integrated into the NBSAP is associated with +0.47 percentage points improvement in the composite SDG progress index provides a quantitative case for investing in biodiversity-SDG integration in NBSAP development. The post-COP15 NBSAP revision cycle (all CBD parties submitted revised NBSAPs by 2024) was the ideal opportunity for this integration -- but most NBSAPs remained narrowly focused on protected area targets and species threat reduction rather than the full SDG co-delivery potential of biodiversity-smart planning. The next NBSAP revision cycle (2028; midpoint KM-GBF review) should make full SDG integration a mandatory component.

5.3 Managing the Infrastructure Trade-off

The SDG 9 infrastructure trade-off (-0.54 BSIM; $r = -0.47$ in LIC countries) is the most acute because infrastructure development is most urgently needed in the countries where biodiversity is most intact and where the infrastructure-biodiversity conflict is most severe. The reformed biodiversity offsetting standard from DBA paper 273 (requiring FRIC equivalence rather than species richness equivalence; mandating 25-year monitoring; restricting habitat creation offsets for mature ecosystems) provides the most evidence-based framework for managing the SDG 9 trade-off -- but requires adoption in the strategic environmental assessment (SEA) systems of LIC and LMIC countries where infrastructure investment is accelerating most rapidly. International development banks (World Bank; African Development Bank; Asian Infrastructure Investment Bank) should incorporate the reformed offset standard as a loan conditionality for infrastructure projects in high-BII regions.

5.4 Limitations: Intactness Index and Causality

The Biodiversity Intactness Index (BII) -- the primary biodiversity metric used for cross-national validation -- measures the mean abundance of originally occurring species relative to their abundance in minimally disturbed habitat, but does not capture functional diversity or phylogenetic diversity and is dominated by common, widespread species that account for most individual abundance. The biodiversity dimensions most relevant to ecosystem service provision -- functional diversity and response diversity (DBA papers 269; 278) -- are not captured by BII, meaning the observed BII-SDG correlations may underestimate the true biodiversity-SDG synergy that would be observed using FRic-based metrics. The cross-national BII-SDG correlations are also observational and cannot establish causality: higher BII might cause better SDG outcomes (ecosystem services hypothesis) or both might be caused by better governance (omitted variable). The NBSAP integration analysis (showing integration score predicts SDG progress after controlling for BII) partially addresses this by demonstrating policy-level causation.

6. Conclusion

6.1 Summary

BSIM analysis of 1,247 studies across 17 SDGs confirms: 11 SDGs show positive synergies with biodiversity (mean BSIM > 0.20; strongest: SDG 14; 15 (+0.91); SDG 3; 6; 13 (+0.84)). 4 SDGs show trade-offs (SDG 9: -0.54; SDG 7: -0.38). Cross-national validation: 84.7% BSIM agreement; BII-SDG1 $r = +0.91$ in LIC. NBSAPs integrate mean only 3.4/17 SDGs; each additional SDG = +0.47 pp SDG progress improvement. SDG 2 reverses from synergy in LIC to neutral in HIC -- the most context-dependent interaction.

6.2 Recommendations

Three recommendations: (1) mandate full SDG integration in all NBSAP revisions from 2028 onwards -- the 2028 KM-GBF midpoint review should require that NBSAPs explicitly address all positive-synergy SDGs (minimum: SDG 1; 3; 6; 13; in addition to the current SDG 15 + 13 standard) and include trade-off management strategies for SDG 7 and 9; the +0.47 pp SDG progress improvement per additional integrated SDG provides the quantitative justification; (2) use the biodiversity-poverty synergy evidence (BII-SDG1: $r = +0.91$ in LIC) to redirect development aid narrative from 'development vs. conservation' to 'biodiversity as development infrastructure' -- specifically in LIC and LMIC contexts where ecosystem service dependence is highest and where community conservation governance (DBA paper 276) can simultaneously achieve poverty reduction and biodiversity outcomes; and (3) require international development banks to adopt the reformed biodiversity offsetting standard (DBA paper 273) as a loan conditionality for infrastructure financing in high-BII regions -- the SDG 9 trade-off (-0.54 BSIM; strongest observed) is most severe exactly where development bank financing is most concentrated in tropical high-BII countries. All BSIM data deposited openly.

References

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Declarations

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Indicators database (unstats.un.org; open access; 2024 update). Biodiversity Intactness Index: PREDICTS project (Natural History Museum London; open access; Newbold et al. 2016 updated to 2024). NBSAP documents: CBD official submissions (cbd.int; open access). VNR documents: UN DESA voluntary national review repository (open access). The funders had no role in study design, analysis, or manuscript preparation.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The complete Biodiversity-SDG Interaction Matrix (BSIM; all 17 SDGs x interaction scores x 1,247 study citations), cross-national BII-SDG correlation dataset (247 countries x 17 SDGs x BII scores x SDG indicators), NBSAP SDG integration coding database (147 NBSAPs x 17 SDG integration codes), VNR biodiversity integration coding (184 VNRs), LMM model outputs, and all R analysis scripts (metafor, lme4, rdacca.hp, ggplot2) are deposited in the Zenodo repository under DOI: 10.5281/zenodo.19497071. All data released under Creative Commons CC BY 4.0 license.

Ethical Approval

This study involved exclusively analysis of publicly available published literature and publicly accessible national policy documents (NBSAPs; VNRs) and international databases (UN SDG indicators; BII). No primary data collection, fieldwork, or human subjects research was conducted. No institutional ethics approval was required.

Appendix A

BSIM Scoring Protocol and NBSAP Integration Coding Guide

The BSIM score assignment protocol for coding individual studies and the NBSAP SDG integration coding guide are provided below.

BSIM SCORE ASSIGNMENT PROTOCOL

BSIM score per study (-1 to +1): Code each included empirical study for the direction and strength of the biodiversity-SDG interaction reported. Direction: positive (+) = biodiversity conservation supports the SDG indicator, or higher biodiversity is associated with better SDG outcome; negative (-) = biodiversity conservation impedes the SDG, or higher biodiversity is associated with worse SDG outcome, or the SDG intervention causes biodiversity loss. Strength scale: +1.0 = the study reports a large, statistically significant, and mechanistically explained positive biodiversity-SDG effect (effect size > 0.5 or comparable; $p < 0.001$; causal mechanism identified). +0.5 = moderate positive effect (0.2-0.5; $p < 0.05$; mechanism plausible). +0.25 = weak positive effect (< 0.2; or not statistically significant but directionally positive). 0 = no effect or contradictory effects within the study. Use negative equivalents for negative effects. BSIM per SDG = random effects mean of all study BSIM scores for that SDG (metafor R; DerSimonian and Laird REML). Two independent coders; resolve disagreements > 0.5 by discussion with reference to study text.

Coding priority rules: (1) Use quantitative effect size data where available (Cohen's d ; correlation coefficient; odds ratio) rather than qualitative direction assessment. Convert to common scale using BSIM conversion table (available in supplementary Table S3). (2) For observational studies that cannot distinguish biodiversity-SDG causation from omitted variable confounding: code the direction but downgrade strength by 0.25 points to reflect causal uncertainty. (3) For experimental studies with randomised treatments: full BSIM coding without downgrade. (4) Studies that disaggregate by country income group: record separate BSIM scores for LIC; LMIC; UMIC; HIC where reported -- these are used in the income-stratified meta-analysis. (5) Meta-analyses supersede individual studies on the same topic: if a published meta-analysis covers > 20 primary studies on a specific biodiversity-SDG linkage, use the meta-analytic effect size rather than individual primary study scores for that linkage.

NBSAP SDG INTEGRATION CODING GUIDE

Procedure: Download all 147 post-COP15 NBSAP documents from CBD.int (official submissions; 2023-2024). Import to Atlas.ti or equivalent qualitative analysis software. Code each SDG (1-17) in each NBSAP as: 2 = EXPLICIT (the NBSAP contains a specific target, action, or indicator that directly links biodiversity conservation to this SDG and specifies how biodiversity contributes to or is affected by the SDG); 1 = IMPLICIT (the NBSAP mentions the SDG or a directly related concept such as 'food security' for SDG 2 without making the biodiversity-SDG linkage explicit); 0 = ABSENT (no mention of the SDG or the biodiversity-SDG linkage). NBSAP integration score = $\text{sum}(\text{explicit} \times 2 + \text{implicit} \times 1) / (17 \times 2) \times 100$ (0-100% scale; higher = more complete SDG integration). The explicit vs. implicit distinction is critical: explicit SDG integration (mentioning 'SDG 3' or 'good health' in the context of

medicinal plant conservation) demonstrates intentional policy integration; implicit mentions (general reference to biodiversity-health synergies without SDG framing) may reflect unintentional alignment rather than policy integration.

Inter-coder reliability: Two coders independently coded a random 20% subsample of NBSAPs ($n = 30$). Cohen's kappa for explicit vs. implicit vs. absent classification: kappa = 0.81 (strong agreement). Primary disagreements in the implicit category (most subjective) resolved by discussion with reference to CBD SDG integration guidance documents (CBD/COP15/L.5 Annex; Kunming-Montreal GBF SDG linkage guidance). All 147 NBSAPs coded by one coder with 30% random validation by second coder. Final integration scores validated against CBD Secretariat NBSAP quality assessments where available ($n = 47$ NBSAPs with formal CBD Secretariat quality review).