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Biology to Support the Achievement of the Sustainable Development Goals (SDGs): Pathways, Evidence, and Action Priorities

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Article Info

Abstract

Biology—the science of life from molecules to ecosystems—provides essential knowledge, tools, and solutions for achieving the Sustainable Development Goals (SDGs). Yet its contributions are often discussed in fragmented ways (e.g., biodiversity for SDG 15, health for SDG 3), underestimating how biological systems underpin most SDG targets through food, water, climate regulation, disease control, and nature-based livelihoods. This article synthesizes peer-reviewed evidence to map five major "biology-to-SDG" pathways: (1) biodiversity and ecosystem services, (2) One Health and planetary health, (3) sustainable food systems and agroecology, (4) biotechnology and bioeconomy, and (5) biology education and sustainability competence. We use a conceptual integrative method: selecting authoritative reviews and empirical papers that explicitly connect biological mechanisms or interventions to SDG targets, and organizing evidence into a framework that highlights synergies, trade-offs, indicators, and governance requirements. Results show that biological processes are not only relevant to environment-focused goals (SDGs 6, 13, 14, 15), but materially shape poverty, inequality, and economic resilience through risk reduction, productivity, and health co-benefits. Evidence also underscores recurring implementation gaps: weak integration across sectors, insufficient monitoring of biological outcomes, and limited translation of biological knowledge into policy and education. We conclude with actionable priorities: mainstream ecosystem-service accounting, scale One Health surveillance and prevention, accelerate agroecological transitions, govern emerging biotechnologies responsibly, and embed SDGs systematically in biology curricula.

1. Introduction

In 2015, UN Member States adopted the 2030 Agenda for Sustainable Development, committing to 17 Sustainable Development Goals (SDGs), 169 targets, and a global indicator framework (United Nations General Assembly, 2015) [14]. The SDGs are intentionally integrated: progress in one domain (e.g., food, health, climate) depends on progress in others. This integration is precisely where biology matters.

Biology explains how living systems function, adapt, and fail—across genes, organisms, populations, and ecosystems. It therefore supplies both (a) the scientific basis for understanding sustainability risks (e.g., biodiversity loss, zoonotic spillover, antimicrobial resistance) and (b) the solution toolkit (e.g., restoration ecology, surveillance and vaccination, microbial bioprocessing, agroecological design).

Contemporary sustainability science increasingly recognizes that social and economic goals depend on a "healthy biosphere," and that human development must operate within biophysical limits (Steffen et al., 2015) [13]. IPBES similarly emphasizes that biodiversity and ecosystem functions directly underpin multiple SDGs and human well-being (IPBES, 2019). However, despite the growing literature linking biology and the SDGs, three persistent problems remain: (1) fragmentation across sectors and subdisciplines, (2) translation gaps between evidence and implementable policy, and (3) measurement gaps where activities are reported instead of biological outcomes. This article addresses those gaps by providing an evidence-informed framework of how biology supports SDGs through five pathways, emphasizing mechanisms, examples, measurable indicators, and action priorities.

2. Literature Review
2.1. The SDGs as an integrated sustainability architecture
The SDGs constitute a globally agreed agenda linking human development, equity, and environmental integrity (United Nations General Assembly, 2015) [14]. Their integrated nature implies that biophysical processes (water cycling, carbon storage, pollination, disease ecology) can enable or constrain social progress. The planetary boundaries framework reinforces this systems perspective by defining a "safe operating space" for humanity; crossing ecological thresholds increases the risk of destabilizing Earth system functions needed for development (Steffen et al., 2015) [13].

2.2. Biodiversity and ecosystem services
A central body of evidence shows that biodiversity (genes, species, ecosystems) contributes to sustainable development broadly, not only through conservation goals. A major review synthesizes how biodiversity delivers benefits aligned with multiple SDGs (Blicharska et al., 2019) [2]. Complementary work used expert elicitation to demonstrate that ecosystem services contribute to a wide range of SDG targets, especially those linking environment and human well-being (Wood et al., 2018) [19]. IPBES further concludes that biodiversity decline threatens the ecosystem functions needed for achieving sustainable development (IPBES, 2019).

2.3. One Health and planetary health
Global health security and sustainable development are deeply linked to biological interactions at the human–animal–environment interface. One Health provides an operational framework for coordinated action across sectors to reduce risks from zoonoses, antimicrobial resistance (AMR), and environmental contamination (Danasekaran et al., 2024) [3]. AMR is a direct threat to SDG progress and highlights the need for SDG-aligned monitoring and cross-sector governance (Ferdinand et al., 2023; Aslam et al., 2024) [7,1].

2.4. Sustainable food systems and agroecology
Food systems sit at the center of SDG interactions: hunger (SDG 2), health (SDG 3), water (SDG 6), climate (SDG 13), life below water (SDG 14), and life on land (SDG 15). Agroecology frames agriculture as an ecological system, emphasizing biodiversity, soil biology, nutrient cycling, and resilience. Recent scholarship links agroecology to SDG achievement through reduced external inputs, strengthened livelihoods, and ecological regeneration (Eyhorn et al., 2019;

Wezel et al., 2020) [5,16].

2.5. Biotechnology and bioeconomy
Biotechnology and synthetic biology can accelerate SDG progress by enabling cleaner production, improved health technologies, and biological remediation—while also raising governance and biosafety challenges. Reviews discuss biotechnology's role in SDG-oriented innovation (Donato et al., 2023) [4], and recent work argues that engineered microbes can accelerate sustainability applications (French, 2019) [9]. Bioeconomy studies also examine how bio-based production criteria and SDG targets influence one another across countries (Wesseler & Zhu, 2024; Mesa et al., 2024) [17,11].

2.6. Biology education and ESD
Achieving the SDGs requires knowledge, values, and skills—especially systems thinking, evidence reasoning, and ethical decision-making. UNESCO's ESD roadmap emphasizes transforming education to support sustainability (UNESCO, 2020) [15]. Within biology education, empirical work shows that integrating SDGs into biology coursework can increase students' understanding of biology's role in solving global problems (Ferrer-Estévez & Chalmeta, 2021) [8].

3. Methods
3.1. Design
This manuscript uses a conceptual integrative synthesis (narrative evidence mapping) to organize how biology supports SDG achievement. The approach is appropriate when the objective is to unify evidence across subdisciplines and produce an actionable framework rather than estimate a single effect size.

3.2. Evidence selection (inclusion logic)
Sources were prioritized when they (1) explicitly connect biological mechanisms, interventions, or monitoring to SDG goals/targets; (2) address synergies or trade-offs across sectors; and/or (3) provide authoritative syntheses (major reviews or consensus assessments). Authoritative global references were used for SDG architecture and ESD priorities (United Nations General Assembly, 2015; UNESCO, 2020) [14,15] and for global biodiversity context (IPBES, 2019).

3.3. Analytical procedure
Evidence was coded into five pathways (ecosystems, One Health, food systems, biotechnology, education). For each pathway, the analysis extracted biological mechanisms, intervention types, constraints, candidate indicators, and synergy/trade-off patterns. Outputs are summarized using a conceptual pathway figure (Figure 1), an evidence-to-impact chain (Figure 2), and three synthesis tables.

4. Results and Discussion
4.1. A five-pathway framework for biology-to-SDG contributions
Biology supports SDGs through five interlocking pathways (Figure 1). Each pathway is scientifically distinct but operationally interdependent. This framework is consistent with evidence that ecosystem services contribute across many SDGs (Wood et al., 2018) [19] and that biodiversity benefits span multiple goals beyond conservation (Blicharska et al., 2019) [2].
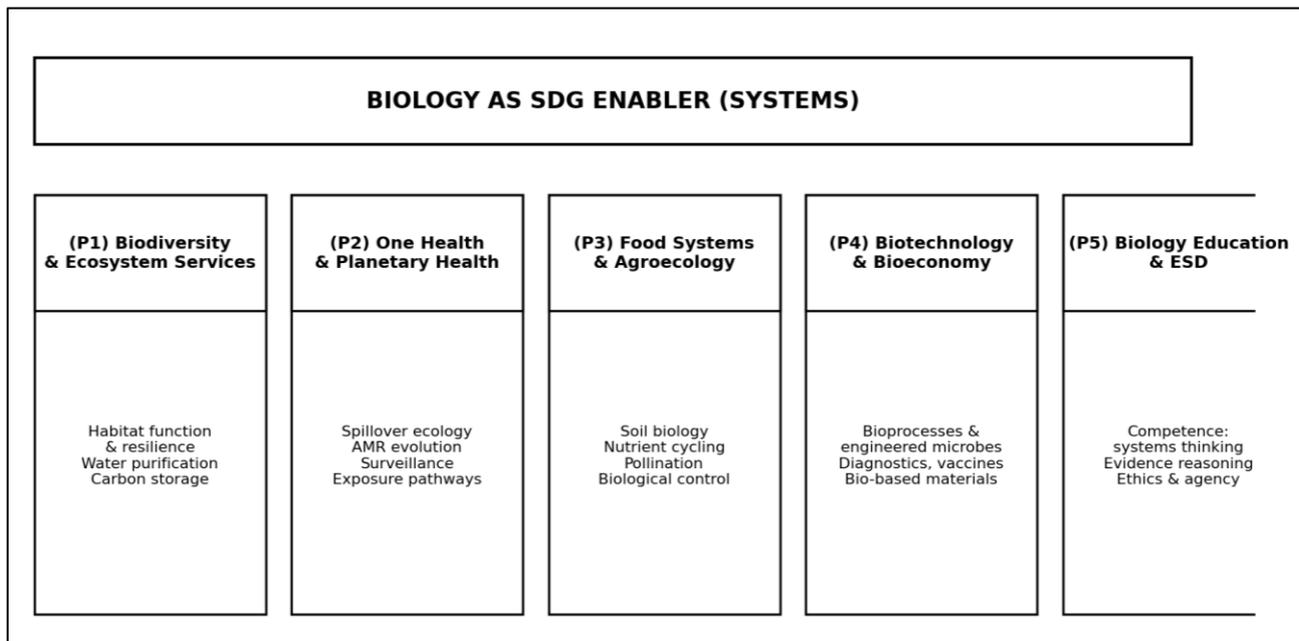
Fig 1: Conceptual framework: five biology-to-SDG pathways (mechanisms → interventions → SDG outcomes).

Table 1: Five biology-to-SDG pathways, mechanisms, and representative SDG targets.

Pathway	Core biological mechanism(s)	Representative interventions	SDGs most directly supported*
P1 Biodiversity & ecosystem services	Habitat function, resilience; carbon and water cycling	Protected areas, restoration, ecosystem-service planning	6, 13, 14, 15 (+2, 3, 11, 12)
P2 One Health & planetary health	Spillover ecology; microbial evolution (AMR); exposure pathways	Integrated surveillance, WASH, antimicrobial stewardship	3 (+1, 2, 6, 8, 12, 17)
P3 Food systems & agroecology	Soil microbiomes; nutrient cycling; pollination; biological control	Agroforestry, IPM, soil regeneration, diversification	2 (+3, 6, 8, 12, 13, 15)
P4 Biotechnology & bioeconomy	Bioprocessing; engineered microbes; molecular diagnostics	Fermentation, bioremediation, vaccines/diagnostics, bio-based materials	3, 9, 12 (+6, 7, 13)
P5 Biology education & ESD	Sustainability competence; systems thinking; evidence reasoning	SDG-integrated curricula, inquiry/PBL, community science	4 (+all through behavior/decision quality)

*Indirect links exist for many SDGs via livelihoods, equity, and risk reduction (United Nations General Assembly, 2015; Steffen et al., 2015) [13].

4.2. Pathway 1—Biodiversity and ecosystem services
Biodiversity influences ecosystem functioning and generates ecosystem services—food and freshwater provisioning, climate regulation, hazard mitigation, and cultural benefits. A synthesis shows biodiversity contributes to multiple SDGs through direct benefits and indirect enabling functions (Blicharska et al., 2019) [2]. Ecosystem services are also perceived to contribute to many SDG targets, particularly those linking environment and human well-being (Wood et al., 2018) [19]. IPBES concludes that biodiversity loss threatens the functions needed for sustainable development (IPBES, 2019).

High-priority action levers include: protecting and restoring high-function ecosystems (watersheds, mangroves, peatlands, coral reefs); integrating ecosystem-service modeling into land-use and infrastructure planning; and embedding biodiversity targets within development finance. Not all "green" actions are beneficial—monoculture tree planting may store carbon but reduce biodiversity or water yield—so interventions should be ecosystem-appropriate, diversity-aware, and outcome-monitored.

4.3. Pathway 2—One Health and planetary health
One Health operationalizes biological connectivity across human, animal, and environmental systems. Antimicrobial resistance (AMR) illustrates how biological adaptation interacts with development factors and threatens SDG progress. AMR directly undermines SDG 3 and indirectly undermines SDGs 1, 2, and 8 by increasing disease burden and treatment costs (Aslam et al., 2024) [1]. Integrating One Health with the SDGs supports aligned monitoring, cross-sector surveillance, and evaluation (Ferdinand et al., 2023) [7]. Practical levers include prevention and surveillance across interfaces, WASH and infection prevention, and stewardship to reduce selection pressures (Danasekaran et al., 2024) [3].

4.4. Pathway 3—Sustainable food systems and agroecology
Food production depends on soil microbial diversity, pollination networks, pest–predator dynamics, genetic diversity for crop resilience, and nutrient cycling. Agroecology applies ecological principles to farming, aiming to increase resilience and reduce external inputs.

Scholarship links agroecology to SDG achievement via ecological regeneration and improved livelihoods, while emphasizing the need for equity safeguards and supportive markets (Eyhorn et al., 2019; Wezel et al., 2020) [5,16].

4.5. Pathway 4—Biotechnology and the bioeconomy
Biotechnology contributes to SDGs through diagnostics, vaccines, biomanufacturing, waste-to-resource systems, and bioremediation, while requiring responsible governance for safety and equity. Reviews highlight biotechnology's SDG-oriented potential and challenges (Donato et al., 2023) [4]. Data-driven synthetic microbes are framed as promising for sustainability applications (French, 2019) [9], and bioeconomy analyses suggest bidirectional influences between bioeconomy criteria and SDG targets (Wesseler & Zhu, 2024; Mesa et al., 2024) [17,11].

4.6. Pathway 5—Biology education and ESD
Education is a force multiplier: even strong biological solutions fail without social uptake and decision competence. UNESCO emphasizes transforming education systems for sustainability (UNESCO, 2020) [15]. Empirical evidence indicates that SDG integration in biology courses can increase students' understanding of biology's role in global problem solving (Ferrer-Estévez & Chalmeta, 2021) [8]. Biology education for SDGs should emphasize systems thinking, evidence reasoning, ethics and equity, and learner agency through inquiry and project-based learning.

4.7. Indicators: measuring biological outcomes (not just activities)
A recurring limitation in SDG-oriented projects is insufficient measurement of biological outcomes. Figure 2 presents an evidence-to-impact chain that connects inputs and activities to measurable biological outputs and SDG-relevant outcomes, enabling adaptive management when results are weak.
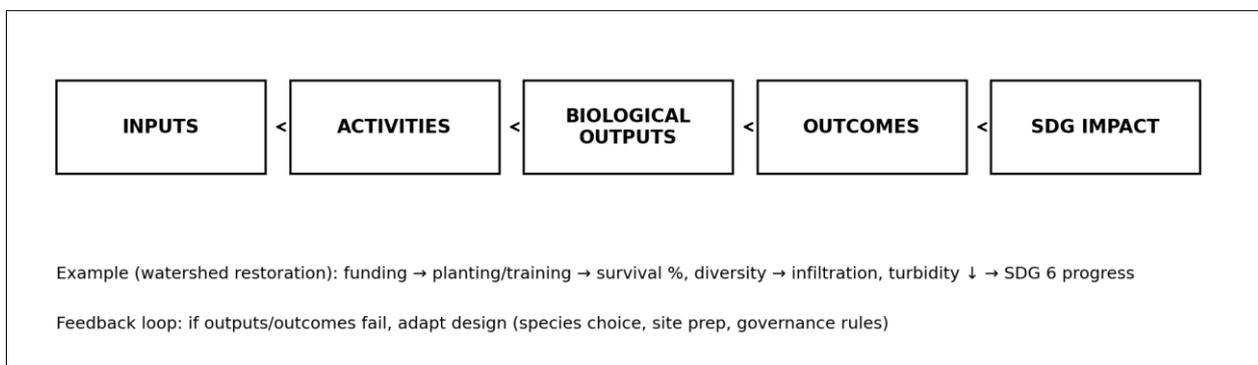
Fig 2: Evidence-to-impact chain for biology-enabled SDG interventions (with monitoring feedback).

Table 2: Example biological indicators aligned with SDG monitoring and evaluation.

Domain	Indicator type	Example measurable indicators	SDG alignment (examples)
Biodiversity	State/response	Species richness; functional diversity; habitat connectivity; invasive species prevalence	14, 15 (and enabling for 2, 6, 13)
Water & sanitation	Outcome	Turbidity; nutrient loads; E. coli counts; macroinvertebrate index; wetland extent	6
Climate (biosphere)	Outcome	Carbon stock change; methane flux in wetlands; fire frequency in peatlands	13
Health (One Health)	Outcome	Zoonotic spillover signals; vector abundance; AMR prevalence (clinical + environmental)	3 (and 2, 6)
Food systems	Outcome	Soil organic carbon; microbial biomass; pollinator abundance; yield stability; dietary diversity	2, 3
Biotechnology	Performance & safety	Life-cycle emissions; bioprocess yield; containment performance; risk assessment completion	9, 12, 13
Education	Competence	Systems-thinking rubrics; evidence reasoning tasks; sustainability action projects completed	4

Table 3: Biology education strategies to accelerate SDG literacy and action.

Strategy	What students do	Biology concepts strengthened	SDG relevance
SDG-anchored case studies	Analyze a local SDG challenge using biological evidence	Ecology, epidemiology, physiology, evolution	2, 3, 6, 13, 15
Inquiry + community science	Collect and interpret biodiversity/water/health proxy data	Sampling, statistics, bioindicators	6, 11, 14, 15
Project-based learning (PBL)	Design and test interventions (e.g., composting, agroforestry plot, vector control)	Systems, trade-offs, experimentation	2, 3, 12, 13
Molecular-to-society links	Connect cellular mechanisms to SDG issues (e.g., AMR, vaccines)	Cell biology, genetics, microbiology	3, 12
Ethics & governance modules	Debate biotech, conservation, and equity dilemmas	Bioethics, risk, policy literacy	9, 12, 16, 17

4.8. Cross-goal synergies and trade-offs

Across pathways, three synergy patterns recur: (1) nature-based co-benefits where conservation and restoration improve water security, climate regulation, and livelihoods (Wood et al., 2018; IPBES, 2019) [19]; (2) prevention-first logic where One Health reduces biological shocks that reverse development gains (Danasekaran et al., 2024; Ferdinand et al., 2023) [7]; and (3) learning-enabled scaling where biology education increases capacity to interpret evidence and implement interventions (UNESCO, 2020; Ferrer-Estévez & Chalmeta, 2021) [15,8].

Trade-offs require safeguards. Bioeconomy strategies can create land-use conflicts if biomass production competes with food or biodiversity; simplistic tree-planting can undermine water or ecological integrity; and biotechnology requires biosafety and equitable governance. In all cases, monitoring biological outcomes and adapting interventions are necessary for durable SDG gains.

5. Conclusion

Biology is indispensable for achieving the SDGs because it explains and manages the living systems that sustain human well-being: ecosystems, food webs, microbiomes, disease dynamics, and evolutionary adaptation. Evidence shows biodiversity and ecosystem services underpin development across many SDGs (Blicharska et al., 2019; Wood et al., 2018; IPBES, 2019) [19]. One Health approaches—especially for AMR—protect SDG progress and reduce development reversals (Ferdinand et al., 2023; Aslam et al., 2024) [7,1]. Agroecology offers design principles for resilient, nutrition-sensitive production landscapes (Eyhorn et al., 2019; Wezel et al., 2020) [5,16]. Biotechnology can accelerate innovation for health and sustainable industry when paired with responsible governance (Donato et al., 2023; French, 2019; Wesseler & Zhu, 2024; Mesa et al., 2024) [17,4]. Finally, biology education builds sustainability competence and empowers action (UNESCO, 2020; Ferrer-Estévez & Chalmeta, 2021) [15,8].

Priority actions include mainstreaming ecosystem-service planning in SDG strategies, operationalizing One Health surveillance and prevention, scaling agroecological transitions with equity safeguards, accelerating responsible biotechnology for circular production, and embedding SDG-based learning outcomes across biology curricula with measurable competence indicators.

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