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From biodiversity knowledge to societal impact: How ecology and taxonomy drive global innovation, economic development and sustainable futures for India

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Abstract
The societal value of ecology and taxonomy depends on translating reliable biodiversity knowledge into validated applications that address environmental and human needs. However, scientific discovery alone does not guarantee ecological improvement, economic viability, or equitable benefits. This structured critical review maps 100 purposively selected journal article records published between 2020 and 2025 across biodiversity-related ecosystem services, pollination and sustainable agriculture, One Health, environmental monitoring, restoration, and the translation of research into practice. It examines potential application pathways alongside requirements for validation, user demand, financing, regulation, institutional capacity, and benefit sharing. International examples provide comparative contexts rather than rankings of national performance. With particular reference to India, the review identifies priorities concerning taxonomic reference resources, ecological baselines, long-term monitoring, local implementation capacity, and the distinction between potential market opportunities and demonstrated societal impact. Soil invertebrates provide a cross-cutting example of how taxonomic and ecological knowledge can inform environmental assessment and sustainable land management. A conceptual knowledge-to-impact framework is proposed to connect reliable identification and ecological evidence with validated applications, stakeholder adoption, and measurable outcomes. Given the metadata-based scope, these pathways require further full-text assessment and empirical validation before their effectiveness or wider societal benefits can be established.

Keywords: Biodiversity, ecosystem services, taxonomy, sustainable development, One Health, bioeconomy, India

Introduction

Taxonomy and ecology play important roles in contemporary society, beyond biodiversity loss and new species descriptions. Reliable organism identification supports surveillance and regulatory activities, the application and enforcement of conservation laws and the elaboration of standards regarding the environment. Ecological analysis helps describe and understand the contributions and responses of biotic systems to environmental perturbations and the impacts of various stress factors. The organismal responses, interactions and relations identified and understood through ecological research and analysis help make decisions regarding the restoration and management of agro-ecosystems, prevention of and protection from invasive species and the control of harmful organisms. This understanding can also inform decisions related to agriculture and the management of ecosystems and can mitigate the risks of infectious diseases. However, numerous and diffuse benefits of ecological research and analysis do not occur automatically. The observations must be condensed into a "package" that is of interest and can be supported and repeated by decision makers at an operational scale.

The term 'societal impact' embodies a number of different meanings, and their value should not be considered as equivalent to a single monetary value. 'Environmental improvement' can mean better health conditions and less exposure to pollution. 'Social improvement' can mean increased participation by the community, improved equity in the provision of services and improved public health and preparedness. 'Economic improvement' can mean the creation of new and skilled jobs and averted negative impacts. To promote ecological improvement and innovation, it is better to elaborate a clear account of expected results and beneficiaries as well as counterfactual cases and uncertainties.

India's environmental diversity, together with the increasing demand for the management of the environment by various institutions, strengthens the relationship between knowledge and implementation. It is worthwhile to create a local reference collection, and/or to develop and validate pollinator monitoring and/or restoration assessment methodology, even without setting up a company. On the other hand, an ecologically beneficial startup may attract potential clients before showing any ecological benefits. This paper studies four application clusters and examines the institutional mechanisms to sustain scientific capacity as a public good. [1, 2]

Review methodology and interpretation

The study is a structured critical review and a purposive evidence map. One hundred scholarly metadata tagged journal publications dated 2020 to 2025, published in the areas of biodiversity and ecosystem services, pollination and agroecology, One Health, environmental assessment, restoration and knowledge translation were selected. During screening, emphasis was on the identifiable Digital Object Identifier (DOI), the year of publication, the status of the article and the relevance, breadth of application and impact of each publication. Different research themes are identified, and it cannot be interpreted as an exhaustive, systematic census, because logs of complete database searches, all full-text articles and independent assessments of risk of bias are not available.

A translation framework is used to analyze evidence. The focus is on user/institution and perceived application, and

the limitations of each case. The presence of the terms 'economic', 'conservation' or 'sustainable' in article titles does not mean that the study describes, evaluates or measures a documented improvement in financial or other community benefits, ecosystem services or conditions. Outcomes attained in different studies cannot be pooled if valuation methods, spatial scale, beneficiaries and counterfactual scenarios are different.

The international cases referred to are illustrative examples rather than a complete global ranking. Variations in legislation, land tenure, funding, ecological baselines and sectoral structures, among others, limit the transferability of the cases reviewed to the Indian context. Therefore, the emphasis in this paper is on monitoring with the use of independent standards, community participation, and science–policy interfaces rather than adapting complete models from various cases. Where necessary, quantitative graphics are drawn only from the literature reviewed, and otherwise stated.

Ecosystem services

The selected bibliographic record comprises “Potential for Artificial Intelligence (AI) and Machine Learning (ML) Applications in Biodiversity Conservation, Managing Forests, and Related Services in India”, “Prioritizing India’s landscapes for biodiversity, ecosystem services and human well-being” [1], “Climate warming in the Himalayas threatens biodiversity, ecosystem functioning and ecosystem services in the 21st century: is there a better solution?”, “Invasive alien plant species: Their impact on environment, ecosystem services and human health” [2]. Biodiversity indicators and ecosystem service outcomes work at different causal levels. Management of natural resources focuses on who benefits, for how long, and at what cost. Monetary estimates determine policy relevance. Valuing a good or service does not ensure that a good or service is funded in the market. Together, the records illustrate the diversity and range of topics covered within a given thematic label. When a given dataset is considered against peers, similar terms in research do not establish similar field performance. Consequently, research contribution is clearer when cross study comparison is not made, and datasets, organisms, sampling units and independent tests are considered.

The review record includes “Valuing ecosystem services from an indigenous perspective from a Global Biodiversity Hotspot, the Western Ghats, India” [3]; “Land-use history determines ecosystem services and conservation value in tropical agroforestry” [4]; “Tradeoffs and synergies among ecosystem services, biodiversity conservation and food production in coffee agroforestry” [5]; “Integrating Capabilities and Ecosystem Services Approaches to evaluate Indigenous connections with nature in the Western Ghats, India” . Indicators of biodiversity and ecosystem services operate at different levels of causation. Management options require clarity regarding which functions are being measured, who gains benefit and over what period. Monetary values may aid in policy relevance, but valuation methodologies incorporate a range of assumptions and may not necessarily lead to the establishment of a market or to the raising of funds to support the intended policy change. The publications include a range of possible observations, and describe methods to support different types of decisions. A rigorous adaptation of the publications to a different situation requires an understanding of the actual context in which the observations were made, the meaning of the results and how an error may change the conclusions drawn.

The selected bibliographic record comprises "Implications of bacterial, viral and mycotic microorganisms in vultures for wildlife conservation, ecosystem services and public health", "Urban green space in India: Perception of cultural ecosystem services and psychology of situatedness and connectedness" [6], "A long-term and comprehensive assessment of urbanization-induced impacts on ecosystem services in the capital city of India" [7], and "Urban stream assessment system (UsAs): An integrative tool to assess biodiversity, ecosystem functions and services" . Biodiversity indicators operate on a different causal level from ecosystem-service outcomes. To make adequate management decisions, it is crucial to evaluate which functions are measured, over which time period, and who benefits. Although putting a monetary value on biodiversity may provide insights into policy relevance and clarify the terms of debate, different assumptions are made by proponents of various valuation methods, and market relevance and the will to finance cannot be derived from valuation. The most important synthesis question is not which title contains the most recently published method. The important question is if the evidence allows a specific biological observation to survive new data, changed conditions or examination by experts. Therefore, claims about the scale and costs of improvements should be considered provisional unless reported field use and maintenance are included.

Regarding ecosystem services, the bibliographic references include “The Economic Valuation of Ecosystem Services of Biodiversity Components in Protected Areas: A Review for a Framework of Analysis for the Gargano National Park”; “Conservation Agriculture as a System to Enhance Ecosystem Services” [8]; “Plant native: comparing biodiversity benefits, ecosystem services provisioning and plant performance of native and non-native plants in urban horticulture”; “Ecosystem services provided by agroforestry home gardens in Bengkulu, Indonesia: Smallholder utilization, biodiversity conservation, and carbon storage” . Depending on the resource being assessed, demand for biodiversity and ecosystem services may fall at different levels of the causal chain. When making management decisions, the decision maker must be sure what is being measured (i.e. impacts, outcomes or goals, etc.), for whom the impacts are being measured and the time horizon for measuring the impacts. Often, impacts may be ambiguous and open to interpretation; therefore, the mechanisms for valuation are used to estimate the impact. Use of such mechanisms may not always indicate the existence of a market for the service or that it is necessarily financially viable. Ranking the methods or listing topics covered may be possible; however, impact may not be determinable. The next step is to evaluate the studies according to predetermined standards and identify what conclusions may be justified. This protects the argument from false precision.

Agriculture and Pollination

For Agriculture and Pollination, the provided bibliographic record includes “The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: a quantitative synthesis” [9]; “Landscape crop diversity and semi-natural habitat affect crop pollinators,

pollination benefit and yield" [10]; "Native honey bees as flower visitors and pollinators in wild plant communities of a biodiversity hotspot"; "Overview of Bee Pollination and its Economic Value for Crop Production" [11]. It is necessary to keep separate yield, crop quality, and pest control, and the overall insect abundance. The context of landscape composition and seasonal variation, pesticide use, and farm practices should be considered in assessing ecological response. In practice, replicated field comparisons, costs to the farmer and the level of ongoing management required are as important as the observation that a practice encourages more species. Considered together, these records demonstrate the breadth of questions framed under a given thematic area. Biological tasks and their evidence standards should serve as the basis of comparison; similar terminology does not imply similar field performance. Therefore, research contributions are clearer if limitations and independent studies are examined before making generalizations across studies.

The selected bibliographic record includes "Crop and landscape heterogeneity increase biodiversity in agricultural landscapes: A global review and meta-analysis" [12]; "A critical analysis of the potential for EU Common Agricultural Policy measures to support wild pollinators on farmland"; "Wild insect diversity increases inter-annual stability in global crop pollinator communities" [13]; "A Growers' Perspective on Crop Pollination and Measures to Manage the Pollination Service of Wild Pollinators in Sweet Cherry Cultivation" . Yield, crop quality, pest control and insect richness should be separated. Ecological responses are context dependent. Replicated field comparisons, farmer costs and management, and the observation that a practice supports a larger number of species are as valid. The grouping provides examples for critical comparison, not for pooled effect estimation. The literature focuses on different observations and the kinds of decisions that methods might inform. A rigorous translation of the sampling context requires an understanding of the original and surrounding sampling environment, the meaning of the results, and how errors would affect interpretation.

In agricultural sciences and pollination, the selected bibliographic record encompasses "Pollinators, pests and yield-Multiple trade-offs from insecticide use in a mass-flowering crop" [14], "Wild bees nest in the stems of cultivated Rubus plants and act as effective crop pollinators", "Importance of regenerative agriculture: climate, soil health, biodiversity and its socioecological impact", "Apple pollination is assured by wild bees when honey bees are drawn away from orchards by mass co-flowering crop, oilseed rape" [15]. It is crucial to investigate yield, crop quality, pest control and insect/bug diversity, and other trade-offs, separately. Ecological responses in an agricultural setting are context-dependent, e.g. landscape composition, seasonal changes, pesticide use, and farm practices. However, in the applied context, particularly in farm practices, the replication of a field experiment, and its cost and management, are as critical as the observation that a practice supports a higher number of species. The essential synthesis question is, in the context of an agricultural practice, not which title describes a novel technique. It is whether an observation survives testing with respect to new data and/or alternative conditions, and holds up against the challenge of domain experts. Hence, conclusions on reduction in cost, scale or impacts should be considered preliminary, unless field practice, usage and maintenance are included.

Regarding agriculture and pollination, the selected bibliographic record includes "Potential distribution of crop wild relatives under climate change in Sri Lanka: implications for conservation of agricultural biodiversity"; "Global effects of land-use intensity on local pollinator biodiversity" [16]; "Wild insects and honey bees are equally important to crop yields in a global analysis" [17]; and "The impacts of tropical agriculture on biodiversity: A meta-analysis" [18]. From an ecological perspective, it is vital to distinguish among yield, crop quality, pests, and insects. Ecological responses are context dependent due to landscape composition and seasonal variation, as well as farm practices and pesticide use. A given farm practice is as important as a replicated field comparison in applied translation, especially if the observation supports that the practice enables a greater number of species. The title of a selected work provides a general topic, but it cannot be presumed that effect sizes are extractable or that methods are ranked. The next research step is to evaluate the studies using consistent criteria to assess study design, validity, and the type and degree of uncertainty. This process helps identify potentially relevant studies and broaden the scope of the research. To improve the argument from false precision, following research steps are supported.

The selected bibliographic record includes "Butterfly biodiversity increases with prairie strips and conservation management in row crop agriculture" and "Limited honeybee hive placement balances the trade-off between biodiversity conservation and crop yield of buckwheat cultivation". Yield and crop quality, as well as pests and insects, should be studied independently. Landscape composition, seasonal changes, pesticide use and farm activities make the ecological response context dependent. From an applicable perspective, repetitive field comparisons are as important as cost and ongoing management on the part of the farmer, and the observation that a practice supports a greater number of species. Taken together, these records show the range of questions grouped under a single thematic title. The correct unit of comparison is the biological function and the standard of evidence provided; comparing terminology does not mean comparing field performance. As a result, the scope of the research contribution is clearer when consideration is given to the datasets, organisms, sampling units and independent tests, before grouping studies together.

One Health

With one health, the selected bibliographic records include "Revisiting the One Health Approach in the Context of COVID-19: A Look into the Ecology of this Emerging Disease"; "Pathways linking biodiversity to human health: A conceptual framework" [19]; "Wild animal and zoonotic disease risk management and regulation in China: Examining gaps and One Health opportunities in scope, mandates, and monitoring systems"; "Biodiversity loss, emerging pathogens, and human health risks" [20]. Determining the direction of pathogen transmission often requires additional information. For example, interpreting the movement of wildlife may require additional information about contact behavior of farm animals, the ecology of possible disease vectors, land use, and the purpose and design of the surveillance. The records

reviewed highlight the range of questions grouped under a single thematic area, and provide evidence that the terminology is not necessarily comparable across studies. Ultimately the extent of similarity must be determined by the standard of evidence used in research.

With respect to health, the bibliographic record includes "Dilution effects in disease ecology" [21], "The COVID-19 pandemic is directly related to biodiversity loss and the health of ecosystems" [22], "Biodiversity and Health in the Urban Environment" [23], and "Urban Forest biodiversity and cardiovascular disease: potential public health benefits from California's street trees" . The presence of organisms, pathogens, and people does not necessarily indicate the direction of infection. Risk is also a function of the behavior of the host, the vector if present, land use, and design of the surveillance system. It is important to distinguish between detection, exposure, infection and illness. Avoid assuming that biodiversity change is always bad for human health. The examples are provided for critical comparison and not to be combined to yield an average effect. The journals of research differ in what they observe and what recommendations their studies might facilitate. A careful examination of the context in which the data was collected helps to understand the true meaning of the findings and how an error might affect the conclusion.

The records in the selected bibliography are "Examining the paradox of urban disease ecology by integrating the perspectives of Urban One Health and Ecology with Cities" [24]; "Invasive alien species and disease risk: An open challenge in public and animal health" [25]; "The one health perspective to improve environmental surveillance of zoonotic viruses: lessons from COVID-19 and outlook beyond" [26]; "Animal board invited review: Risks of zoonotic disease emergence at the interface of wildlife and livestock systems" [27]. The presence of organisms, pathogens, and people by itself does not indicate the direction of transmission of an infectious agent. Risks depend on the identity of the potential hosts, their contact behaviour, the ecology of the potential vectors, and the land use and surveillance design. Interpretations should be clear about what was detected, exposed, infected, or made ill; and avoid assuming that changes in biodiversity are always bad or always good for human health. The main synthetic question is not which title claims to use the most recent technological advance. It is whether evidence provided integrates a biological observation that is biologically plausible and survives scrutiny and expert judgment. For this reason, scale and cost claims should be viewed as preliminary.

Within one health, the selected bibliographic record comprises "Socioecological vulnerability and the risk of zoonotic disease emergence in Brazil" [28]; "Malassezia: Zoonotic Implications, Parallels and Differences in Colonization and Disease in Humans and Animals"; "A better classification of wet markets is key to safeguarding human health and biodiversity"; "Harnessing soil biodiversity to promote human health in cities" [29]. The presence of organisms and pathogens, and people, does not by itself determine the direction of the flow of diseases. The type of host and contact behavior is important as is the ecology of the vectors, the land use and the design of the surveillance. Interpretations must distinguish exposure, infection and illness, and not assume that change in biodiversity will always impact on human health in a predictable manner. A title level map shows the major topics covered in the literature, but does not provide evidence of the effects of the literature, or provide an ordering of the literature. The next step in the research is assessment of the full text literature using consistent criteria for study design, validation, uncertainty, and applicability, with special focus on availability of research data. This ensures that the argument is not made with false precision.

Under one health, the bibliographic record includes "Studying bats using a One Health lens: bridging the gap between bat virology and disease ecology" and "Climate change and other risk drivers of animal health and zoonotic disease emergencies: the need for a multidisciplinary and multisectoral approach to disaster risk management". The co-occurrence of organisms, pathogens and people doesn't by itself establish the direction of disease transmission. Risk is determined by the identity of the host, contact behavior of the host and vector, ecology of the vector, land use and design of the surveillance. Interpretations should distinguish exposure, infection and illness and should not assume that all biodiversity change is detrimental to human health. Read together, these records show the range of questions that have been encompassed under one thematic umbrella. Similarity of terminology doesn't by itself establish comparable performance in the field. The research contribution is therefore clearer when the research datasets, organisms, samples and other independent tests are considered, before making cross-study comparisons.

Environmental management

The bibliographic record for the selected environmental management area includes the references "Testing multiple substrates for terrestrial biodiversity monitoring using environmental DNA metabarcoding" [30], "Methodology for fish biodiversity monitoring with environmental DNA metabarcoding: The primers, databases and bioinformatic pipelines", "Environmental DNA metabarcoding for biodiversity monitoring of a highly diverse tropical fish community in a coral reef lagoon: Species richness estimation and detection of habitat segregation", "Environmental DNA metabarcoding for benthic monitoring: A review of sediment sampling and DNA extraction methods" . Biological surveillance can, in some cases, replace chemical and physical surveillance. However, its applicability depends on the variability of the baseline, the response of the species, and the reproducibility of the measurement. The application of a sentinel organism depends on the clarity of the connection of the organism to the stressor, and the decision threshold. Available technology may lessen the time needed for analysis. However, it cannot fix deficiencies in sampling, and a poor regulatory framework. Together, the records show the breadth of the different questions addressed in a research area. Similarly naming studies does not establish equivalence in research performance. Therefore, generalization based on independent scientific research, samples, organisms, and tests is necessary to clarify research contribution.

The following bibliographic records document the evaluation and monitoring of coral reef biodiversity using eDNA metabarcoding techniques. These records also reference studies documenting the use of eDNA metabarcoding to monitor insects and other biota. "Environmental DNA metabarcoding for monitoring

metazoan biodiversity in Antarctic nearshore ecosystems" [31] describes the application of this technique to monitor invertebrate community changes in the Antarctic. "Environmental DNA metabarcoding as a tool for biodiversity assessment and monitoring: reconstructing established fish communities of North-Temperate lakes and rivers" [32], also references the use of eDNA metabarcoding to evaluate and monitor fish community changes in freshwater ecosystems. Monitoring provides a means to detect biological changes and complements the use of chemical and physical measurement to assess environmental impacts. Choice of biomarkers for bio-monitoring is based on several criteria, including their reliability, sensitivity and measurement reproducibility. The extent to which an organism responds to a stressor determines its value as a biomarker. Biomonitoring requires a clear correlation to the stressor of concern. eDNA metabarcoding has the potential to fill some of the existing data gaps on biological changes in various ecosystems, especially in locations where adequate sampling has not been conducted.

The selected bibliographic record includes "Revisiting the effect of PCR replication and sequencing depth on biodiversity metrics in environmental DNA metabarcoding" [33]; "Capturing open ocean biodiversity: Comparing environmental DNA metabarcoding to the continuous plankton recorder"; "Drone-assisted collection of environmental DNA from tree branches for biodiversity monitoring"; "The future of biodiversity monitoring and conservation using environmental DNA" [34]. Biological surveillance, in certain aspects, can complement chemical and physical measurements, but its utility depends on a number of factors, including baseline variability, responsiveness of the species and the reproducibility of measurements. The best illustration of this is the application of the sentinel organism, which needs to have a transparent link with the stressor, and have a decision threshold. The purpose of synthesis is to evaluate if the evidence connects the biological observation with a conclusion that is independent of new data and/or alteration in conditions and survives scrutiny of peer reviewers. Thus, claims of scale and/or costs reduction, should be viewed with caution, unless use and maintenance data is provided.

The selected bibliographic record includes "Environmental DNA Methods for Ecological Monitoring and Biodiversity Assessment in Estuaries" [35], "Environmental DNA metabarcoding reveals and unpacks a biodiversity conservation paradox in Mediterranean marine reserves" [36] and "An integrated spatio-temporal view of riverine biodiversity using environmental DNA metabarcoding" [37]. Biological surveillance can be integrated with chemical and physical measurements to accomplish ecosystem comprehensiveness. Using biological indicators (e.g. sentinel species) can work in similar fashion to the use of physical and chemical indicators, subject to considerations of baseline variability, measurement reproducibility, and species responsiveness. Each requires a definitive link to the stressor and a threshold for a decision. Advances in technology can minimize analysis time, but can't overcome poorly designed studies, incomplete taxonomy, and weak regulatory pathways. A map showing title level records represents topics covered in the literature, but does not permit extraction of effect sizes, or prioritize methods. Consistency in assessment of study design, validation, uncertainty and applicability will facilitate evaluation of data availability. This approach protects the argument from unwarranted ambiguity.

Conservation and restoration

In conservation and restoration, the record under consideration contains "The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches" [38], "From ecological functions to ecosystem services: Linking coastal lagoons biodiversity and human well-being" [39], "Land-use intensity alters networks between biodiversity, ecosystem functions and services" [40], and "A social-ecological-technological systems framework for urban ecosystem services" [41]. Restoration and ecosystem outcomes should not be confused with each other. Planting efforts, or short-term vegetation cover, represent only a partial recovery of an ecosystem. Ecological recovery should be monitored in terms of function and connectivity, including the social consequences, with pragmatic temporal limits and clear counterfactuals. Evidence from one landscape rarely transfers to other landscapes. In summary, the records under consideration illustrate the variety of questions that have been grouped under a single thematic focus. Generally, in biology, similar terms do not indicate comparable performance in the field. Thus, clarity and research contribution are improved when comparison is made to data sets, organisms, sampling units and independent lines of evidence before generalizing beyond the studied cases.

In conservation and restoration, the selected bibliographic record includes "Restoration of seagrass habitat leads to rapid recovery of coastal ecosystem services" [42]; "Restoring the forest revives our culture: Ecosystem services and values for ecological restoration across the rural-urban nexus in South Africa" [43]; "Global trends and scenarios for terrestrial biodiversity and ecosystem services from 1900 to 2050" [44]; "Global priority areas for ecosystem restoration" [45]. Restoration inputs and ecosystem outcomes must not be confused. Area treated, planting effort, or short-term vegetation cover, provide only partial evidence of ecological recovery. Monitoring should include functions, connectivity, and social consequences, and should have realistic temporal horizons and clear counterfactuals. Evidence from one landscape rarely transfers unchanged to another. The intention of the grouping is for critical comparison, and not for pooled effect estimation. The publications differ in what they observe and the type of decisions that their methods are meant to inform. A translation to other contexts demands understanding the meaning of the results, the sampling context and what mistakes in interpretation would mean.

The bibliographic records in conservation and restoration include "Ecological restoration of field margins enhances biodiversity and multiple ecosystem services in rice agroecosystems" [46]; "Remote sensing for mapping ecosystem services to support evaluation of ecological restoration interventions in an arid landscape" [47]; "The impact of ecological restoration on ecosystem services change modulated by drought and rising CO2" [48]; and "The supply of multiple ecosystem services requires biodiversity across spatial scales" [49]. It is critical to differentiate the ecological restoration inputs and ecosystem outcomes. A priori, ecological restoration often improves biodiversity, connectivity and functions and alters the distribution of ecosystem services. Evidence from one location is seldom

transferable to another. The major synthesis question is not which record cites a new tool or technique. It is whether the available body of evidence provides a biological observation or basis for a claim that holds up under new data and under scientific scrutiny. That, of course, includes scale and cost reduction.

The conservation and restoration literature of interest includes “Bioinvasion impacts on biodiversity, ecosystem services and human health in the Mediterranean Sea” [50], “Application of Ecological Restoration Technologies for the Improvement of Biodiversity and Ecosystem in the River” [51], “Multitrophic biodiversity enhances ecosystem services and functions in agriculture and ecological intensification” [52] and “Enhancing biodiversity and ecosystem services in quarry restoration- challenges, strategies and practice” [53]. Distinguish between restoration inputs and outcomes (i.e. ecological recovery) The effects of restoration should be measured over a realistic time frame using counterfactuals. Evidence from one landscape rarely applies to others. The extraction of the effects of interventions from the literature is useful to identify the main gaps and highlight where the best available evidence lies (Title-level map). However, full appraisal of the literature, including design, methodology, impact and data availability, is necessary in order to preserve the robustness of the argument.

With regards to conservation and restoration, the selected bibliographic record includes “Restoration of semi-natural grasslands boosts biodiversity and re-creates hotspots for ecosystem services” [54], and “Public support for restoration: Does including ecosystem services as a goal engage a different set of values and attitudes than biodiversity protection alone?” [55]. Restoration inputs and ecosystem outcomes should not be confused. Area treated, planting effort or short-term vegetation cover, provide only a partial indication of ecological recovery. Monitoring should include a combination of the composition, functions, connectivity and social consequences. A realistic time frame and a clear indication of the counter-factual should be considered. Evidence from one landscape rarely applies to another. Read together, these records show the range of questions lodged under one thematic heading. The correct unit of comparison is the biological task and its evidence standard; similarity of terminology does not mean comparable performance in the field. The research contribution is therefore clearer when datasets, organisms, sampling units and independent tests are taken into account prior to cross-study generalization.

Bioeconomy and translation

Regarding the bioeconomy and translation, the selected bibliographic record includes “Biodiversity and Ecosystem Services of the Campo Rupestre: a Sustainability Roadmap of Brazil’s Hottest Biodiversity Hotspot” [56], “Ecological Restoration for Sustainable Development in China” [57], “Simulating the Impact of Future Climate Change and Ecological Restoration on Trade-offs and Synergies of Ecosystem Services in Two Ecological Shelters and Three Belts in China” [58], “Trade-offs and Synergies of Ecosystem Services in Inland River Basins under the Influence of the Ecological Water Transfer Project: A Case Study of the Tarim River Basin” [59]. “Ecological Validity” is not the only type of “test.” Others include “credible customer demand,” “operating costs,” “quality assurance,” “institutional fit,” and “fair allocation of benefits.” The “self-funding market” argument relies on the expectation that an NBI can produce public value and benefit without creating an enduring market for the service. While many of the methods employed in these studies were similar, the references illustrate the depth and breadth of the types of questions being asked in this general area. The correct biological unit of comparison and the standard of evidence must be determined before cross-study comparisons can be made. In most cases, the research contributions from the studies are clearer when analyzed at the data set, organism, and sampling unit levels.

"Cost-benefit Analysis of Ecological Restoration Based on Land Use Scenario Simulation and Ecosystem Services on the Qinghai-Tibet Plateau" [60], “The Role of Coastal Biodiversity Conservation on Sustainability and Environmental Awareness in Mangrove Ecosystem of Southern Malang, Indonesia” [61], “Ecosystem Services Valuation for Conservation and Development Decision Making: A Review of Valuation Studies and Tools in the Far-Eastern Himalaya” [62], and “Where are the Trade-offs in Multiple Ecosystem Services in the Process of Ecological Restoration? A case study of the Vegetation Restoration Area on the Loess Plateau, Northern Shaanxi” [63] are included in bibliographies relating to the bioeconomy and translation.

Economic opportunities require going beyond ecological validity to explore if there is a viable market (with credible customer demand), what are the operational costs, and is the intervention a good fit with the rules and regulations and helps to fairly allocate the benefits? Valuation, jobs and businesses use different indicators. Often nature-based solutions can create public value without being self-financing or creating a market, and thus financing and governance are part of the causal pathway. The studies enable a critical comparison. A precise translation of methods to new settings is essential for a deep understanding of the original sampling domain, the meaning of the findings, and the potential impacts of wrong interpretation.

The recommended bibliographic record contains “Evaluating tramway infrastructure on biodiversity and ecosystem services” [64], “Protecting biodiversity to support ecosystem services: An analysis of trade-offs and synergies in southwestern China” [65], “Biodiversity mitigates trade-offs among species functional traits underpinning multiple ecosystem services” [66], and “Ecological plasticity governs ecosystem services in multilayer networks” [67]. Opportunities related to the bioeconomy entail additional tests of ecological validity. These include credible customer demand, operating costs, and quality assurance. Additionally, there must be an assessment of institutional and policy fit, and the fair allocation of benefits. Value can be created in different ways, and positive impact can be realized when certain indicators are met. For example, the evidence could support the creation of positive impact and value by providing public goods and services. For nature-based solutions and other interventions, positive impact can be created even if the market does not self-fund the cost. To what extent do the selected research titles signal new methods? There are different ways of synthesizing evidence. Instead, the focus should be on the biological question, “how does new evidence relate to the old?” (e.g. impact, scale, costs) Only when evidence has been field-tested can claims of large-scale impact be substantiated.

For taxonomy and ecology as foundations of usable knowledge, the bibliographic record includes "Integrating Ecological and Economic Approaches for Ecosystem Services and Biodiversity Conservation: Challenges and Opportunities" [68]; "Ecosystem restoration in fire-managed savanna woodlands: effects on biodiversity, local livelihoods and fire intensity" [69]; "Ecosystem services linked to nature-based solutions for resilient and sustainable cities in India" [70]. Economic opportunities call for additional testing beyond ecological validity: customer demand, operating costs, quality assurance, organizational fit and benefit distribution. Different indicators may apply for the same intervention, e.g., valuing nature for business and creating green jobs. The direction of causal impact from laws, policies and institutions to the social, economic and environmental problems is clear. Nature-based solutions may offer public value without creating a self-funding market.

Taxonomy and ecology as foundations of usable knowledge

Knowledge of taxonomy is a critical element of successful biological control programs and other pest management strategies. Distinguishing native from introduced species is critical for managing invasive species and monitoring pollinators, pests and other biological controls. Field observations may be assessed by comparing with accepted reference records. Technological tools, such as molecular barcoding and eDNA, allow detection and classification beyond the visible eye. Taxonomic research can facilitate detection of organisms in water, soil, sediment and other substrates, as well as in mixed-species communities. Reliable determination of a legally or economically significant species may require morphological examination and specialist judgment, even if an automated result is available.

Ecology provides the basis for explanation. Pollinators, for example, are appreciated for their interactions with crops and/or habitats and management, not simply their presence on a checklist. The same is true for predators and the effect they have on pest suppression. Restoration success cannot be assessed based on the number of trees planted. There are many factors, including unintended changes, survival and the balance of the ecosystem. Ecological understanding has to be converted into testable management decisions, usually through baseline measurement and/or repeatable monitoring.

Ecotoxicology describes the mechanisms by which chemical or other physical stresses affect a living organism. Effects on living organisms can also be described using sentinel species, biomarkers, as well as community indicators. These approaches work best when taxonomy and ecological design are used in conjunction with analytical QC to determine actionable thresholds. These need to be defined with the end user institution in mind. Translational quality is higher when these are integrated. [1, 2]

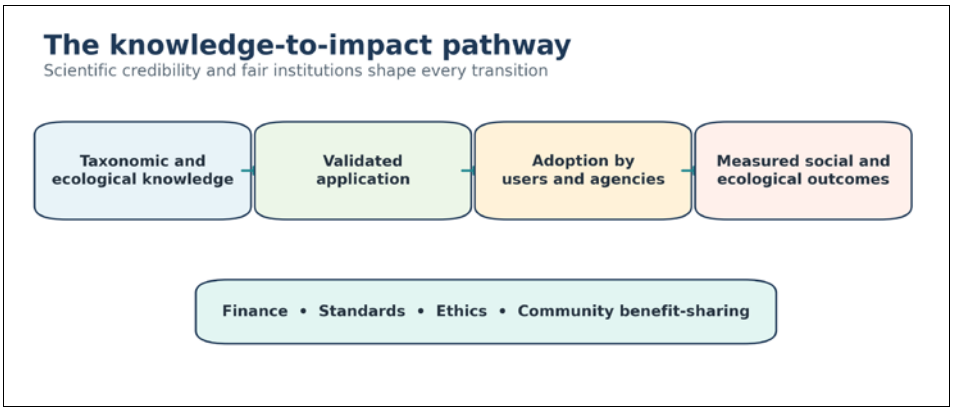


Fig 1: Conceptual knowledge-to-impact pathway with enabling institutional conditions.

Food systems, pollination and sustainable agriculture

Certain ecosystem services are not included in traditional productivity accounts. Some pollinating insects assist in the reproduction of crops and other plants. Other insects and other organisms can help regulate pests. Soil organisms help with the decomposition of organic matter and the release of nutrients to be taken up by the crops. Many other services are provided by organisms, and the relationships may vary with crop type, habitat configuration, season and agricultural management. For that reason, a general biodiversity indicator cannot be used to measure the ecosystem services requested by producers.

There are some practices that are said to positively affect biodiversity (e.g., habitat strips, hedgerows, diversified fields, less disruptive inputs). However, their effects may vary with the context of the land and crop, and even with season, and may involve trade-offs among suppression of pests, pollination and yield, as well as labor demands.

A field trial that measures insect taxa, but not crop or pest results, gives an example of a single type of outcome, not all potential benefits. For robust assessment, appropriate management controls are compared, variability from year to year is accounted for, and costs of maintenance are identified. Farmers are not interested in an abstract index of biodiversity. They want reliability, cost-effectiveness and appropriate guidance.

The translation pathway means a collaborative effort among ecologists, agricultural researchers, extension services, and producers. With taxonomic reference resources, survey results are standardized; field tests interventions, extension resources provide guidance for implementation, and monitoring resources validate that effects are long-lasting. There is potential for new businesses in assessing pollinators and biological control agents as well as other biodiversity-related farm services. The success of these enterprises will depend on how well the industry is able to fulfill genuine outcome claims. [9, 10, 11]

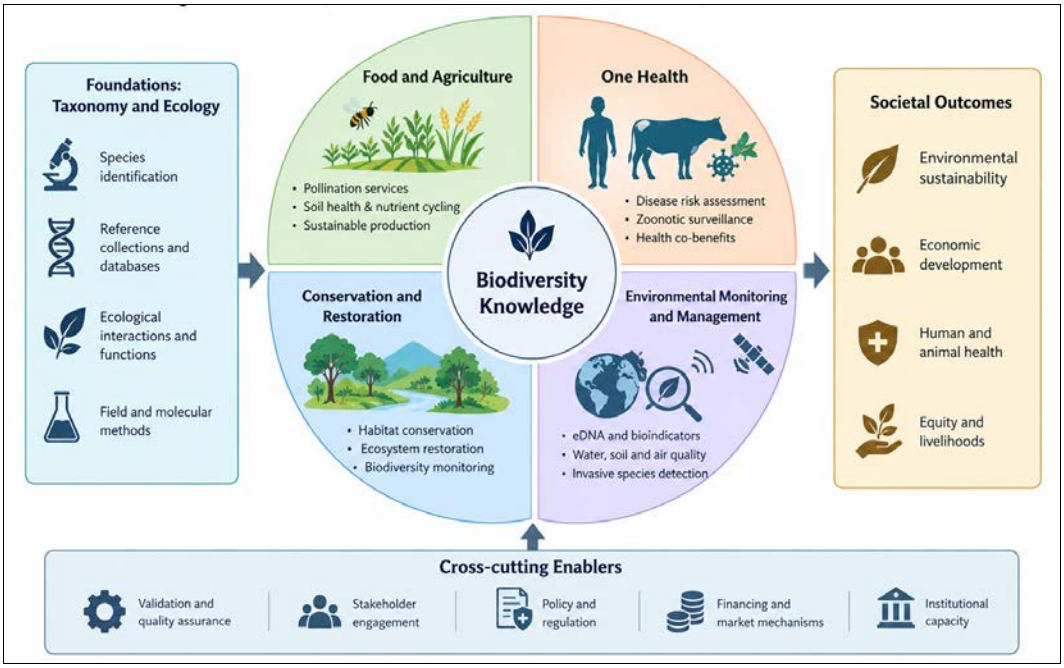


Fig 2: Four connected societal application domains of ecology and taxonomy.

Table 1: Four pathways from zoological knowledge to applications

Domain	Scientific contribution	Potential application	Evidence needed
Food and agriculture	Pollinator and pest ecology	Monitoring and habitat management	Measured yield/pest response
One Health	Host/vector taxonomy and ecology	Surveillance and exposure assessment	Confirmed risk and follow-up
Conservation	Species and habitat knowledge	Restoration and coexistence	Biodiversity and social outcomes
Environmental management	Biological indicators	Pollution and soil monitoring	Field validity and thresholds

One Health, surveillance and environmental exposure

The One Health approach integrates human and animal systems while not making assumptions about biodiversity's impact on disease. Changes in the environment, land-use, animal contact and vector behavior as well as surveillance modify how organisms interact, and some changes in biodiversity may affect reservoir or vector communities. Richness of a given ecosystem does not determine disease outcomes, and simple correlations can not establish a general rule. Research translation depends on integration of multidisciplinary approaches. Transparent systems and protocols are needed to connect pathogen identification with sampling and integration of ecology and public health.

Knowledge of taxonomy helps to distinguish vectors, hosts and concerned organisms, which aids in surveillance. Molecular tools help with difficult identifications, but they have to be used with care and in the context of established references. To provide an efficient surveillance system, it is necessary to determine intervention thresholds, time of reporting, diagnostics and confirmation as well as legal and ethical constraints. Knowledge of ecology is important. Detecting a vector does not necessarily mean establishing transmission, and presence of pathogen genetic material does not necessarily mean a pathogen is viable.

Environmental exposure assessment includes soil, water and organismal indicators of health. Both sentinel taxa and biotic response measures can augment chemical monitoring. Their utility depends on their sensitivity, specificity and the ecological baseline of the system in question. The opportunity in India is beyond the more widespread use of assays; it is the development of pathways to get field observations from evidence to risk assessment and to responsible authority actions. Interdisciplinary approaches, coordination across sectors and reliable records are key. [19, 20]

Biodiversity conservation, coexistence and restoration

Taxonomic and ecological baselines help identify vulnerable populations and/or changing habitats and pressures from extraction and/or development. One way to boost these baselines is to enhance survey and monitoring capabilities. However, an increase in records of detection may simply be the result of an increase in survey efforts, and not necessarily reflect improvement of the targeted population. Conservation goals and objectives should be clearly stated to evaluate the performance of ecological systems and the indicators of those systems. Synonymy, taxonomic confusion and cryptic diversity can affect ecological outcomes, and thus, threats to, and management of, biodiversity.

One way to convert ecological science to practice is through ecological restoration. Improving ecosystems and returning them to their original function, structure and composition can benefit humans, plants and animals. Recovering fragmented ecosystems and improving connectivity can benefit the distribution of ecosystem services. Outcomes may also be reflected in improvements in the quality of hydrology, soil functions and other ecosystem services. Additionally, ecosystem restoration projects can also impact and improve social well-being and biodiversity. Projects may also create trade-offs if local land use, cultural values and water requirements are not sufficiently considered.

Human-wildlife coexistence and invasive species management require similar kinds of care. The potential ecological impact of an intervention has to be balanced against its effect on livelihoods and the institutional realities

of process and fairness. Some international examples provide important tools such as standardized assessment, biosecurity coordination, long term monitoring and transparent consultation. The success of the introduced innovations should be field tested. [38, 39, 40, 41]

Research and the opportunities it brings

The process of research goes beyond the publication. The results of research have to be integrated and adapted to the specific circumstances of the case. An intervention has to be tested and adopted by potential clients. Environmental consultancies and laboratories, as well as businesses providing monitoring services, and restoration enterprises, occupy parts of this chain. The required skills are often interdisciplinary.

Valuation studies can help determine the worth of ecosystem services. However, monetary values may vary depending on the perspective, method, and assumptions. Different approaches to economic valuation may yield inconsistent answers. In the absence of agreement on valuation and integrated assessment, a high economic valuation of an ecosystem may not necessarily result in market ability and/or sustained funding for its conservation. For public goods and public finance, design and implementation of successful institutions hinge on several factors, including costs of transaction, equitable distribution of benefits, and access to benefits.

Employment is also an outcome that must be measured rather than presumed. A training program can provide certificates; a startup can generate sales. Sustainable livelihoods may depend on the survival of businesses that serve the market, particularly if they are ecologically viable. In addition, income may need to be equitably distributed to local knowledge holders. Responsible innovation necessitates and supports the community's right to access and benefit from the use of biological resources. Accountability and good governance are long lasting public values that transcend the swiftness of startup creation.

Table 2: Economic opportunity and evidence requirements

Service setting	Possible employment	Necessary validation	Economic evidence
Ecological surveys	Field taxonomists and analysts	Repeatable methods and quality control	Cost per usable assessment
Molecular monitoring	Technicians and specialists	Barcoding references and controls	Demand and turnaround times
Restoration assessment	Ecologists and local field teams	Long-term biodiversity and hydrological metrics	Stable financing and job quality
Agricultural ecological services	Extension and monitoring teams	Farm-level outcomes	Affordability and recurrent demand

Global comparison and lessons for India

International comparisons of cases can be useful in describing various institutional mechanisms, rather than competing to place countries in a league table. Some places have developed competitive markets for professional ecological assessments, while others prioritize integrated applied ecology (agriculture, biosecurity and conservation), or urban ecosystem management. There are different enabling conditions for these, including demonstrable user requirements, standards and specifications, and technology and financial resources, along with a credible process for monitoring outcomes. These enabling conditions cannot always be discerned by the number of times a particular area has been published. This is because different regulatory and ecological contexts, as well as the requirements for ecological research and the field of application, vary.

India, for example, has considerable scientific and administrative capacities, but impact pathways vary. Biodiversity assessments, Agriculture and Health sector surveys, Environmental Impact Assessments and Conservation activities may all be pursued by different organizations, with varying data requirements. An ICT application, developed to meet requirements in one State or location, may have little applicability in others. Indeed, research evidence from one biome may have limited applicability in others. The best approach may be to jointly define a problem, state the criteria for success and, where necessary, adapt procedures and methodologies to the local context.

The greatest lesson that can be transferred is procedural, rather than technological. Where research methodologies are reference dependent, standards need to be defined and auditable results required. Users should state the problem, financing should be available to sustain an initiative, and monitoring should extend beyond the first implementation. A plural ecosystem of research and application, rather than a single national commercialization policy, would be more desirable.

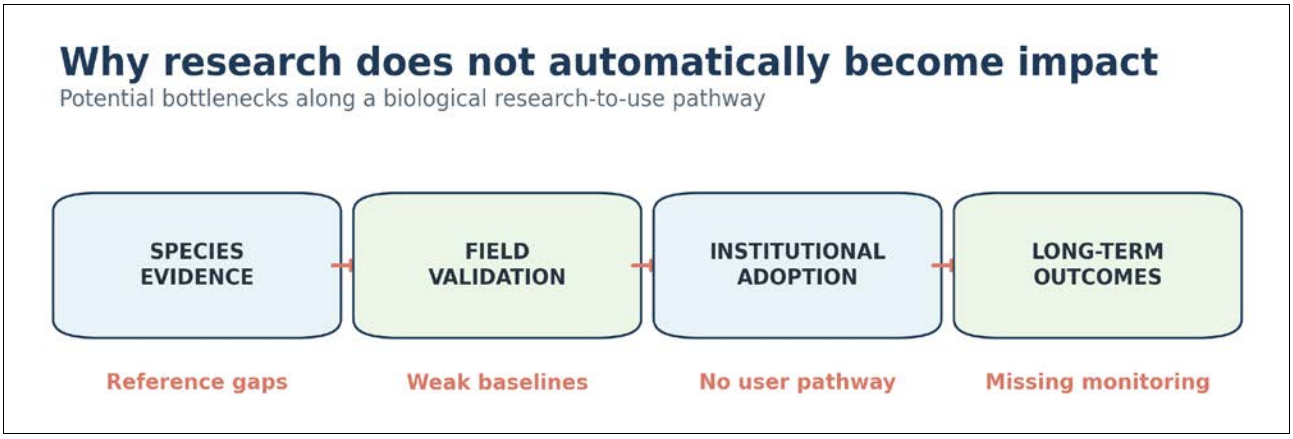


Fig 3: Research-to-implementation bottlenecks requiring explicit validation and monitoring.

Table 3: International comparison questions for adaptation to India

Context	Illustrative application	Transfer criterion
United Kingdom	Ecological assessment services	Standards, licencing, enforcement context
Netherlands	Agricultural ecology and biocontrol	Cropping systems and local species
Australia	Biosecurity and invasive-species monitoring	Ecological risk and agency capacity
United States/Germany	Applied biodiversity data infrastructure	Long-term funding and data stewardship
Singapore	Urban ecological planning	Density, ecology and governance differences

Soil invertebrates and sustainable land management

Soil invertebrates represent the most diverse animal phylum across terrestrial ecosystems and straddle the intersection of taxonomy with issues concerning soil management, land use, and ecosystems services. Different earthworm, arthropod, and other soil invertebrate groups can have significant effects on decomposition, bioturbation, and food web dynamics. However, changes in soil invertebrate communities in response to stress are very context-dependent. The type, intensity, and timing of soil management, season, soil texture, history of pesticide or fertilizer use, and level of sampling effort influence the findings of soil invertebrate surveys. There are very few soil invertebrate indicators available to assess stress on an ecosystem. Before a potential indicator service is developed, the stress (e.g. compacted soil, pollution, salination, etc.) of concern should be evaluated to see if there is an organismal metric that is consistent and robust. Moreover, the information provided by the metric should complement routine soil analyses.

Continued collaboration between universities and land management agencies can provide students the opportunity to develop the needed case studies to assess the feasibility of proposed indicator services. The universities have the taxonomic references and university collected specimens, and land management agencies have the replicated land management studies.

Economics calls for care. Identification can be offered as a service only if a number of logistical and economic factors can be addressed. Measurement of a biologically meaningful indicator does not transform it to an economically valuable product. Public interest programs may be the right delivery mechanism to realize the environmental benefits that are diffuse and wide ranging. For land managers, the meaningful end is improved monitoring and decision-making, and not the sale of a taxonomic metric. [30]

India's research-to-impact gaps and staged roadmap

The first gap relates to continuity from knowledge production to use. Taxonomic surveys, ecological measurements, and economic evaluations are often published in different formats and on incompatible time horizons. Techniques are often validated in the laboratory without determining whether the agencies and/or producers can bear the costs. The second gap pertains to the lack of reference materials, trained staff, and quality assurance. The third gap deals with measurement: programs often count activities and/or inputs. These are local analytical categories and not unfounded claims about all institutions in India.

Year 1 and 2:

The identification of high value problems is essential to ensure that available research resources effectively address end users' needs. Small scale projects, including pilot tests, can tackle questions related to pollinator services, environmental DNA (eDNA) and soil health. Each pilot should define the validation strategy, implementation budget, community engagement approach, and baseline environmental and social indicators. Knowledge inventories should identify restrictions on use of sensitive biological data, and document the contributions of field collectors and holders of traditional knowledge.

Year 2 and beyond:

Demonstration partnerships may link universities, laboratories, government, research, producer and end-user groups and firms. At this stage, project evaluation should address questions such as how many times a given approach or technology was tested by independent parties, the time it takes to make a decision, the cost of making a usable assessment, the time it takes to make the assessment, how quickly and extensively the approach or technology is adopted, and environmental indicators of the intervention. Beyond year 4 only approaches that demonstrate consistent demand, ecological value and sustainability costs should be scaled. Projects should keep evaluating distributional effects, job quality and equity in benefit sharing. [56] [57] [58, 59]

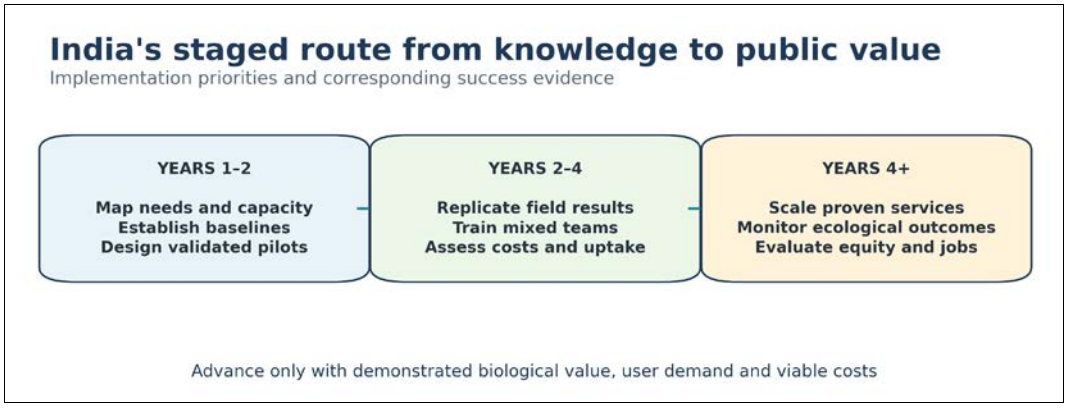


Fig 4: Proposed phased roadmap for ecology-led sustainable development in India.

Table 4: A staged research-to-impact roadmap for India

Horizon	Priority action	Lead partners	Evidence of success
Years 1–2	Needs mapping, baselines, method pilots	Universities, agencies, communities	Valid references and indicators
Years 2–4	Replication, training and demonstration	Laboratories, producers, firms	Ecological gain and user adoption
Years 4+	Scale effective services and evaluate equity	Public institutions and sector partners	Long-term outcomes, jobs, fair benefits

Critical synthesis and future research

The reviewed domains illustrate a general asymmetry. Scientific techniques often outpace systems for endorsing and adopting them. Taxonomic accuracy can enhance the reliability of ecological indicators; however, it doesn't automatically recommend a policy. Ecological evidence can show how management affects function and/or services of an ecosystem; however, translating this evidence to policy/management is often constrained by jurisdiction, finance and community. Valuation can make currently neglected benefits visible, but not all benefits can be quantified, or are safely transferable. Therefore, a knowledge-to-impact framework should recognize the demarcation between science, economy and public policy.

Future studies should assess when a biodiversity-inclusive policy or other intervention yields "additional" benefits relative to the current situation; identify the main barriers to the adoption of biodiversity-inclusive policies and the circumstances where such policies/interventions adversely affect different social groups; and test the fairness of access to employment and biodiversity research and the benefits of innovation. There is potential for within-discipline, cross-discipline, comparative and longitudinal studies to fill research gaps for agriculture, urban, forest and freshwater ecosystems in India.

The main thing is to link biological metrics to decisions and consequences. Evidence based on repeated field tests, clear counterfactuals, longitudinal data and independent assessment can strengthen the case that a given intervention has led to the desired impact. Consequently, we will assess practical policies for their effect on equity, affordability and efficacy, and not for their novelty. [38, 39, 40, 41]

Conclusion

Ecology and taxonomy provide essential foundations for understanding biodiversity, ecosystem functioning, and the relationships between biological systems and human well-being. Their societal value depends on the reliability of scientific evidence, validation under relevant ecological conditions, and integration into management, policy, and community-level decision-making. The literature mapped in this review covers potential applications in pollination and agricultural sustainability, One Health, biodiversity conservation, ecosystem-service assessment, environmental monitoring, and ecological restoration. Translating scientific knowledge into measurable benefits requires taxonomic accuracy, ecological baselines, validated methods, stakeholder engagement, institutional capacity, and long-term monitoring. Furthermore, ecosystem-service valuation alone does not establish economic viability, policy adoption, or realised societal benefits; these require independent assessment of costs, benefits, uncertainties, and distributional effects.

For India, a practical research-to-impact approach could prioritise locally relevant ecological challenges, strengthen taxonomic and biodiversity reference resources, establish reproducible monitoring protocols, and foster collaboration among researchers, institutions, practitioners, and local communities. Pilot interventions should be assessed against defined baselines and, where feasible, appropriate comparison conditions before wider implementation. Evaluation should consider ecological effectiveness, economic feasibility, and social equity using suitable indicators. Overall, this review provides a conceptual framework for connecting biodiversity research with potential societal applications and identifies priorities for further investigation. However, because the analysis relies primarily on bibliographic metadata and article titles, it does not establish the comparative effectiveness of specific interventions or demonstrate measurable societal impacts. The proposed framework should therefore be regarded as a basis for future evidence-based research, validation, and context-sensitive implementation rather than a confirmed model of impact.

Limitations and scope of evidence

This review maps 100 DOI-linked journal article records published between 2020 and 2025, with initial relevance classification based primarily on bibliographic metadata and article titles. Therefore, it represents a thematic literature map and conceptual synthesis rather than a systematic full-text review or quantitative meta-analysis. Metadata-based classification may not fully capture individual studies' methods, findings, and limitations, while database coverage, indexing practices, search terminology, and screening procedures may influence the evidence included. Differences in study designs, ecosystems, outcome measures, and research contexts also limit direct comparisons across application domains. Economic valuation does not necessarily demonstrate commercial viability, and observed associations alone cannot establish causality. Similarly, international examples and proposed research-to-impact pathways may not be directly transferable to India because of ecological, socioeconomic, and institutional differences. The review does not independently establish the effectiveness of specific interventions or quantify their societal impacts. Future research should use reproducible search and screening procedures, critical full-text assessment, and study-specific evaluation of methods, outcomes, and uncertainties. Quantitative synthesis should be undertaken only when sufficient comparable evidence is available; otherwise, structured narrative synthesis is more appropriate.

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