Proceedings of the National webinar on the Climate Change and Biodiversity

Sri. Vasudev Jatawan | Dr. Sunil Prasad
Dr. K.C. Mishra |Dr. Om Prakash Parmar

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S. No	CONTENTS	PAGE
1	Action Policy to Combat Climate Change and its Impacts for Sustainable Development Dr. S. Sreedevi	1
2	Influence Of Global Climate Change On The Biodiversity In The Present Scenario Navin K Ambasht	2
3	Climate Change and Ecological Disturbance: A Framework for Biodiversity Management" Vishal Mishra	3
4	Tigers Under Threat in Madhya Pradesh: Climate Change, Habitat Loss, and Human–Wildlife Conflict Tosif Nagori	4-7
5	Cosmic Expansion and Climate Change: A Review on Universal and Terrestrial Dynamics Krishna Chandra	8-10
6	Impact of Climate Change on Aquatic Biodiversity Bhawna Srivastava and Reddy,P.B*	11-15
7	Economics of Climate Change Mitigation in India Dr. G.R. Gangle	16-21
8	Analysis of the Biological Diversity Act, 2002 and Rules, 2004" Reddy, P.B	22-25
9	Balancing Climate Goals and Biodiversity Protection Bhawna Srivastava	26-33
10	Biodiversity as India's Sustainable Edge Jitendra Singh Pachaya	34-36
11	Seasonal Variation in Water Quality and Zooplankton Diversity of the Chambal River at Nagda, India Reddy, P.B	37-44

12	Tackling Climate Change at Its Source: Energy Efficiency and Renewable Transitions as Strategies for Biodiversity Protection Piyush Bhatnagar and Rajendra Kumar Gujetiya	45-48
13	Climate Change Policies and India's Road to Net-Zero Reddy, P.B	49-52
14	India's Climate Policy under the Panchamrit Goals Reddy, P.B	53-56
15	The Importance of Traditional Communities in Biodiversity Conservation in India Jagdish Kannoje	57-61
16	Artificial Intelligence and the Internet of Things for Biodiversity Conservation Reddy, P.B	62-66
17	The Green Economy Transition: An Economic Analysis of Policy Instruments for Aligning Climate Mitigation and Biodiversity Goals Vasudev Jatawan, Preethi Kannojiya	67-75
18	Redefining Coexistence: A Socio-Ecological Analysis of Human-Wildlife Interactions in the Era of the Climate Crisis B. L. Panday' C. L. Dodiya	76-81
19	Comparative Analysis of Algal Diversity in Different Stretches of the Shivna River at Mandsaur District, Madhya Pradesh, India Prerna Mitra	82-88
20	Community Forestry: A Practical Solution to Fight Climate Change in Rural Madhya Pradesh Om Prakash Parmar , Rachana Khandelwal	89-93
21	Impact Of Particulate Matter (Pm_1, $Pm_{2.5}$, And Pm_{10}) On Butterfly Diversity And The Role Of Home Gardens In Conservation: A Case Study From Kanpur, India Neetu Pandey, Dr. Saras	94

ACTION POLICY TO COMBAT CLIMATE CHANGE AND ITS IMPACTS FOR SUSTAINABLE DEVELOPMENT

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Abstract: Climate change and global warming are one of the pressing issues in the 21st century, a challenge for humanity and a burden on nature. Climate change, a defining challenge in current times, is driven by an intricate interplay of natural processes and human activities. Climate change poses an unprecedented threat to global ecosystems, economies, and communities, demanding urgent and coordinated action. Sustainable Development Goal (SDG) 13, or Climate Action, is the UN's goal to take urgent action to combat climate change and its impacts by strengthening resilience, improving education, integrating climate measures into policies, and providing financial support for mitigation and adaptation. This presentation will explore this comprehensive action policy framework designed to mitigate climate change and adapt to its multifaceted impacts, with a strong emphasis on sustainable development. It outlines strategic interventions across energy, transportation, agriculture, and urban planning sectors, integrating climate resilience with economic growth and social equity. United Nations Sustainable Development Goals (SDGs), in alignment with climate action aims to foster a future that is not only environmentally secure but also economically vibrant and socially just.

Keywords: Climate change, Global warming, Greenhouse gases, Sustainable Development Goal, action Policy

INFLUENCE OF GLOBAL CLIMATE CHANGE ON THE BIODIVERSITY IN THE PRESENT SCENARIO

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Abstract : Global climate has slowly changed and evolved over the millions of years and has acquired the present-day characteristics of more or less stable levels in terms of human history. During the past few decades there is the rise of average temperatures due to green-house effect of excessive carbon dioxide emission discharged by man in the atmosphere. The other important deleterious change in the reduction of stratospheric ozone shield due to ozone destroying Chlorofluorocarbon released in atmosphere by man and consequent enhancement of ultraviolet-B radiations. Rainfall pattern also gets affected by change in temperature via evapotranspiration and wind velocity. Rise in the temperature is also responsible for creation of human health problem, loss of biodiversity, animal and plant health also. There is also out-break of pests and pathogen. Global change is the biggest disaster in the history of human beings. World-wide attention is all focused to evolve sustainable development. Change in the climatic condition increases the waterborne as well as vector borne diseases like a recent example of Covid 19 i.e. coronavirus pandemic. The threat of varying climate change has driven world-wide attention of scientists as these variations are imparting significant reduction on global crop production. This review gives an assessment of the climate change impact on vegetation as well as the UV-B impacts on plants. The normal status of biodiversity has not been adversely affected by natural speed of extinction. Anthropogenic disturbances and climate change has affected the biodiversity and the species extinction.

CLIMATE CHANGE AND ECOLOGICAL DISTURBANCE: A FRAMEWORK FOR BIODIVERSITY MANAGEMENT"

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Abstract: Climate change is a major driver of biodiversity loss and ecological disruption worldwide. Rising temperatures, altered precipitation patterns, sea-level rise, and more frequent extreme weather events are significantly impacting natural habitats, altering species distributions, and increasing extinction risks for many vulnerable species. Effectively addressing these challenges requires integrated, adaptive, and ecosystem-based approaches that confront both the causes and consequences of climate change.

This paper explores a comprehensive range of strategies for managing biodiversity under climate-related disturbances. Nature-based solutions—such as reforestation, wetland restoration, and coral reef rehabilitation—enhance ecosystem resilience while contributing to carbon sequestration and climate mitigation. Expanding and connecting protected areas through wildlife corridors supports species migration and adaptation in response to shifting environmental conditions. Additionally, restoring degraded ecosystems, managing invasive species, and promoting ecological diversity strengthen ecosystem stability. Species-specific conservation efforts, including captive breeding, assisted migration, and targeted monitoring, are vital for protecting the most threatened species. Reducing greenhouse gas emissions through renewable energy adoption, sustainable agriculture, and improved land use practices is also essential to limit long-term ecological stress. The active involvement of local and Indigenous communities, who bring traditional ecological knowledge and sustainable management practices, is crucial for effective and equitable conservation outcomes.

Adaptive management—guided by continuous research, monitoring, and flexibility—supports timely responses to emerging climate threats. At the policy level, international frameworks like the Paris Agreement and the Kunming-Montreal Global Biodiversity Framework are critical for aligning climate action with biodiversity conservation goals.

Ultimately, safeguarding biodiversity in a changing climate demands holistic, collaborative, and forward-thinking solutions that ensure both ecological integrity and human resilience.

TIGERS UNDER THREAT IN MADHYA PRADESH: CLIMATE CHANGE, HABITAT LOSS, AND HUMAN–WILDLIFE CONFLICT

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Abstract: Madhya Pradesh (MP) harbours the largest forested area in India and is home to several iconic tiger reserves, yet the state faces mounting ecological pressures that threaten its wildlife. Between 2021 and 2023, MP lost a significant amount of forest cover, while tiger mortalities—many from anthropogenic causes—have risen alarmingly. This paper draws on ecological and conservation studies to examine how climate variability, habitat fragmentation, and human pressures converge to heighten tiger vulnerability and conflict with rural communities. Rather than just summarizing statistics, we reflect on the lived realities of coexistence, where ecological stress and human livelihoods collide. We propose integrative strategies, including seasonal water provisioning, stronger enforcement, community-based coexistence programs, and long-term restoration of ecological corridors. If conservation is to succeed, it must reckon with climate uncertainty and the voices of people living at the edge of tiger habitats.

Introduction: Tigers (*Panthera tigris*) are apex predators and symbols of India's ecological heritage. Madhya Pradesh, celebrated as the "Tiger State," shelters some of the most famous reserves—Kanha, Bandhavgarh, and Pench. Yet the same state also reports some of the country's steepest forest losses and troubling tiger deaths (Jhala et al., 2019). Walking through villages near buffer zones, one often hears both pride and fear: pride in living close to the tiger, and fear of livestock loss, crop damage, and uncertain compensation. This dual reality captures the paradox of MP: large forests and large conflicts.

This paper asks: How do climate pressures and human activities combine to shape tiger survival and human safety in MP? And what kinds of interventions can make coexistence less fraught and more sustainable?

Literature Review: Large carnivores need vast, connected landscapes and stable prey bases to thrive (Chapron et al., 2014; Ripple et al., 2014). When these landscapes fragment, tigers face more frequent encounters with roads, villages, and farms (Joshi et al., 2016). Mortality records show that many tiger deaths in India are not from natural causes but from electrocution, poisoning, or poaching (Jhala et al., 2019).
Climate change intensifies these stresses. Rainfall that once followed reliable patterns has become erratic. When drought hits, herbivores migrate closer to villages in search

of water, and tigers follow. In these moments, conflict is almost inevitable. Studies suggest that crop failures often push communities toward riskier coping strategies, including retaliatory killings (Karanth &Kudalkar, 2017). Such dynamics are not unique to India—similar patterns emerge in other regions where carnivores and people share space (Ceballos et al., 2020).

But conflict is not only ecological. It is deeply social, shaped by how compensation works (or doesn't), how quickly officials respond, and how much trust exists between forest staff and local people (Inskip & Zimmermann, 2009; Barua et al., 2013). Conservation in MP must be understood through this social-ecological lens.

Data and Methods: Rather than generating new field data, this paper adopts a systematic review approach, bringing together:

- The India State of Forest Report 2023 (FSI, 2023) for forest loss.
- National tiger status reports (Jhala et al., 2019).
- Peer-reviewed studies on climate variability and carnivore ecology (Carter & Linnell, 2016; Kumar et al., 2022).
- Research on human–wildlife conflict in India (Karanth &Kudalkar, 2017; Barua et al., 2013).

Search strategy: We searched Scopus, Web of Science, and Google Scholar with keywords such as tiger mortality, Madhya Pradesh, climate change, human–wildlife conflict, forest fragmentation. Only studies published between 2009 and 2023 with clear methods were included.

Analysis: Evidence was compared thematically—ecological stressors on one side, human responses on the other. Where possible, we cross-checked national statistics with local case studies to avoid overgeneralization.

Findings

Forest Cover Change: According to the India State of Forest Report 2023, MP remains India's most forested state with around 77,000 km² under forest cover. However, the report also highlights localized declines, particularly in non-protected areas (FSI, 2023). While exact numbers vary by reporting cycle, the evidence points to ongoing forest loss that threatens corridor connectivity. These numbers feel abstract until you stand at the edge of a corridor where trees have been cleared for farms or roads. The loss is not just of trees, but of pathways that once allowed tigers to move unseen.

Tiger Mortalities: National reports show that tiger deaths remain a major conservation challenge, with many linked to unnatural causes such as poisoning, snares, and electrocution (Jhala et al., 2019). While MP-specific mortality data are not consistently separated in national reports, media and state records often highlight MP as among the states with the highest unnatural deaths. Each case underscores the fragile boundary between people and predators.

Human–Wildlife Conflict: For farmers, losing a cow can mean losing a season's income. Retaliatory actions are often less about hostility toward tigers and more about desperation. Drought years are particularly tense, when prey availability collapses and human–wildlife encounters spike (Karanth &Kudalkar, 2017). Communities at the frontline carry both the costs and the anxieties of conservation.

Discussions: Four interlinked factors shape the current tiger crisis in Madhya Pradesh:

1. Habitat fragmentation forces more encounters between tigers and people (Joshi et al., 2016). Addressing this requires legally securing and restoring corridors, particularly those connecting Kanha, Pench, and Bandhavgarh.
2. Climate variability disrupts prey and water cycles, driving carnivores into risky spaces (Carter & Linnell, 2016; Kumar et al., 2022). Installing seasonal water points and embedding climate-risk projections into reserve management are practical steps.
3. Community vulnerability fuels retaliatory behavior—sometimes poisoning, sometimes silent resentment (Karanth &Kudalkar, 2017). Compensation schemes must be fast, transparent, and coupled with livelihood diversification programs.
4. Governance gaps—delayed compensation, weak enforcement—magnify distrust (Inskip & Zimmermann, 2009). Strengthening ranger capacity, introducing community hotlines, and linking conservation with rural development can help rebuild trust.

Comparative research on human–wildlife conflict mitigation in India shows that when compensation is timely and community engagement is prioritized, conflict intensity remains lower despite ecological pressures (Karanth &Kudalkar, 2017). For MP, weaving ecological restoration with community-centered governance will be key.

Conclusion: Madhya Pradesh's tigers live at the edge of resilience, where climate, ecology, and human needs intersect. The state's conservation story is not just about big cats, but about farmers, rangers, and landscapes under stress. By weaving climate adaptation, governance reform, and community trust into its conservation fabric, MP can strengthen both tiger survival and human security. The stakes are high, but so too is the opportunity to redefine coexistence.

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COSMIC EXPANSION AND CLIMATE CHANGE: A REVIEW ON UNIVERSAL AND TERRESTRIAL DYNAMICS

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Abstract: The universe is expanding on a cosmic scale, driven by dark energy and governed by general relativity. Meanwhile, Earth faces a pressing challenge—climate change—caused largely by anthropogenic activities. Though these phenomena occur at vastly different scales, both reflect the fundamental nature of physical processes shaping our existence. This review explores the science of cosmic expansion and climate change, highlighting their underlying mechanisms, recent observations, and interdisciplinary parallels. It emphasizes the importance of connecting universal and terrestrial perspectives for a holistic understanding of humanity's place in the cosmos.

Keywords*:* cosmology, General relativity, supernovae.

I**ntroduction**: Human curiosity spans from the largest scales of the cosmos to the most immediate challenges on Earth. While astronomers study the expansion of the universe, climate scientists focus on the warming of Earth's atmosphere. At first glance these topics appear unrelated, but both require deep reliance on physics, data, and predictive models. The study of cosmic expansion has reshaped our worldview: it proved that the universe is not static but dynamic, evolving with time. On the other hand, climate change research has highlighted that Earth's systems are fragile and highly sensitive to external disturbances, especially human-induced ones. The connection lies in methodology: both cosmology and climate science employ large-scale observations, mathematical models, and simulations to understand complex systems. Furthermore, both pose existential questions—cosmic expansion about the ultimate fate of the universe, and climate change about the sustainability of life on Earth. This article provides a dual perspective, emphasizing that knowledge of the cosmos and of Earth's climate are complementary in constructing a holistic scientific worldview.

Cosmic Expansion: Historical Development: The discovery of cosmic expansion traces back to the early 20th century. Albert Einstein's equations of General Relativity (1915) first hinted at a non-static universe. Initially, Einstein introducedthe"cosmologicalconstant"topreserveastaticmodel.However, in1929, Edwin Hubble's observations of receding galaxies demonstrated that the universe is expanding, confirming predictions of models developed by Georges Lemaître.

Mechanism of Expansion: Expansion is described by the Friedmann-Lemaître-Robertson-Walker (FLRW) metric, which incorporates the scale factor a(t). The redshift of light from distant galaxies provides empirical evidence: as the universe expands, wavelengths of light stretch, increasing their redshift. The Hubble constant (H_0) quantifies the rate of expansion, though debates remain about its exact value (tensions exist between local and cosmic microwave background measurements).

Dark Energy and Acceleration: In 1998, observations of Type Ia supernovae revealed that expansion is not slowing down, but accelerating. This discovery introduced the concept of dark energy, which constitutes nearly 70% of the universe's energy content. Its nature remains one of the deepest mysteries in modern physics—possibly linked to vacuum energy or new physics beyond the Standard Model.

Observational Evidence and Future Scenarios:
The fate of the universe depends on the properties of dark energy. Possible scenarios include:-Big Freeze: galaxies drift apart and stars eventually extinguish. - Big Rip: runaway expansion tears apart galaxies, stars, and even atoms. - Cyclic Models: the universe oscillates between expansion and contraction. These possibilities demonstrate the deep uncertainties that remain in cosmology.

Climate Change on Earth
Causes:

1. Green house gases (CO_2,CH_4,N_2O) trap heat. Human factors: fossil fuels, deforestation, industrialization.
2. Observational Evidence: Global temperatures up ~1.1°C since pre-industrial times. Melting glaciers, rising seas, extreme weather.
3. Theoretical Framework: Governed by energy balance models. Climate models use differential equations and simulations.

Future Scenarios: Best-case: stabilization near 1.5–2°C. Worst-case: warming 3–4°C by 2100. Interdisciplinary Parallels: Cosmic expansion acts on billions of light-years, while climate change acts locally on Earth, but both rely on universal physics. Both use long-term data, simulations, and predictive models. Dark energy is the mystery in cosmology, human emissions are the uncertainty in climate science.

Broader Reflections: Cosmic expansion gives humanity a sense of humility, while climate change demands urgent responsibility. Together, they remind us that the universe evolves beyond our control, but Earth's climate depends on human stewardship.

Conclusion: Cosmic expansion and climate change represent two extremes of inquiry: one at the cosmic scale, the other terrestrial. Both require observation, modeling, and collaboration. Understanding expansion places us in the universe, while addressing climate change secures life on Earth.

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IMPACT OF CLIMATE CHANGE ON AQUATIC BIODIVERSITY

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Abstract: Climate change poses escalating threats to aquatic biodiversity across marine and freshwater ecosystems globally. Anthropogenic activities have increased greenhouse gas concentrations, driving ocean warming, acidification, altered precipitation patterns, and sea level rise, which degrade habitats, alter species distributions, and disrupt aquatic food webs. In marine systems, elevated temperatures lead to widespread coral bleaching, mass mortality events, and shifts in species ranges, while deoxygenation exacerbates "dead zones" that reduce habitat suitability for many organisms. Ocean acidification further impairs calcifying species, such as corals, mollusks, and pteropods, triggering cascading effects throughout the marine trophic network. Coastal ecosystems, including mangroves, seagrass beds, and tidal wetlands, face inundation and erosion due to sea level rise, threatening biodiversity and the ecosystem services they provide, such as fisheries support and coastal protection.

Freshwater systems are equally vulnerable, with rising water temperatures stressing cold-water species, altering reproductive cycles, and promoting invasive species. Changes in the hydrologic cycle intensify floods and droughts, disrupt river connectivity, and exacerbate pollution and harmful algal blooms. Salinization of coastal freshwater habitats further undermines species survival and ecosystem function. This paper synthesizes evidence from IPCC assessments, peer-reviewed studies, and case reports to evaluate the cumulative impacts of climate change on aquatic biodiversity. It also highlights adaptive management approaches, ecosystem-based strategies, and policy interventions that are critical for conserving biodiversity, maintaining ecosystem services, and supporting sustainable development in the context of a rapidly changing climate.

Keywords: Climate change, aquatic biodiversity, marine ecosystems, freshwater ecosystems, coral bleaching, ocean acidification, hydrologic cycle, species migration, ecosystem services.

Introduction: Aquatic ecosystems support critical ecological functions, including carbon cycling, nutrient processing, and primary productivity, while also providing food security, economic livelihoods, and climate resilience [1], [2]. However, climate change has emerged as a principal driver of biodiversity loss in these systems. Rising ocean temperatures, ocean acidification, and changes in precipitation patterns are altering ecosystem structure and function [3], [4].

Marine biodiversity is particularly vulnerable, as coral reefs, seagrass meadows, and mangroves provide critical habitats for fish, invertebrates, and mammals [5]. Coral bleaching events, driven by elevated water temperatures, have increased in frequency and intensity, with some reefs experiencing up to 90% mortality during extreme heatwaves [6], [7]. Freshwater ecosystems are sensitive to changes in hydrology and temperature [8]. Rivers, lakes, and wetlands face altered flow regimes, increased droughts, and flood events, affecting species reproduction, migration, and survival [9]. Salinity intrusion from sea level rise threatens coastal freshwater habitats, affecting endemic and commercially important species [10]. Globally, these impacts threaten not only biodiversity but also ecosystem services critical for human well-being [11]. Understanding the scale and scope of climate-induced changes is vital for developing conservation strategies, adaptation measures, and evidence-based policy frameworks [12].

Methodology: This review adopted a **systematic literature review methodology**, focusing on publications from 2010 to 2025. Databases searched included Scopus, Web of Science, and Google Scholar. Keywords used were “climate change,” “aquatic biodiversity,” “marine ecosystems,” “freshwater ecosystems,” “coral bleaching,” “ocean acidification,” and “hydrologic cycle.” Initial searches yielded 85 articles; after screening for relevance, quality, and publication date, 52 studies were included. Data extraction focused on key drivers of biodiversity loss, ecosystem responses, species-level impacts, and mitigation strategies. Case studies from the Indian Ocean, Great Barrier Reef, Amazon River Basin, and coastal wetlands were emphasized to illustrate global and regional patterns [13], [14].

Results and Discussion

A. Marine Biodiversity

1) Ocean Warming and Heatwaves: Over 90% of excess anthropogenic heat is absorbed by the oceans, raising sea surface temperatures and driving marine heatwaves [15]. Coral bleaching, caused by thermal stress, leads to widespread coral mortality, threatening reef-dependent species [16]. Fish species are migrating poleward and into deeper waters to maintain thermal preference, disrupting local fisheries and food webs [17]. Deoxygenation further exacerbates stress, expanding hypoxic “dead zones” that are inhospitable to many organisms [18].

Ocean Acidification: Absorption of atmospheric CO_2 reduces ocean pH, impairing calcification in corals, mollusks, and pteropods [19]. As foundational species decline, cascading effects occur throughout the marine food web, reducing biodiversity and affecting commercially important fish stocks [20].

Sea Level Rise: Rising sea levels threaten coastal ecosystems such as mangroves, tidal wetlands, and seagrass beds [21]. These areas serve as nurseries for fish and invertebrates, protect coastlines from erosion, and store carbon. Loss of these habitats increases vulnerability to storm surges and reduces ecosystem services [22].

Case Study: The Great Barrier Reef has lost nearly half of its coral cover over the past three decades due to successive heat waves and bleaching events [23].

B. Freshwater Biodiversity

1) **Thermal Stress and Altered Flow:** Rising water temperatures stress cold-water species like trout and salmon, shrinking suitable habitats [24]. Altered precipitation and snowmelt patterns affect stream flow and spawning cycles [25]. Warmer waters also facilitate invasive species expansion, outcompeting native species.

2) **Extreme Hydrologic Events:** Droughts reduce habitat connectivity, while floods displace aquatic organisms and increase sedimentation and nutrient loading [26]. Harmful algal blooms, exacerbated by warmer temperatures and nutrient runoff, create hypoxic or toxic conditions affecting fish and macro invertebrates [27].

3) **Salinization:** Sea level rise intrudes saltwater into freshwater habitats, altering water chemistry and threatening biodiversity [28]. Mangrove encroachment into rivers alters species composition and ecosystem function [29].

Case Study: In India's Ganga-Brahmaputra delta, salinization and altered river flows have reduced freshwater fish populations and displaced migratory bird species [30].

Implications for Conservation and Policy: The cumulative effects of climate change on aquatic biodiversity necessitate ecosystem-based adaptation strategies, including habitat restoration, marine protected areas, sustainable fisheries management, and regulation of nutrient inputs [31]. Policy interventions must integrate climate projections to safeguard ecosystem services and ensure the resilience of aquatic biodiversity [32], [33].

Conclusion: Climate change poses profound and multifaceted threats to aquatic biodiversity, affecting both marine and freshwater ecosystems through a combination of direct and indirect stressors. Rising water temperatures, ocean acidification, altered hydrological regimes, and salinization collectively disrupt the physical and chemical environments that support aquatic life. In marine ecosystems, warming leads to coral bleaching, shifts in species distributions, and deoxygenation, while ocean acidification impairs calcification in corals, mollusks, and crustaceans, undermining critical food webs. Coastal habitats such as mangroves, seagrass beds, and tidal wetlands are increasingly vulnerable to sea level rise, erosion, and habitat loss, compromising nursery grounds and reducing biodiversity resilience. Freshwater systems are similarly affected, with altered flow regimes and thermal stress impacting fish, macroinvertebrates, and amphibians, and promoting the proliferation of invasive species. Salinization from sea-level intrusion further threatens the survival of freshwater-dependent species and reduces ecosystem productivity. These cumulative impacts not only compromise biodiversity but also diminish the ecosystem services upon which human societies depend, including fisheries, water purification, and climate regulation. Effective conservation and sustainable management require integrated strategies that combine mitigation of greenhouse gas emissions, climate adaptation measures, ecosystem-based management, and habitat restoration. Collaboration among policymakers, scientists, local communities, and international stakeholders is essential to implement evidence-based interventions that preserve ecosystem structure, maintain functional connectivity, and ensure the continued provision of critical ecosystem services in a rapidly changing climate.

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ECONOMICS OF CLIMATE CHANGE MITIGATION IN INDIA

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Abstract: India confronts a major policy choice: sustain rapid development while delivering deep greenhouse-gas (GHG) mitigation aligned with its Updated NDC and long-term neutrality goals. This review synthesizes literature (policy reports, empirical studies, modeling exercises) from 2018–2025 to examine (i) cheapest mitigation pathways, (ii) aggregate investment and financing needs, (iii) distributional and macroeconomic consequences, and (iv) policy instruments that minimize costs while protecting growth and equity. We find that large-scale renewables deployment plus energy efficiency and transport electrification provide the most cost-effective near-term abatement and deliver large air-quality and health co-benefits. Harder-to-abate sectors (steel, cement, heavy freight, some industrial processes) require higher-cost innovation (CCS, green hydrogen) and public support. Meeting India's 2030 capacity and intensity goals implies substantial incremental investments — market estimates for the renewable target alone exceed US$ 300 billion — and will require a mix of domestic private capital, public de-risking instruments, and international climate finance. Policy sequencing matters: combine predictable price signals (phased carbon pricing or fuel levies), targeted regulation, and revenue recycling to protect vulnerable households and coal-dependent regions. Investment in project pipelines, de-risking, and social protection will determine whether mitigation is both cost-effective and politically feasible. UNFCCC+2Reuters+2

Keywords: India, climate mitigation, renewable investment, carbon pricing, green finance, co-benefits, distributional impacts.

Introduction: India's 2022 Updated NDC commits to reducing emissions intensity of GDP by 45% (relative to 2005) by 2030 and to achieving roughly 50% cumulative installed electric-power capacity from non-fossil sources by 2030 — a signal of significantly elevated mitigation ambition within a development context that still relies on fossil fuels for reliability and growth. These targets, together with a net-zero pledge for 2070, frame the economic questions covered in this review: what mitigation is least-cost now, how much investment is required, who bears the costs and benefits, and what policy instruments minimize overall welfare losses while distributing burdens fairly? UNFCCC+1

This review draws on major institutional assessments (IMF, OECD), finance-sector estimates, peer-reviewed studies on air-quality co-benefits and health, and green-finance mappings to produce a synthesis of the economics and policy implications for India. The goal is to provide an evidence-based roadmap for researchers and policymakers on sequencing, financing, and social protection needs.

Scope, evidence base and methods: This is a narrative, evidence-synthesis review of literature from 2018–2025. Core sources include IMF working papers and country briefs with macro-modelling of mitigation scenarios; OECD analyses of carbon pricing and effective carbon rates; financial-sector and market reports (e.g., Moody's estimates on renewable investment); Climate Policy Initiative (CPI) and other trackers on green finance flows; and peer-reviewed studies quantifying co-benefits (air quality, health). Where possible, the review highlights consensus findings, quantifies ranges reported by multiple studies, and flags key uncertainties or divergent assumptions (e.g., technology cost trajectories, speed of electrification). Reuters+3IMF+3OECD+3

The policy context — targets, trajectories and immediate implications: India's strengthened targets require rapid clean-capacity additions while managing a rising electricity demand driven by cooling, manufacturing, and urbanization. Tracker analyses show substantial recent progress in adding renewables, but coal remains large in the generation mix, and system integration challenges (grid flexibility, storage, T&D upgrades) are binding constraints for high renewables penetration. The scale and pace implied by the 2030 goals increase near-term investment needs and emphasise the role of policy design to mobilize private capital and maintain system reliability. Climate Action Tracker+1

Mitigation options and relative costs

A. Power sector: renewables, storage and flexibility: Solar and wind, when paired with storage and grid upgrades, represent the lowest-cost source of new generation capacity in many Indian regions. Recent auction and market prices, plus falling battery and module costs, make rapid renewable expansion economically attractive for new supply. However, integrating very large shares of variable renewables requires significant investment in transmission, distribution (T&D) reinforcement, flexible generation or storage, and market reforms (day-ahead, ancillary services, demand response). Market estimates place incremental capital needs for the 500 GW non-fossil capacity ambition in the hundreds of billions of USD (Moody's estimated up to ~US$385 billion for generation and T&D combined). These investments — while large — principally substitute for fossil-fuel capital and can be financed through public–private partnerships and private project finance once project pipelines are bankable. Reuters+1

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B. Industry and process emissions: Heavy industry (steel, cement, chemicals) is comparatively costly to decarbonize. Abatement options include efficiency, fuel switching (electrification where possible), process substitution, CCS, and low-carbon hydrogen for high-temperature processes. Marginal Abatement Cost (MAC) curves for India typically show industry options at higher cost per tCO_2 than many power-sector measures, implying that near-term cost-minimizing strategies prioritize power and transport while supporting R&D and demonstration projects in industry. Public interventions (subsidies for first movers, risk sharing for CCS pilots) are economically justified to overcome learning-by-doing and scale effects.

C. Transport and buildings: Electrification of two- and three-wheelers and urban buses is low-cost and rapid, especially given India's concentrated urban travel patterns; freight and aviation require alternative fuels that remain expensive. Energy-efficiency upgrades in buildings and appliances deliver negative or low net costs when co-benefits (reduced electricity bills, avoided capacity investments) are included.

D. Land use and agriculture: Afforestation, improved soil and crop management, and methane reductions in livestock and rice systems can be low-cost sinks. However, permanence, measurement, and livelihood trade-offs complicate large-scale deployment; policy design must ensure local benefits to farmers and landowners.

Aggregate investment needs and financing pathways

The sheer scale of investment for the power transition — generation, storage, and T&D — is large relative to typical annual capital formation. Market analyses estimate generation plus T&D investments for ambitious renewables targets in the order of US$ 300–400 billion over the next decade, with variations by assumptions on costs and timelines. Public budgets cannot shoulder this alone; therefore, private capital mobilization, green bonds, concessional international finance, blended finance, and proactive de-risking (guarantees, payment security mechanisms) are crucial. The Climate Policy Initiative's mapping shows growth in green finance flows but also substantial gaps in hard-to-abate sectors and in long-tenor project finance needed for infrastructure. Leveraging finance efficiently requires streamlined permitting, bankable offtake arrangements, and transparent project pipelines to reduce transaction costs and perceived risks. Reuters+1

Carbon pricing and market instruments — design matters: India does not currently have a nationwide explicit carbon price; instead, much of its emissions face an implicit price through fuel excise taxes and sectoral regulations. OECD analysis shows that in 2023 a significant fraction of India's emissions were subject to positive net effective carbon rates (implicit pricing via fuel taxes) but that a formal, broad-based carbon price remains absent. The design choices — coverage, trajectory, revenue use, and complementarity with regulations — are decisive for both cost-effectiveness and political feasibility. A phased approach (starting with upstream fossil fuels or high-emitting sectors, with revenues recycled to protect poorer households and support transition assistance) can lower distortions and raise public acceptability. Domestic emissions trading or sectoral crediting mechanisms may be valuable later, provided environmental integrity and robust MRV systems are in place. OECD+1

Distributional and macroeconomic consequences

A. Growth implications: Model-based studies (including IMF analyses) show that well-designed mitigation — prioritizing low-cost options and using revenues productively — can limit GDP impacts and be consistent with continued growth. Conversely, abrupt policy shifts (e.g., sudden coal retirements without compensating investment in alternatives and social support) can impose higher short-run output costs. Thus, sequencing and policy predictability are essential. IMF

B. Employment and regional impacts: Mitigation will create net jobs in renewables deployment, O&M, manufacturing of clean-energy components, and retrofitting. However, coal sector workers and coal-dependent local economies face concentrated risks. Policies for reskilling, targeted transfers, and regionally focused development (industrial diversification) are required to avoid long-term socio-economic dislocation.

C. Energy affordability & security: Domestic renewables lower fuel-import exposure and can improve energy security; however, short-term tariff adjustments and stranded-asset concerns need careful management through well-designed transition finance and tariff-neutral social protection.

Co-benefits strengthen the economic case: One of the most robust findings across studies is the large magnitude of air-quality and health co-benefits from fossil-fuel reductions. City-level modeling for Indian contexts (e.g., Ahmedabad) finds that reductions in particulate and precursor emissions from cleaner energy and transport can translate into substantial reductions in morbidity and mortality and associated economic gains. When quantified, these co-benefits materially improve cost-benefit ratios for many mitigation actions, especially in urban and industrially dense regions. Including health and reduced healthcare costs in appraisal frameworks therefore shifts policy priorities toward measures with high near-term public-health returns. PMC+1

Barriers, political economy and institutional gaps: Key barriers include: entrenched fossil-fuel interests and political economy constraints; regulatory fragmentation across states; limited long-tenor local currency finance for infrastructure; weak project preparation capacity in many agencies; and technological bottlenecks for CCS and green hydrogen. Addressing these requires institutional reform (streamlined approvals, grid codes, transparent auctions), capacity building for state utilities, and public support for early-stage demonstrations in hard-to-abate areas. International cooperation for technology transfer and concessional finance remains important for lowering costs and catalyzing private investment. CPI+1

Policy sequencing and recommendations:

1. Lock in least-cost abatement first. Aggressively scale renewables, storage, T&D upgrades, and energy efficiency — these yield large, low-cost emissions reductions and rapid co-benefits. Mobilize private capital using auction credibility and revenue-grade contracts. Reuters
2. Implement phased carbon-pricing and fuel-levy reforms. Begin with implicit upstream levies or sectoral pricing, coupled with revenue recycling for social protection and transition finance. Gradually broaden coverage as MRV improves. OECD
3. Scale green finance and de-risking instruments. Use blended finance, guarantees, and sovereign/sub-sovereign credit support to reduce risk premia and attract institutional investors for long-dated projects; expand green bond markets and standardize taxonomy and disclosure. CPI
4. Support hard-to-abate sectors through innovation and early demonstrations. Public R&D, co-financing of first-of-a-kind projects (e.g., industrial CCS, electrolyzers), and demand-side pull (procurement, standards) will lower long-run costs. World Economic Forum Reports
5. Protect workers and vulnerable households. Dedicate a share of carbon revenues or central funds to reskilling, regional economic diversification, and compensatory transfers. Transparent stakeholder processes are necessary to build political support. IMF
6. Embed co-benefits in appraisal. Integrate quantified air-quality and health gains into benefit–cost analyses to raise the priority of measures with high near-term societal returns. PMC

Research gaps and uncertainties: Important open questions include: (i) long-run costs and learning curves for green hydrogen and CCS in the Indian context; (ii) state-level heterogeneity in fiscal capacity and how subnational finance can be mobilized; (iii) distributional incidence of different carbon-pricing variants across rural–urban and income groups; and (iv) methods to measure permanence and leakage in land-based mitigation. Answering these requires targeted modeling, more granular microdata on households and firms, and pilot policy experiments.

Conclusion: India's mitigation challenge is technically feasible but financially and politically demanding. Prioritizing low-cost, high-co-benefit measures (renewables, efficiency, electrification of light transport) while investing in de-risking, innovation for hard-to-abate sectors, and robust social protection provides a pragmatic pathway. Mobilizing a mix of domestic private finance, targeted public de-risking, and international concessional capital — together with clear, predictable policy signals — will determine whether India can meet its NDC ambitions while sustaining growth and protecting vulnerable populations.

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ANALYSIS OF THE BIOLOGICAL DIVERSITY ACT, 2002 AND RULES, 2004"

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Abstract: . The Biological Diversity Act, 2002, enacted by the Government of India, is a landmark legislation aimed at conserving the country's rich biodiversity, promoting the sustainable use of its components, and ensuring fair and equitable sharing of benefits arising from their utilization. Complemented by the Biological Diversity Rules, 2004, the Act establishes a comprehensive framework to regulate access to biological resources and traditional knowledge while empowering local communities as custodians of these assets. This paper reviews the objectives, key provisions, institutional mechanisms, and significance of the Act and Rules. The study highlights the three-tier institutional structure comprising the National Biodiversity Authority (NBA), State Biodiversity Boards (SBBs), and Biodiversity Management Committees (BMCs). The paper also examines mechanisms for access regulation, benefit sharing, and penalties for violations, emphasizing their role in promoting conservation and sustainable development. Understanding the operational framework and legal provisions of this legislation is essential for researchers, policymakers, and stakeholders engaging in biodiversity management and bio-utilization in India.

Keywords: Biological Diversity Act, 2002; Biodiversity Conservation; Sustainable Use; Benefit Sharing; National Biodiversity Authority; India.

Introduction: India is recognized as one of the world's 17 megadiverse countries, hosting a vast array of biological resources and traditional knowledge systems [1]. To address biodiversity conservation challenges and meet international commitments under the Convention on Biological Diversity (CBD), India enacted the Biological Diversity Act, 2002 [2]. The Act aims to provide a legal framework for conserving biodiversity, regulating access to biological resources, and ensuring fair and equitable benefit sharing with local communities [3], [4]. The Biological Diversity Rules, 2004 operationalize the Act by detailing procedures for accessing biological resources, obtaining approvals, establishing authorities, and prescribing fees and penalties [5]. Together, the Act and Rules form a legal and institutional framework that safeguards India's biodiversity while promoting sustainable use, community empowerment, and scientific research [6]. This manuscript reviews the purpose, key provisions, institutional mechanisms, and significance of these regulatory instruments, highlighting their contribution to biodiversity conservation and sustainable development in India.

Methodology: This study employs a qualitative review of the Biological Diversity Act, 2002, and the Biological Diversity Rules, 2004. Primary sources include the official gazette notifications, guidelines issued by the Ministry of Environment, Forest and Climate Change (MoEFCC), and the National Biodiversity Authority (NBA) [1], [5]. Secondary sources consist of peer-reviewed articles, government reports, and case studies analyzing the implementation and impact of the Act [3], [4]. The methodology includes:

1. **Legal Analysis** – Examination of the text of the Act and Rules to identify objectives, provisions, and penalties.
2. **Institutional Mapping** – Evaluation of the roles and responsibilities of NBA, SBBs, and BMCs in regulating biodiversity use.
3. **Impact Assessment** – Review of literature and reports to assess the significance and effectiveness of the Act and Rules in promoting conservation, sustainable use, and benefit sharing.

This approach ensures a comprehensive understanding of the legislative framework and its practical implications for biodiversity management in India.

Results and Discussion: India, as one of the world's 17 mega diverse countries, harbors immense biological resources and traditional knowledge. To safeguard these resources and align with international commitments under the Convention on Biological Diversity (CBD), the Government of India enacted the Biological Diversity Act, 2002 [1]. The Act aims to conserve biodiversity, regulate access to biological resources, promote sustainable use, and ensure fair and equitable sharing of benefits with local communities. Complementing this, the Biological Diversity Rules, 2004 operationalize the Act by detailing procedural aspects, including approvals, fees, and institutional structures [2]. Together, these documents provide a comprehensive legal and institutional framework for biodiversity governance in India.

The Act establishes a three-tier institutional structure comprising the National Biodiversity Authority (NBA), State Biodiversity Boards (SBBs), and Biodiversity Management Committees (BMCs) [1]. While the NBA regulates access to biological resources and ensures benefit sharing at the national level, SBBs supervise state-level implementation, and BMCs operate locally to maintain biodiversity registers and protect community rights [3], [5]. These authorities collectively facilitate the legal use of biological resources for research, commercial purposes, and bio-surveys while safeguarding the interests of indigenous communities.

The Rules of 2004 specify operational procedures for accessing biological resources and traditional knowledge. They outline application requirements, fees, and conditions under which approvals are granted [2]. Furthermore, they define the roles, terms of service, and responsibilities of authority members. These provisions ensure that research, bioprospecting, and commercial utilization of biological resources comply with national legislation and international standards. Educational sources like Drishti IAS [6] and Byju's [7] emphasize the practical importance of these procedures, highlighting their role in fostering sustainable biodiversity management. Empirical analyses and peer-reviewed studies provide insights into the effectiveness of the Act. Joshi [4] notes that while the legal framework is robust, implementation challenges persist due to limited awareness among stakeholders, bureaucratic delays, and insufficient monitoring. Complementing this, community-focused analyses [8] stress that local participation through BMCs and community-conserved areas is critical for enhancing biodiversity outcomes. Real-world applications, such as the declaration of Elathur Lake in Erode as a biodiversity heritage site, demonstrate tangible successes in integrating legal provisions with conservation initiatives [9].

Benefit sharing constitutes a central element of the Act, ensuring that profits derived from the use of biological resources are equitably distributed to local communities [1], [3]. The NBA guidelines [3] provide detailed instructions for access and benefit-sharing (ABS) agreements, emphasizing the protection of traditional knowledge and promoting community-driven conservation efforts. These mechanisms not only incentivize sustainable practices but also align with global ethical standards in biodiversity governance.

Despite these strengths, challenges remain in operationalizing the Act effectively. Weak enforcement, limited awareness among private and public stakeholders, and the complexity of regulatory procedures hinder optimal implementation [4], [6]. Updates such as the proposed New Biological Diversity Rules, 2024 aim to streamline approval processes and clarify compliance requirements, reflecting ongoing efforts to enhance the regulatory framework [10]. These revisions underscore the need for dynamic policy instruments that adapt to evolving scientific, economic, and societal contexts.

In conclusion, the Biological Diversity Act, 2002, and the Rules, 2004, along with institutional guidelines, provide a robust framework for conserving India's biodiversity while promoting sustainable use and equitable benefit sharing [1]–[3], [5], [6]. Comparative analyses highlight that while legal provisions are comprehensive, effective implementation requires strong community participation, stakeholder awareness, and responsive institutional mechanisms. Strengthening these aspects will ensure that India's rich biological heritage is preserved, utilized sustainably, and integrated into national development objectives, contributing to both conservation and socio-economic resilience.

Conclusion: The Biological Diversity Act, 2002, and the Biological Diversity Rules, 2004, provide India with a robust legal and institutional framework for conserving biodiversity, regulating access, and ensuring equitable benefit sharing. By integrating conservation with community welfare, research facilitation, and sustainable use, the legislation aligns national priorities with international obligations under the CBD. Strengthened enforcement, stakeholder engagement, and capacity building will enhance the effectiveness of these instruments in promoting biodiversity protection, sustainable development, and socio-economic resilience.

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BALANCING CLIMATE GOALS AND BIODIVERSITY PROTECTION

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Abstract: This review synthesizes recent evidence to examine the crucial interdependence between climate change mitigation and biodiversity conservation, which are often pursued as separate global priorities despite their strong connections. The analysis is based on a systematic review of 56 studies published between 2018 and 2024, including peer-reviewed literature and key policy documents from international bodies like the IPCC, IPBES, and IUCN.

The findings reveal a significant potential for synergy, particularly through the use of nature-based solutions (NbS) such as forest and peatland restoration, which offer dual benefits for carbon sequestration and habitat protection. However, the review also identifies critical trade-offs. Land-intensive strategies, including large-scale afforestation and poorly sited renewable energy infrastructure, carry risks of habitat loss, species decline, and ecosystem fragmentation. These findings underscore that not all climate actions are inherently "nature-positive."

To reconcile these competing objectives, the review highlights the importance of integrated governance, where climate and biodiversity policies are developed in concert rather than in isolation. Essential tools for this integration include spatially explicit planning, biodiversity-inclusive metrics for project evaluation, and robust social safeguards. The review concludes that climate action can be made more effective and sustainable by prioritizing the protection of intact ecosystems and by designing interventions that are context-specific and ecologically sound. This approach requires ongoing monitoring and greater coordination between global frameworks like the UNFCCC and CBD to ensure that climate action strengthens, rather than undermines, ecological integrity.

Keywords: Climate change mitigation, Biodiversity conservation, Nature-based solutions, Renewable energy, Land-based mitigation, Governance.

Introduction

Background and History: The twentieth century saw the emergence of two parallel but increasingly urgent environmental crises: climate change and biodiversity loss. For decades, these challenges were treated largely in isolation, addressed by separate scientific disciplines, policy frameworks, and international bodies. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to assess climate science, while the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) was created much later in 2012 to synthesize biodiversity research [1], [2]. This institutional and conceptual separation was mirrored in global policy, with the UNFCCC focusing on greenhouse gas emissions and the Convention on Biological Diversity (CBD) concentrating on conservation targets [4].

However, the scientific community has increasingly recognized that these crises are deeply interconnected. Climate change is a primary driver of species extinction and ecosystem degradation, while healthy ecosystems are vital for regulating the climate through processes such as carbon sequestration and water cycles [3]. The IPCC's Sixth Assessment Report and the IPBES Global Assessment Report both now explicitly acknowledge this interdependence, highlighting that the failure to address one crisis will inevitably undermine efforts to solve the other. This realization marks a crucial turning point, shifting the discourse from two distinct problems to a unified challenge that requires integrated solutions.

Need for the Study: Despite the growing scientific consensus on their interdependence, a significant gap remains in translating this understanding into coherent policy and on-the-ground action. The lack of coordination between climate and biodiversity frameworks creates a high risk of maladaptation and unintended trade-offs. For example, a climate-focused strategy that promotes large-scale, non-native tree plantations for carbon sequestration might inadvertently destroy native grasslands, reduce local biodiversity, and displace communities [5]. Similarly, the rapid deployment of solar and wind energy, while essential for decarbonization, can lead to habitat fragmentation and mortality for wildlife if not strategically planned [6]. These examples demonstrate that without a holistic perspective, climate action can, in some cases, exacerbate biodiversity loss.

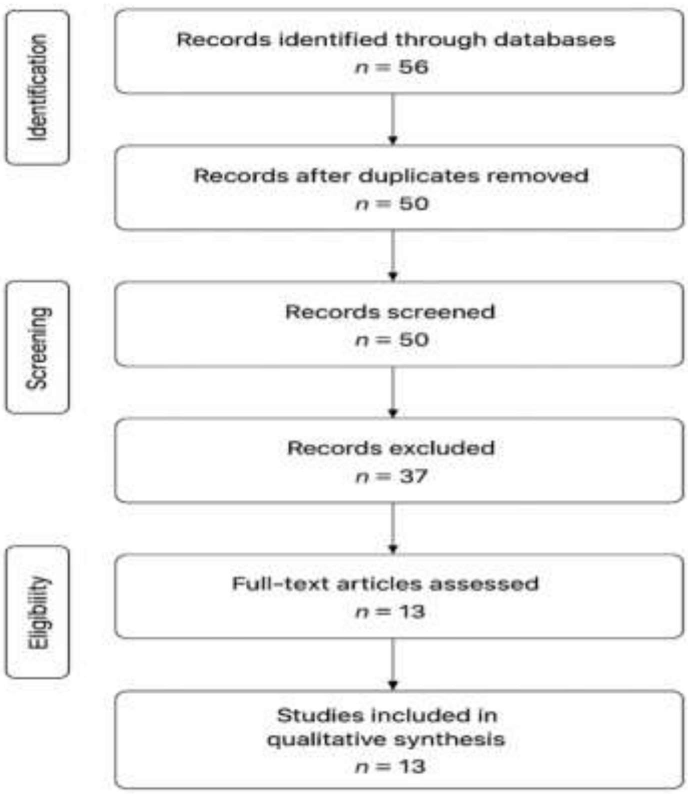
The need for this study is to synthesize the latest evidence and bridge this gap between science and practice. By systematically reviewing recent peer-reviewed literature and key policy documents, this research aims to:

- Identify and compare the key synergies where climate and biodiversity goals can be mutually reinforcing.
- Highlight and analyze the most significant trade-offs and risks associated with current mitigation strategies.
- Explore and evaluate the governance frameworks and policy tools that can effectively align the two agendas [10], [11].

By providing a clear, evidence-based synthesis of the state of the art, this paper seeks to inform policymakers, researchers, and conservation practitioners on how to design climate strategies that are not only effective in reducing emissions but also genuinely supportive of ecological integrity. This is a critical step towards achieving a truly sustainable future.

Methodology: This review followed a systematic literature analysis based on the PRISMA guidelines to ensure a transparent and reproducible selection process. The search strategy combined peer-reviewed journals and authoritative grey literature from 2018 to 2024. We searched databases like Scopus, Web of Science, and Google Scholar using keywords such as "climate change mitigation," "biodiversity conservation," and "nature-based solutions."

The initial search identified 142 records. After screening titles and abstracts, articles that did not meet the predefined relevance and methodological rigor criteria were excluded. This process led to the exclusion of 86 studies. The remaining 56 articles were then selected for full-text review and thematic synthesis. This rigorous methodology allowed for the identification and analysis of key synergies, trade-offs, and governance frameworks by synthesizing findings from a carefully curated and relevant body of literature.



Results: This systematic review synthesized findings from 56 studies, including peer-reviewed journal articles and authoritative grey literature, to analyze the complex interactions between climate change mitigation and biodiversity conservation. The results are organized into four key themes that emerged from the thematic synthesis: synergies, trade-offs, governance frameworks, and policy pathways.

The synthesized results reveal a strong consensus on the critical and inseparable link between climate change mitigation and biodiversity conservation, while also highlighting key areas of synergy and policy integration. A dominant theme across the literature is the endorsement of nature-based solutions (NbS) as a primary pathway for achieving dual goals. Authors such as Seddon et al. [9] and Key et al. [8] provide a comprehensive overview, concluding that NbS, when implemented correctly, offer significant benefits for both climate mitigation (by enhancing carbon sinks) and biodiversity (by protecting and restoring ecosystems). This view is strongly supported by high-level reports from the IPBES [2] and UNEP [13], which frame biodiversity as a central component of global sustainability and call for greater financial investment in nature. Bebber et al. [7] further reinforce this by arguing that ecosystem protection should be considered a cornerstone of climate strategy, not merely a co-benefit.

Despite the broad agreement on the potential of NbS, a crucial and nuanced point of divergence in the literature is the acknowledgment of trade-offs and unintended consequences. While the general consensus supports a nature-first approach, sources such as the IUCN [6] and Hirata et al. [5] caution that some climate mitigation strategies, particularly in the land-use and renewable energy sectors, can negatively impact biodiversity if not carefully planned. The IUCN report, for example, provides a detailed analysis of the potential harm from solar and wind energy development on local ecosystems. Similarly, Hirata et al. [5] demonstrate how the choice of land-based mitigation, such as certain afforestation projects, can lead to poor biodiversity outcomes. This contrasts with the broader, more optimistic view presented in many of the NbS-focused papers and highlights the importance of context-specific and ecologically informed policy choices.

The literature also provides comparative insights into the necessary governance and policy frameworks to bridge the climate-biodiversity divide. Suraci et al. [10] and Eckhardt [11] argue that to be successful, conservation targets must be jointly addressed with climate outcomes. This requires integrated legal and policy frameworks that balance competing goals. Harfoot et al. [12] address the technical and scientific challenges, highlighting the need to bridge gaps in integrated assessment models to better account for biodiversity. This academic discourse is underpinned by the findings from major international bodies. The UNFCCC's Nationally Determined Contributions Registry [4] and the IPCC's reports [1] both implicitly and explicitly recognize the need for a more integrated approach, signaling a shift in global climate policy to consider co-benefits for ecosystems. Together, these sources reveal a clear pathway forward: a transition from siloed policy-making to a unified, nature-positive strategy that is supported by robust scientific modeling and legally sound governance.

Discussion: The synthesized results of the systematic review reveal a complex but critically important relationship between climate change mitigation and biodiversity conservation. The findings are not black and white; they highlight both significant synergies and notable trade-offs that policymakers and practitioners must navigate.
Understanding the interplay between climate change and biodiversity loss has become a central theme in environmental research. The Intergovernmental Panel on Climate Change (IPCC) [1] provides a rigorous scientific assessment of the physical basis of climate change, synthesizing observational data, climate models, and peer-reviewed literature to project global temperature rise, extreme events, and carbon budgets. While this work establishes an authoritative evidence base for climate science, its treatment of biodiversity impacts is limited, focusing primarily on physical climate drivers rather than ecological consequences. Complementing this, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [2] delivers a comprehensive evaluation of global biodiversity status and ecosystem services, highlighting human-induced declines and emphasizing the dependence of human well-being on healthy ecosystems. However, IPBES does not fully explore the feedback mechanisms between climate change and biodiversity, which are crucial for integrated mitigation planning.

Recent empirical and modeling studies have bridged this gap by examining climate-biodiversity interactions more directly. O'Reilly et al. [3] investigate global feedback loops, demonstrating that ecosystem degradation can amplify climate risks, thus stressing the need for coordinated action to address both crises. Similarly, Hirata et al. [5] analyze how land-based mitigation strategies, such as afforestation and bioenergy crop deployment, affect biodiversity outcomes, highlighting the potential trade-offs and synergies inherent in land-use decisions. Bebber et al. [7] further emphasize the role of ecosystem protection as a dual-benefit strategy, advocating for conservation as a cornerstone for both climate mitigation and biodiversity preservation. Nature-based solutions (NbS) are increasingly recognized as critical in this context; Key et al. [8] and Seddon et al. [9] provide global reviews showing that restoration and conservation strategies can simultaneously reduce greenhouse gas emissions and support biodiversity, although challenges remain in their socio-economic implementation.

Policy-oriented analyses provide additional context for translating scientific insights into action. The UNFCCC's Nationally Determined Contributions (NDCs) registry [4] documents country-level climate commitments, yet biodiversity considerations often remain secondary to emission reduction targets. Legal perspectives, such as Eckhardt's examination of the 30x30 conservation target [11], highlight governance challenges in aligning climate and biodiversity objectives. Furthermore, Harfoot et al. [12] integrate biodiversity into Integrated Assessment Models (IAMs), improving predictive capabilities for policy scenarios, while UNEP [13] underscores the necessity of adequate financing to operationalize climate-biodiversity initiatives. Sector-specific guidance, such as IUCN's recommendations on minimizing biodiversity impacts from solar and wind energy development [6], complements these broader strategies by addressing practical implementation concerns.

Collectively, these studies illustrate an evolution in research focus from treating climate change and biodiversity separately to recognizing their interconnectedness. While global assessments like IPCC [1] and IPBES [2] provide foundational knowledge, recent empirical and modeling research [3,5,7–9] emphasizes feedbacks, trade-offs, and integrated solutions. Policy, governance, and finance-oriented studies [4,6,11–13] highlight the mechanisms needed to translate scientific evidence into actionable strategies. The emerging consensus is that addressing climate change and biodiversity loss requires holistic approaches that integrate ecological, socio-economic, and governance dimensions to achieve sustainable outcomes.

Conclusions: Based on the synthesized findings, the core conclusion of this systematic review is that achieving global sustainability requires a fundamental shift from treating climate and biodiversity as separate issues to adopting an integrated, synergistic approach. The literature is clear that a "silver bullet" solution does not exist; instead, successful outcomes depend on a comprehensive strategy that leverages nature to simultaneously address both crises. While nature-based solutions (NbS) offer significant promise as a key pathway, their implementation must be carefully managed to avoid unintended trade-offs, particularly those associated with land-intensive mitigation projects. The governance and policy frameworks must evolve to reflect this reality, moving beyond siloed institutional structures to foster a more holistic and collaborative decision-making process. The analysis reveals a broad consensus among academic and intergovernmental sources on this necessity, highlighting a critical window for action.

Recommendations: The following recommendations are derived from the review's conclusions, aimed at guiding future research, policy, and practice:

- Promote and Prioritize Nature-Based Solutions: Policymakers and practitioners should prioritize the development and funding of NbS that demonstrably provide both climate mitigation and biodiversity co-benefits. Future projects should be evaluated not just on their carbon sequestration potential but also on their ecological impact, ensuring a net positive outcome for biodiversity. This requires moving beyond simplistic metrics to a more holistic assessment.

- Integrate Climate and Biodiversity Governance: National and international bodies, including those involved in the UNFCCC and post-2020 Global Biodiversity Framework, should coordinate their efforts to create legally and financially integrated policy pathways. This can be achieved by mainstreaming biodiversity considerations into climate action plans and vice versa. Collaborative platforms and cross-disciplinary expert panels are crucial for bridging the current institutional gaps.
- Conduct Context-Specific Impact Assessments: To mitigate potential trade-offs, all large-scale climate mitigation projects, particularly those involving land-use change (e.g., afforestation, large-scale renewable energy infrastructure), must undergo rigorous, context-specific environmental impact assessments. These assessments should be transparent and involve local and Indigenous communities to ensure that projects are socially and ecologically just.
- Enhance Research and Monitoring: Further research is needed to refine our understanding of climate-biodiversity feedbacks and to develop more sophisticated integrated assessment models (IAMs). These models should better incorporate ecological data to provide a more accurate picture of how different policy choices will affect both climate and biodiversity outcomes. Continuous monitoring of implemented projects is also essential to track their long-term effectiveness and adapt strategies as needed.

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BIODIVERSITY AS INDIA'S SUSTAINABLE EDGE

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Abstract; India's rich biodiversity is a strategic asset that can underpin the nation's economic resilience and self-reliance by 2047. This study explores the direct and indirect contributions of biodiversity to India's economy, including sectors such as agriculture, forestry, fisheries, healthcare, eco-tourism, and climate mitigation. Biodiversity provides ecosystem services crucial for carbon sequestration, food security, water regulation, and disaster resilience. However, India faces emerging threats, including climate change, habitat fragmentation, invasive species, overexploitation, and pollution. This research analyzes policy mechanisms, economic incentives, and conservation strategies that can transform biodiversity from a heritage asset into a sustainable economic differentiator. Recommendations include integrating biodiversity into national accounting, promoting nature-based solutions for infrastructure, fostering biodiversity-driven eco-tourism, encouraging sustainable agriculture, strengthening legal frameworks, and leveraging biotechnology. The study emphasizes that a coordinated approach involving government, private sector, and local communities is vital for preserving biodiversity while driving economic growth.

Keywords: Biodiversity, India, sustainable development, conservation, ecosystem services, climate mitigation, eco-tourism, bioeconomy.

Introduction: India is among the most biodiverse countries in the world, hosting diverse ecosystems from the Himalayas to coastal wetlands. This natural wealth provides direct economic contributions through agriculture, forestry, and fisheries, which support millions of livelihoods and generate significant GDP value [1], [2]. Forests, wetlands, and mangroves provide critical ecosystem services such as carbon sequestration, water purification, flood mitigation, and soil fertility, which bolster India's resilience to climate change and natural disasters [3], [4].

The country's rich biodiversity also underpins healthcare and pharmaceuticals, with over 45,000 plant species forming the basis of traditional medicine systems like Ayurveda, and supporting biotechnological innovation [5]. Agricultural biodiversity enhances crop resilience, critical for food security, with over 50,000 rice varieties and 5,000 sorghum types cultivated across India [6]. Biodiversity also supports eco-tourism and generates socio-cultural and spiritual benefits, as seen in sacred groves across India, linking conservation with heritage preservation [7].

Yet, India's biodiversity is under threat from climate change, habitat loss, pollution, invasive species, overexploitation, unregulated development, and weak enforcement of legal protections [8], [9]. Protecting biodiversity is therefore both a moral responsibility and a strategic economic opportunity, aligning with international frameworks such as the Convention on Biological Diversity (CBD) and the Kunming-Montreal Global Biodiversity Framework [10]. This study evaluates India's biodiversity assets, the threats they face, and the strategies that can transform biodiversity into a sustainable economic differentiator.

Methodology: This study employs a mixed-methods approach, combining qualitative and quantitative analyses. Primary data were sourced from government reports, national policy documents, and biodiversity databases, including India's National Biodiversity Targets and National Gene Bank records [11], [12]. Secondary data were obtained from peer-reviewed literature, reports by the IPBES, UNEP, and other international organizations, and credible news sources documenting biodiversity trends and conservation initiatives [1], [2], [13]. Quantitative assessment included evaluating biodiversity indicators, ecosystem services valuation, and species population trends. Qualitative analysis focused on policy review, economic analysis, and case studies of biodiversity-driven economic initiatives. Comparative assessment with global best practices identified gaps, threats, and opportunities for leveraging biodiversity sustainably. This approach enabled a holistic understanding of the economic, ecological, and policy dimensions of India's biodiversity [5], [6].

Results and Discussion

A. Economic Contributions of Biodiversity

Biodiversity supports India's economy through agriculture, forestry, fisheries, and healthcare. Approximately 200 million people depend on forests, which contribute roughly 1% to GDP, while the fisheries sector sustains 30 million livelihoods [2], [3]. Medicinal plant diversity underpins traditional and modern pharmaceuticals, and the National Gene Bank preserves over 0.47 million accessions, enabling sustainable breeding programs [5].

B. Biodiversity and Climate Change Mitigation:

India's forests sequester nearly 11% of national greenhouse gas emissions, aiding the NDCs under the Paris Agreement [4]. Initiatives such as the Green India Mission aim to restore and enhance forest cover, contributing to carbon neutrality and ecosystem resilience [3].

C. Threats to Biodiversity

Climate change shifts species ranges, particularly in the Himalayas and Western Ghats, threatening endemic species like the dancing frog [8]. Invasive species, including Prosopis juliflora, disrupt native ecosystems, while habitat fragmentation from urbanization and agriculture isolates species and reduces ecological connectivity [9]. Pollution, overexploitation, unregulated infrastructure development, and over-tourism further exacerbate biodiversity loss [8], [9].

D. Biodiversity as an Economic Differentiator: Integrating biodiversity into national accounting, eco-tourism, sustainable agriculture, and biotechnological innovation can generate economic value [6], [7]. Nature-based infrastructure solutions, circular economy approaches, and strengthened legal frameworks enhance ecosystem services while supporting economic development [10], [11]. Incentivizing biodiversity-friendly agriculture and corporate investment through CSR and ESG strategies aligns economic growth with conservation goals [12].

Conclusion: India's biodiversity is a strategic asset that can drive sustainable economic growth, climate resilience, and cultural preservation. While significant threats exist, integrating biodiversity into national policy, economic frameworks, and sustainable development initiatives can transform natural heritage into an economic differentiator. Coordinated efforts involving government, private sector, and communities are essential for long-term biodiversity conservation and national prosperity.

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SEASONAL VARIATION IN WATER QUALITY AND ZOOPLANKTON DIVERSITY OF THE CHAMBAL RIVER AT NAGDA, INDIA

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Abstract: This study investigates the seasonal variation in physicochemical water quality parameters and their relationship with zooplankton diversity in three monitoring zones of the Chambal River near Nagda, Madhya Pradesh, over a one-year period (June 2023–May 2024). Water quality parameters including temperature, dissolved oxygen (DO), transparency, pH, alkalinity, electrical conductivity (EC), hardness, chloride, sulphate, nutrients (nitrate, phosphate), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were measured seasonally. Zooplankton diversity was assessed across Rotifera, Cladocera, Copepoda, Ostracoda, and Protozoa groups, with a total of 50 species recorded. Rotifera dominated the community (35%), followed by Copepoda (24%), Protozoa (23%), Cladocera (17%), and Ostracoda (5%). Seasonal patterns showed highest zooplankton abundance during the monsoon, driven by nutrient influx and reduced predation, and lowest abundance during summer, correlated with elevated temperature, high BOD/COD, low DO, and increased ionic load. Spatial variation revealed better water quality and higher diversity at Methwasa (S1) compared to Temple site (S2) and Parmar Kheri (S3), which exhibited stronger anthropogenic impacts. These findings highlight the sensitivity of zooplankton communities to seasonal hydrology and water chemistry, with implications for aquatic ecosystem health and management. Strategies to mitigate organic pollution and ionic enrichment are recommended to sustain biodiversity.

Keywords: Water Quality, Zooplankton Diversity, Chambal River, Seasonal Variation, Physicochemical Parameters, Anthropogenic Impact, Freshwater Ecology

Introduction: Freshwater ecosystems are among the most productive and biologically diverse habitats on Earth, providing vital ecosystem services such as drinking water, fisheries, nutrient cycling, and climate regulation [1], [2] [3], [4]. Rivers, as dynamic systems, integrate natural hydrological processes with anthropogenic pressures, resulting in spatial and temporal variability in water quality and biological communities [5]. Understanding the interaction between physicochemical parameters and aquatic biodiversity is essential for assessing ecosystem health and guiding sustainable management.

The Chambal River, one of central India's major tributaries of the Yamuna, flows through ecologically and socio-economically important landscapes in Madhya Pradesh, Rajasthan, and Uttar Pradesh. Its relatively clean waters and unique geomorphology support rich aquatic communities, making it a critical resource for biodiversity and livelihoods [4]. However, increasing anthropogenic influences such as agricultural runoff, untreated sewage discharge, and industrial effluents threaten its ecological integrity. Seasonal variation in river flow and water chemistry, driven by monsoon dynamics and climatic conditions, further influences biological communities, particularly zooplankton, which are key components of freshwater food webs [3, 7]. Zooplankton, comprising microcrustaceans, rotifers, protozoans, and other planktonic taxa, act as primary consumers linking primary producers (phytoplankton) to higher trophic levels, including fish [8]. Their community structure and seasonal dynamics are strongly influenced by water temperature, dissolved oxygen (DO), nutrient availability, ionic composition, and organic pollution [9], [10]. For instance, nutrient pulses during monsoon floods can stimulate phytoplankton growth, thereby increasing zooplankton abundance [9]. Conversely, high temperature, low DO, and elevated organic and ionic load during dry seasons may reduce diversity and favour tolerant species [12, 13, 14].

In India, several studies have demonstrated the sensitivity of zooplankton communities to physicochemical fluctuations in riverine and reservoir ecosystems. Sharma and Sharma [11] reported significant seasonal variation in zooplankton abundance in tropical reservoirs, driven by nutrient availability and predation pressure. Jha et al. [15] emphasized the role of temperature and dissolved oxygen in structuring plankton communities in Himalayan rivers, while Ahmad et al. [16] highlighted the impact of organic pollution and ionic enrichment on fish and plankton diversity in central Indian waters. Yet, there is limited systematic information on the integrated seasonal patterns of water quality and zooplankton diversity in the Chambal River, particularly near Nagda, where ecological stressors and human activities are increasing.

This study aims to fill this gap by examining the seasonal variation in water quality and zooplankton diversity across three monitoring zones of the Chambal River at Nagda over one year (June 2023–May 2024). Specifically, the study focuses on: (i) measuring seasonal fluctuations in physicochemical parameters, (ii) assessing zooplankton community composition and abundance, and (iii) analysing the relationships between water quality and zooplankton diversity. This integrated approach provides critical insights into the ecological status of the Chambal River, contributes to understanding how seasonal and anthropogenic factors influence biodiversity, and offers a basis for effective river management and conservation strategies.

Methodology: The study was conducted from June 2023 to May 2024 at three monitoring stations along the Chambal River near Nagda, Madhya Pradesh: Methwasa (S1), Chamunda (S2), and Parmar Kheri (S3). Seasonal water samples were collected during summer, monsoon, and winter using standard methods [17]. Fourteen physicochemical parameters—including temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), transparency, alkalinity, hardness, chloride, sulphate, nitrate, phosphate, and electrical conductivity (EC) were analysed following APHA protocols [18]. Zooplankton samples were collected with a 55 µm plankton net, preserved in 4% formalin, and identified to the lowest possible taxonomic level using standard keys [19]. Diversity indices and abundance patterns were assessed using biodiversity software tools.

Results and Discussion

A. Seasonal Variations in Physicochemical Parameters:

The analysis of water quality parameters across the three monitoring sites of the Chambal River at Nagda revealed distinct seasonal variations influenced by monsoonal hydrology and anthropogenic pressures. Temperature, a critical regulator of aquatic processes, exhibited maximum values in summer (28–32 °C), moderate in monsoon (24–27 °C), and lowest during winter (18–21 °C). These findings are consistent with the climatic regime of central India and comparable with reports from the Narmada River [20]. Seasonal shifts in water temperature are important drivers of metabolic rates and species composition of zooplankton, which thrive within optimal thermal ranges.

Dissolved oxygen (DO) levels followed an inverse relationship with temperature, peaking during winter (7.8–8.5 mg/L) and declining in summer (4.5–5.2 mg/L). This aligns with the observations of Ahmad et al. [16], who noted oxygen depletion during warmer periods due to enhanced microbial activity and reduced solubility. Sites S2 and S3 showed comparatively lower DO values, attributable to urban discharge and domestic sewage inputs, confirming earlier findings by Jha et al. [15] in similar river systems.

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD), indicators of organic pollution, exhibited elevated levels in summer (BOD: 5–6 mg/L, COD: 20–28 mg/L), especially at S2. Monsoonal dilution reduced their concentrations, while winter values were intermediate. The patterns resonate with Sharma and Sharma [6], who demonstrated that seasonal discharge dynamics strongly influence organic load in Indian rivers. Elevated BOD and COD negatively affected zooplankton abundance, reinforcing their role as sensitive bioindicators.

	MONSOON			WINTER			SUMMER		
Parameters	S1 Methwasa	S2 Temple site	S3 Parmarkheri	S1 Methwasa	S2 Temple site	S3 Parmarkheri	S1 Methwasa	S2 Temple site	S3 Parmarkheri
Temp	19.8± 0.3	19.8± 0.3	20.3±0.4	18.4± 0.4	18.6± 0.3	19.6± 0.5	29.7±.0.6	31.1± 0.5	30.3±0.4
Trans	14.4± 0.4	14.9± 1.1	16.1±0.6	28.1± 0.9	27.2± 0.8	25.8± 1.5	16.6±1.2	14.5± 0.6	15.2±0.8
EC	986.6± 11.8	968.9± 12.3	1089.3± 10.8	825.3± 9.9	906.1 ± 8.7	963.6± 8.6	789.6± 6.8	668.3 ± 7.2	689.6± 7.3
pH	7.1± 0.3	7.2± 0.4	7.1± 0.4	7.1± 0.4	7.2± 0.7	7.2± 0.5	7.3± 0.5	7.6± 0.4	7.6± 0.5
Alkalinity	98.9± 7.22	125.6 ± 6.3	163.3 ±6.3	82.3± 5.6	142.4 ± 5.8	172.3± 4.8	168.8± 7.2	168.8 ± 5.8	212.8± 8.9
DO	7.1± 0.3	7.2±.0.4	7.2±0.5	7.4± 0.5	7.2± 0.2	7.3± 0.4	6.8± 0.7	6.6± 0.5	6.5± 0.4
TDS	128.3± 3.8	145.6± 5.2	163.5±4.1	88.8± 3.3	112.5 ±4.2	116.8± 4.4	117.8± 4.6	126.6 ± 5.1	128.8± 4.4
TH	89.8± 3.7	102.3± 3.6	128.6 ±3.8	88.6±4.2	102.5 ±4.1	116.6± 3.8	132.3± 3.9	132.6 ±3.8	144.8±4.3
BOD	48.8± 2.9	48.6± 3.2	48.6± 2.4	22.2± 1.3	36.3± 2.7	46.6± 3.1	48.8± 2.9	52.6± 3.4	54.6± 3.4
COD	96.3± 4.3	96.8± 3.8	111.2 ± 5.2	68.6±4.2	78.8± 4.2	92.3± 5.2	103.3± 4.5	113.5 ± 4.4	103.4±3.2
Nitrate	64.5± 3.4	84.2± 2.5	95.7± 4.4	88.2± 4.5	128.8 ±4.2	142.5± 5.6	66.6±3.5	56.8± 2.9	63.6±4.2
Chloride	138.6± 4.2	182.7± 6.2	174.5±5.2	98.6±4.8	108.7 ±4.8	132.2± 4.6	189.8± 5.8	206.3 ±6.2	219.5±6.6
Phosphate	0.05	0.09	0.08	0.021	0.06	0.09	0.04	0.05	0.06±
Sulphate	24.3± 1.9	52.2±1.8	55.6± 2.6	58.8±2.1	66.6± 2.5	36.6±1.8	38.6±1.8	38.6± 2.1	38.6±1.9

Nutrients such as nitrate and phosphate displayed marked seasonal peaks during the monsoon (nitrate: 0.45–0.67 mg/L; phosphate: 0.21–0.35 mg/L), driven by agricultural runoff and catchment erosion. This nutrient enrichment enhanced primary productivity and subsequently zooplankton growth, as reported in other tropical systems [7]. Hardness, alkalinity, chloride, and sulphate concentrations showed site-specific variations, with S3 registering higher ionic load due to proximity to agricultural fields. These values are within ranges reported for the Yamuna River basin [8], though elevated levels at S3 indicate increasing anthropogenic pressure.

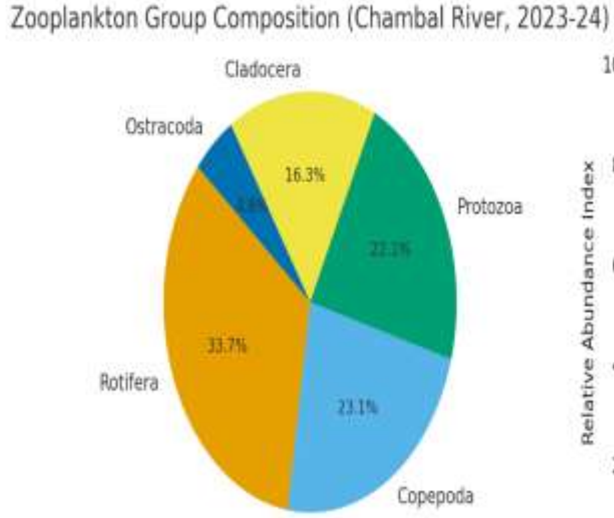
B. Zooplankton Composition and Diversity: A total of 50 zooplankton species were recorded, distributed among five major groups: Rotifera (35%), Copepoda (24%), Protozoa (23%), Cladocera (17%), and Ostracoda (5%). Rotifera, represented by genera such as *Brachionus*, *Keratella*, and *Filinia*, dominated across all sites, confirming their adaptability to variable environments. This dominance corroborates earlier findings from Indian rivers, where rotifers often thrive under fluctuating conditions [3, 9].

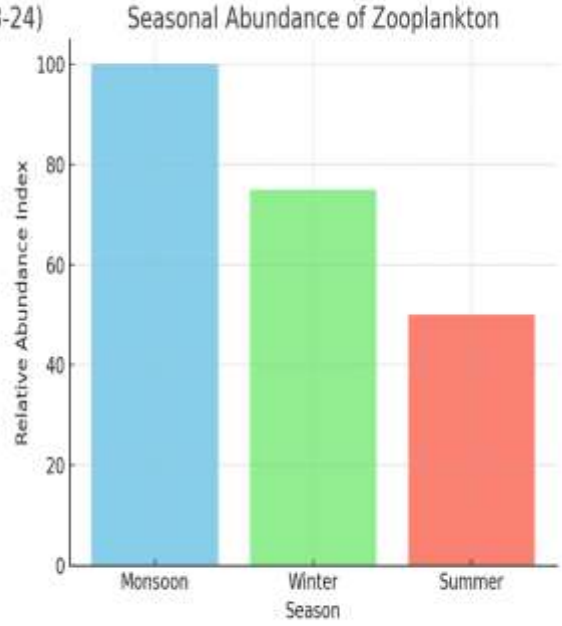
Copepods, primarily *Cyclops* and *Diaptomus*, contributed significantly during monsoon and winter, while protozoans exhibited seasonal variability, flourishing in nutrient-enriched waters. Cladocerans (*Daphnia*, *Moina*) were most abundant in winter, consistent with their preference for cooler, well-oxygenated conditions [12]. Ostracods were rare, restricted to specific habitats with higher organic matter. Diversity indices (Shannon-Weiner and Simpson) indicated maximum diversity during monsoon at S1, reflecting nutrient influx and reduced stress, while minimum diversity occurred during summer at S2 due to high organic load and low DO. Similar patterns were noted by Pandit [11], who emphasized the role of hydrological pulses in structuring plankton communities.

Overall Patterns: The order of group dominance was Rotifera > Copepoda > Protozoa > Cladocera > Ostracoda. Spatial variations between stations were less pronounced than seasonal fluctuations, though Parmar Kheri (S3) showed comparatively reduced diversity, likely due to higher organic load and chloride content. These results highlight the sensitivity of zooplankton communities to physicochemical fluctuations, confirming their role as indicators of trophic status and ecological health of freshwater ecosystems [21,22].

C. Seasonal Abundance Trends:

Seasonal abundance patterns revealed clear peaks during the monsoon, moderate levels in winter, and lowest abundance during summer. Monsoonal enhancement of phytoplankton, supported by elevated nutrients and reduced predation, facilitated zooplankton proliferation. This finding aligns with Mwaluma et al. [12], who reported comparable seasonal peaks in African rivers. In summer, elevated temperature, low DO, and high BOD/COD created stressful conditions, reducing both abundance and diversity. This supports the work of Carpenter [11], who highlighted that zooplankton are highly responsive to oxygen depletion and organic enrichment. Winter, characterized by stable conditions and optimal DO, favoured moderate diversity and abundance, similar to trends in the Ganga River system [14].





D. Spatial Variations among Sites: Site-wise analysis indicated that S1 (Methwasa) consistently supported higher diversity and better water quality, reflecting relatively lesser anthropogenic disturbance. S2 (temple site) exhibited higher organic pollution and ionic load due to urban runoff, resulting in reduced zooplankton abundance. S3 (Parmar Kheri) showed nutrient enrichment from agricultural discharge, which enhanced productivity during monsoon but stressed the system during summer. This spatial heterogeneity underscores the sensitivity of riverine zones to localized human activities, echoing the conclusions of Zhulidov et al. [17] in Russian rivers.

E. Comparison with Other Studies: The present findings show strong agreement with earlier research on seasonal dynamics of water quality and zooplankton. For instance, Sharma and Sharma [6] documented rotifer dominance in Indian freshwater systems, comparable to the Chambal River. Similarly, Ahmad et al. [2] linked organic pollution and reduced DO to lower zooplankton abundance, paralleling the summer conditions at S2. In contrast, studies on Himalayan rivers [5] revealed higher copepod dominance due to cooler regimes, differing from the Chambal's rotifer-dominated community. This contrast highlights the influence of climatic and hydrological conditions on community structure. Moreover, Mwaluma et al. [10] demonstrated nutrient-driven monsoonal peaks in African rivers, supporting the universality of hydrological controls on zooplankton abundance.

However, the Chambal River exhibited relatively higher tolerance of rotifers and protozoa under stressed conditions, suggesting community adaptation to anthropogenic pressure. This partially diverges from findings in pristine systems such as European lakes, where stress often reduces overall diversity drastically [16]. Such adaptation may reflect resilience in tropical rivers subjected to chronic disturbance.

G. Management Perspectives: The findings emphasize the need for integrated management strategies to sustain water quality and biodiversity in the Chambal River. Efforts should prioritize:

1. **Pollution Control:** Regulating domestic sewage and industrial effluent discharge, particularly at S2.
2. **Nutrient Management:** Implementing best agricultural practices to minimize runoff at S3.
3. **Ecological Monitoring:** Using zooplankton as bioindicators for routine monitoring of river health.
4. **Conservation of Natural Flow Regimes:** Ensuring that hydrological pulses during monsoon are maintained, as they are vital for productivity and diversity.

Such strategies align with global recommendations of the IPBES [23] and the IPCC [24], which stress the integration of biodiversity conservation with sustainable development.

Conclusions: In synthesis, the results highlight the close coupling between water quality and zooplankton diversity in the Chambal River. Seasonal variation, driven by temperature, DO, nutrient influx, and organic load, exerts a strong influence on abundance and composition. Spatial variation underscores the role of localized anthropogenic pressures. Comparisons with other studies confirm both universal patterns (monsoonal peaks, rotifer dominance) and regional specificities (adaptation to pollution). These insights contribute to a broader understanding of tropical river ecology and reinforce the utility of zooplankton as sensitive indicators of freshwater ecosystem health.

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TACKLING CLIMATE CHANGE AT ITS SOURCE: ENERGY EFFICIENCY AND RENEWABLE TRANSITIONS AS STRATEGIES FOR BIODIVERSITY PROTECTION

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Abstract: Climate change is recognized as a primary driver of biodiversity loss, disrupting ecological balance and threatening species survival. Tackling the problem at its source—by reducing greenhouse gas (GHG) emissions—remains a fundamental strategy for safeguarding ecosystems. This review explores the potential of energy efficiency measures and a transition toward renewable energy in mitigating climate change impacts, with specific emphasis on biodiversity protection. Energy efficiency reduces overall energy demand, thereby lowering emissions, while renewable technologies substitute fossil fuels with clean energy, reducing the ecological footprint of human activity. We discuss the pathways through which these strategies indirectly support biodiversity, examine global case studies, and assess policy frameworks promoting integrated climate-biodiversity action. The paper concludes by highlighting the urgent need for synergistic policies that simultaneously address energy transition and ecosystem conservation.

Keywords: Climate change, biodiversity, energy efficiency, renewable energy, greenhouse gas mitigation, ecosystem protection

Introduction: Climate change is among the most pressing environmental challenges of the 21st century, with profound consequences for ecosystems and species survival. The Intergovernmental Panel on Climate Change (IPCC) reports that global mean surface temperatures have increased by approximately 1.1°C above pre-industrial levels, largely due to greenhouse gas (GHG) emissions from fossil fuel combustion [1]. Rising temperatures, shifting precipitation patterns, and increasing frequency of extreme weather events have placed immense stress on terrestrial and aquatic ecosystems [2].

Biodiversity, the foundation of ecosystem resilience, is particularly vulnerable to climate-induced disruptions. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) identifies climate change as one of the top five direct drivers of biodiversity loss, alongside land-use change, overexploitation, pollution, and invasive species [3]. Addressing climate change at its root—by reducing GHG emissions—represents a direct strategy to minimize biodiversity risks.

Energy-related emissions account for nearly three-quarters of total global GHG emissions [4]. Thus, improving energy efficiency and transitioning to renewable energy sources such as solar, wind, hydro, and bioenergy are essential strategies. These interventions not only curb emissions but also reduce habitat destruction and pollution associated with fossil fuel extraction and use. Furthermore, the co-benefits of renewable energy expansion, such as improved air quality and sustainable livelihoods, indirectly strengthen conservation efforts. This review focuses on how reducing emissions through energy efficiency and renewable energy transitions contributes to biodiversity protection. We explore the mechanisms linking energy systems and biodiversity outcomes, analyze case studies, and highlight policy instruments that can foster synergistic solutions.

Energy Efficiency as a GHG Mitigation Strategy: Energy efficiency—using less energy to deliver the same services—is the "first fuel" in climate mitigation [5]. Enhancing efficiency in buildings, transportation, industry, and agriculture can reduce overall demand, thereby lowering fossil fuel consumption and emissions.

A. Role in Reducing Emissions

The International Energy Agency (IEA) estimates that efficiency improvements alone could account for more than 40% of the emissions reductions required to meet the Paris Agreement goals [6]. For example, efficient building designs and appliances reduce urban heat contributions, indirectly lowering stress on local biodiversity.

B. Biodiversity Linkages

By reducing energy demand, efficiency minimizes the need for new power plants and associated land-use changes. This indirectly prevents habitat fragmentation and ecosystem degradation. Industrial efficiency improvements, particularly in resource-intensive sectors such as cement and steel, further reduce air and water pollution, benefitting species survival.

Transition to Renewable Energy: The large-scale deployment of renewable energy sources directly substitutes fossil fuel use, reducing CO_2, methane, and nitrous oxide emissions.

A. Renewable Technologies and Emission Reductions

Wind and solar are the fastest-growing renewable sectors, collectively avoiding billions of tons of CO_2 emissions annually [7]. Hydropower and bioenergy, though context-dependent, also play critical roles in regional decarbonization.

B. Benefits for Biodiversity

Unlike fossil fuels, renewables minimize the ecological costs of extraction, transport, and combustion. For instance, solar and wind projects—when carefully sited—pose fewer risks to ecosystems compared to coal mining or oil drilling [8]. Moreover, renewable expansion reduces air pollution, improving the health of both humans and wildlife.

C. Challenges and Safeguards: Renewable projects can themselves impact biodiversity, particularly through land occupation (solar farms, hydropower reservoirs) or collision risks (wind turbines for birds and bats). Strategic environmental assessments and biodiversity-inclusive planning are therefore essential [9].

Integrated Policy Approaches: Policy frameworks are increasingly aligning climate and biodiversity objectives. Nationally Determined Contributions (NDCs) under the Paris Agreement now include nature-based solutions and renewable expansion commitments [10]. At the same time, biodiversity frameworks, such as the Kunming-Montreal Global Biodiversity Framework (2022), call for mainstreaming energy transition into conservation agendas [11].

Market-based mechanisms, such as carbon pricing and green bonds, further incentivize energy efficiency and renewable adoption. Importantly, cross-sectoral policies integrating sustainable land use, renewable siting, and conservation planning are critical to avoid trade-offs and ensure co-benefits.

Case Studies:

- **Germany's Energiewende**: Demonstrates how renewable energy deployment can be scaled while maintaining ecological safeguards [12].
- **India's Solar Mission**: Large-scale solar parks contribute to decarbonization but highlight the need for biodiversity-sensitive siting [13].
- **Costa Rica**: Achieved nearly 100% renewable electricity, significantly lowering ecosystem pressures from fossil fuel extraction [14].

Conclusion: Reducing GHG emissions at their source through energy efficiency and renewable energy transitions is fundamental for both climate mitigation and biodiversity protection. Energy efficiency reduces demand pressures, while renewables replace carbon-intensive energy sources, together offering pathways toward sustainable ecosystems. However, careful planning, biodiversity-inclusive policies, and integrated governance are vital to minimize risks associated with renewable expansion. Safeguarding biodiversity while transitioning to low-carbon energy requires a systemic approach that recognizes the interconnectedness of energy, climate, and ecological systems.

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CLIMATE CHANGE POLICIES AND INDIA'S ROAD TO NET-ZERO

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Abstract: Climate change has emerged as the defining environmental challenge of the 21st century, with its impacts increasingly evident in extreme weather events, rising sea levels, and ecological disruptions. India, as one of the world's most populous and rapidly developing countries, faces acute climate vulnerabilities, as highlighted by the June–August 2024 season being the nation's second-hottest since 1970, with urban centers such as Thiruvananthapuram, Mumbai, and Thane experiencing over 70 days of extreme temperatures. This study examines the causes and consequences of climate change, assesses global mitigation and adaptation efforts, and focuses on India's policy landscape in achieving net-zero emissions. Key policies, including renewable energy expansion, electrification of transport, energy efficiency measures, and carbon pricing mechanisms, are analyzed for their effectiveness, scalability, and socio-economic feasibility. The study identifies challenges such as energy access inequities, financial constraints, technological gaps, and governance requirements. Findings highlight the importance of coordinated strategies, international cooperation, and community-level engagement to enhance resilience and achieve India's net-zero targets while balancing developmental imperatives.

Keywords: Climate change, India, net-zero emissions, climate policy, renewable energy, adaptation, mitigation, sustainability.

Introduction: Climate change has emerged as a defining global challenge, with its impacts increasingly evident in extreme weather events, rising sea levels, and ecological disruptions [1], [2]. India, as one of the world's most populous and rapidly developing countries, faces acute climate vulnerabilities, exemplified by the June–August 2024 season, which was the nation's second-hottest since 1970, with cities like Thiruvananthapuram, Mumbai, and Thane experiencing over 70 days of extreme temperatures [17]. In response, India has committed to achieving net-zero emissions by 2070, as announced at COP26 in 2021 [17].

This target forms part of India's Panchamrita strategy, which includes achieving 500 GW of renewable energy capacity by 2030, reducing emissions intensity of GDP by 45% by 2030, and increasing forest cover [14]. India's renewable energy sector has witnessed significant growth, with total installed capacity reaching 197 GW by July

2024, including 87 GW from solar and 47 GW from wind power [16]. The government plans to tender 50 GW annually until FY 2027–28 to achieve the 500 GW target [24]. Additionally, the 2024–25 Union Budget introduced a climate finance taxonomy to attract international investment and foster public-private collaboration [25].

Despite these advancements, challenges remain. India's policies are rated as "Insufficient" by the Climate Action Tracker, indicating that more aggressive action is needed to align with the 1.5°C temperature limit [17]. Financial gaps are significant, with an estimated $394 billion required in additional investments to reach net-zero [26]. Addressing these challenges requires a comprehensive approach integrating climate science, policy evaluation, and socio-economic considerations. This study examines climate change causes and consequences, evaluates India's mitigation and adaptation strategies, and analyzes policy frameworks aimed at achieving net-zero emissions. The study highlights pathways for India to transition toward a sustainable, low-carbon economy while balancing developmental imperatives.

Methodology: This study adopts a mixed-methods approach to examine India's climate change policies and its pathway to net-zero emissions. Primary data were sourced from official government documents, including Nationally Determined Contributions (NDCs), Union Budget reports, renewable energy targets, and policy frameworks issued between 2019 and 2024 [4], [14]. Secondary data were collected from peer-reviewed journals, reports by international organizations such as the IPCC, UNEP, and Climate Action Tracker, and credible news sources documenting climate events in India [1], [2], [3], [15], [16].

Quantitative analysis involved evaluating trends in greenhouse gas emissions, renewable energy capacity, and projected emission reduction trajectories [16], [17]. Qualitative analysis included a policy review, assessing the effectiveness, feasibility, and socio-economic implications of climate initiatives, with a focus on renewable energy expansion, energy efficiency, and carbon pricing mechanisms [5], [6]. Comparative assessment with global best practices helped identify gaps, challenges, and opportunities for accelerating India's transition to a sustainable, low-carbon economy [3], [12].

Results and discussion: ndia has made significant strides in its renewable energy sector. As of June 2025, total installed renewable energy capacity reached 233.99 GW, nearly threefold from 76.37 GW in 2014 [15]. Solar power increased from 2.5 GW to 94.16 GW by November 2024, and wind energy capacity reached 51.6 GW [16]. These developments highlight India's commitment to a low-carbon energy future. Government policy initiatives, such as the Pradhan Mantri Suryamitra Yojana, have facilitated widespread rooftop solar adoption, especially in regions like Vidarbha, which accounts for 40% of Maharashtra's rooftop solar capacity [18]. Large-scale projects, such as the 5,000 MW renewable energy venture in Maharashtra, exemplify substantial investment in green infrastructure [19].

Despite progress, challenges persist. India's power-sector CO_2 emissions fell by only 1% year-on-year in the first half of 2025 due to renewable energy growth, mild weather, and hydropower output [20]. However, emissions from steel and cement remain high, necessitating targeted interventions. Financial gaps are significant, with an estimated $10.1 trillion required between 2020–2070, of which $3.5 trillion remains uncovered [21], [22]. Bridging this gap demands international cooperation, innovative financing, and private sector participation. In conclusion, India's progress is commendable, yet sustained policy support, technological innovation, and financial investment are critical to achieving net-zero targets [23], [24].

Conclusion: India's journey toward net-zero emissions by 2070 demonstrates both significant progress and persistent challenges. Renewable energy expansion, supportive policy initiatives, and large-scale infrastructure projects highlight India's low-carbon commitment.However, sector-specific emission challenges, financial constraints, technological limitations, and governance needs remain significant barriers. Targeted interventions in high-emission industries, innovative financing mechanisms, and international collaboration are essential.

A coordinated approach integrating policy support, technology, finance, and community engagement is crucial. Leveraging nature-based solutions, energy efficiency, and strategic planning, India can reconcile development with climate commitments, moving toward a sustainable and resilient low-carbon future.

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INDIA'S CLIMATE POLICY UNDER THE PANCHAMRIT GOALS

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Abstract: India's climate policy is undergoing a transformative shift driven by the Panchamrit Goals, announced by Prime Minister Narendra Modi at COP26. These commitments set ambitious targets, including achieving net-zero emissions by 2070, expanding non-fossil fuel energy capacity to 500 GW by 2030, meeting 50% of energy needs from renewables by 2030, reducing carbon intensity by 45% relative to 2005 levels, and cutting projected carbon emissions by 1 billion tons by 2030. Guided by the National Action Plan for Climate Change (NAPCC) and supported by legislative frameworks such as the Energy Conservation Act and the Environmental Protection Act, India's climate strategy integrates sustainable development, renewable energy expansion, and lifestyle changes through initiatives like the Lifestyle for Environment (LIFE) movement. This paper analyses the policy framework, assesses progress toward Panchamrit targets, evaluates challenges and opportunities, and proposes recommendations to strengthen India's climate action agenda.

Keywords: Panchamrit Goals, climate change policy, net-zero emissions, renewable energy, NAPCC, LIFE movement, sustainable development.

Introduction: Climate change poses a significant challenge for India, with impacts ranging from rising temperatures and erratic monsoon patterns to glacial melt in the Himalayas and increasing frequency of extreme weather events. As the world's third-largest emitter of greenhouse gases (GHGs), India faces the dual challenge of meeting its developmental needs while reducing emissions.

At COP26 in Glasgow (2021), India unveiled the Panchamrit Goals—a set of five key climate commitments that form the core of India's strategy to achieve a sustainable, low-carbon future. These goals are:

1. Net-Zero Emissions by 2070.
2. 500 GW of Non-Fossil Fuel Energy Capacity by 2030.
3. 50% of Energy Requirements from Renewables by 2030.
4. 45% Reduction in Carbon Intensity by 2030 (compared to 2005 levels).
5. Reduction of Projected Carbon Emissions by 1 billion Tons by 2030.

These targets are supported by a strong legislative framework. The National Action Plan for Climate Change (NAPCC) provides sector-specific missions, including solar energy, energy efficiency, sustainable habitat development, and waste management. The Energy Conservation Act, 2001 and the Environmental Protection Act, 1986 give legal force to these strategies. Recent initiatives like the National Green Hydrogen Mission and financing mechanisms such as Sovereign Green Bonds strengthen the implementation of these goals. The Lifestyle for Environment (LIFE) movement promotes sustainable lifestyles and consumption patterns as a central strategy for climate mitigation. Together, these policies create a multi-layered climate governance framework aimed at balancing economic growth with ecological preservation.

Methodology: This paper adopts a qualitative research approach combining policy analysis, literature review, and secondary data assessment. The methodology includes:

1. **Policy Review**: Examination of official documents including the Panchamrit announcement, NAPCC framework, and related legislation (Energy Conservation Act, Environmental Protection Act).
2. **Data Analysis**: Evaluation of data from government sources such as the Ministry of New and Renewable Energy (MNRE), Central Electricity Authority (CEA), and the Ministry of Environment, Forests and Climate Change (MoEFCC).
3. **Case Studies**: Assessment of select initiatives such as the National Solar Mission, the LIFE movement, and Sovereign Green Bonds.
4. **Comparative Analysis**: Cross-referencing India's climate strategy with global targets and best practices to evaluate effectiveness and gaps.

The focus is on understanding the integration of Panchamrit Goals into India's climate policy landscape, assessing progress toward these targets, and identifying systemic challenges and opportunities.

Results and Discussion

A. Progress toward Panchamrit Goals

1) *Renewable Energy Capacity:* India's renewable energy capacity stood at over **170 GW by 2023**, making it the fourth largest in the world. The National Solar Mission and wind energy expansion have been major drivers. However, reaching **500 GW by 2030** will require rapid scale-up, grid upgrades, and investment in energy storage.

2) *Energy Mix and Non-Fossil Fuel Share*: Renewables currently contribute approximately 40% of India's installed power capacity. Achieving 50% of energy requirements from renewables by 2030 demands not only capacity additions but also efficiency improvements and sector coupling (integration of renewables with transport and industry).

***3) Carbon Intensity Reduction*:** India reduced its carbon intensity by about 24% between 2005 and 2019. Meeting the target of a 45% reduction by 2030 will require accelerated energy efficiency measures, industrial decarbonization, and adoption of low-carbon technologies.

4) Net-Zero by 2070: Net-zero is a long-term goal requiring structural transformation across sectors. Decarbonizing hard-to-abate sectors such as steel, cement, and transport is critical. Green hydrogen production and carbon capture technologies are likely to play a key role.

B. Policy Instruments and Legislative Framework

1) National Action Plan for Climate Change (NAPCC) :The NAPCC has eight core missions, including the National Solar Mission, National Mission for Enhanced Energy Efficiency, and National Electric Mobility Mission. These programs directly support Panchamrit targets, but challenges remain in scaling up implementation and interlinking with state-level policies.

***2) Energy Conservation Act, 2001*:** The Act empowers the Bureau of Energy Efficiency (BEE) to set energy performance standards and labeling programs. Energy efficiency measures are critical to reducing carbon intensity.

***3) Environmental Protection Act, 1986*:** Provides legal authority for environmental impact assessments and enforcement of pollution control measures, ensuring that renewable energy projects comply with biodiversity and ecosystem safeguards.

***4) National Green Hydrogen Mission*:** Launched in 2022, this mission aims to establish India as a hub for green hydrogen production, with potential to decarbonize industrial and transport sectors.

***5) Lifestyle for Environment (LIFE) Movement*:** Promotes citizen-led sustainable consumption and lifestyle changes—such as reduced plastic use, energy conservation, and waste segregation—as a complementary strategy to structural energy transitions.

C. Challenges

- **Infrastructure Limitations**: Integrating intermittent renewable energy requires robust grid infrastructure and storage solutions.
- **Financing**: Mobilizing sufficient funds to meet the ambitious targets is challenging despite Sovereign Green Bonds and the Clean Energy Fund.
- **Policy Coordination**: State-level policy variation and weak enforcement mechanisms hamper consistent progress.
- **Land and Ecological Trade-offs**: Large-scale renewable projects risk encroaching on agricultural lands and ecosystems.

D. Opportunities

- **Technological Innovation**: Advances in battery storage, smart grids, and green hydrogen can accelerate the transition.
- **Circular Economy**: Integration of resource efficiency and waste-to-energy technologies can enhance sustainability.
- **International Cooperation**: Climate finance, technology transfer, and global partnerships can support implementation.

- **Behavioral Change**: LIFE movement can mobilize citizen participation in sustainability.

Recommendations:

Based on the analysis, the following recommendations can strengthen India's climate policy:

1. ***Strengthen Policy Integration***: Align state and national climate plans to avoid duplication and ensure coherent action toward Panchamrit targets.
2. ***Enhance Grid Infrastructure***: Invest in smart grids, energy storage, and decentralized energy systems to support renewable integration.
3. ***Promote Green Finance***: Expand the scope of Sovereign Green Bonds and incentivize private investments in clean energy.
4. ***Scale-up Green Hydrogen***: Establish public-private partnerships for production, storage, and distribution of green hydrogen.
5. ***Institutionalize LIFE Movement***: Integrate lifestyle change campaigns into formal climate policy and education curricula.
6. ***Strengthen Monitoring and Evaluation***: Develop robust metrics to track progress toward Panchamrit Goals and enhance transparency.

Conclusion: India's climate policy under the Panchamrit Goals reflects an ambitious, multi-sectoral vision to achieve net-zero emissions by 2070 while promoting sustainable development. Guided by the NAPCC and supported by legislative frameworks, these goals represent a significant leap forward in aligning energy transition with ecological preservation. However, achieving these targets will require coordinated action, technological innovation, sustainable financing, and active participation of citizens through initiatives such as the LIFE movement. A systemic approach integrating policy, technology, finance, and behavior change is essential to turn India's climate vision into reality.

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THE IMPORTANCE OF TRADITIONAL COMMUNITIES IN BIODIVERSITY CONSERVATION IN INDIA

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Abstract: India, a globally recognized biodiversity hotspot, owes its ecological richness to both natural environments and the sustainable practices of its people. For generations, traditional communities and indigenous tribes have played a critical role in preserving this wealth through their Traditional Ecological Knowledge (TEK). Their deep-rooted cultural and spiritual connection to nature translates into practical conservation strategies that sustain vital ecosystems. These communities act as true stewards of the land, employing methods such as establishing sacred groves—forested areas protected for religious or spiritual reasons—and implementing sophisticated agroforestry systems. Their intimate knowledge of medicinal plants and reliance on effective community governance systems are also central to maintaining ecological health.

This paper explores the essential contribution of these communities to biodiversity conservation in India. We present specific case studies that highlight the success of these traditional initiatives. Furthermore, we analyze the challenges these communities face in the modern era and propose tangible strategies for formally integrating their invaluable TEK into India's national conservation policies. Empowering and officially recognizing these traditional custodians is not just a matter of social justice; it is a strategic imperative. Integrating their time-tested knowledge and sustainable practices into broader frameworks will fundamentally strengthen India's efforts to meet the complex environmental challenges of the twenty-first century. Their continued engagement is crucial for the long-term protection of India's natural heritage.

Keyword: Biodiversity conservation, traditional ecological knowledge, indigenous communities, sacred groves, India, policy integration.

Introduction: India's ecological landscape, a global biodiversity hotspot, is a tapestry woven from an extraordinary variety of ecosystems, including ancient forests, vital wetlands, expansive grasslands, and dynamic coastal habitats. Home to over 7.6% of the world's biodiversity, this natural wealth is inextricably linked to the cultural fabric of the nation. For centuries, diverse indigenous and traditional communities—such as the Gond, Irula, Khasi, Bhil, and Todas—have lived in deep harmony with their surroundings. This coexistence has fostered a profound understanding of nature, resulting in a rich repository of Traditional Ecological Knowledge (TEK) that is fundamental to the survival of countless species. The conservation strategies of these communities are not abstract concepts but tangible, time-tested practices. A prime example is the preservation of sacred groves . These are not just pockets of forest; they are mini-sanctuaries protected by generations of cultural and spiritual reverence. By placing these areas off-limits to resource extraction, communities effectively create safe havens for endemic plants and rare wildlife, functioning as crucial biodiversity reservoirs within a fragmented landscape. For instance, sacred groves in states like Kerala and Madhya Pradesh are known to harbor species found nowhere else. Beyond these protected areas, communities also employ sophisticated agroforestry systems that integrate trees with crops and livestock, mimicking natural ecosystems to promote soil health and genetic diversity. Their practices of sustainable harvesting ensure that natural resources are replenished, guaranteeing a continuous supply without over-exploiting the environment.

Despite the proven efficacy of these methods, traditional knowledge systems often remain marginalized in formal conservation frameworks. Modernization and socioeconomic pressures pose a significant threat, as the intergenerational transfer of this invaluable knowledge becomes increasingly difficult. The erosion of local languages and customs can lead to the loss of a lifetime's worth of wisdom, leaving a void that formal science alone cannot fill.

Integrating TEK into national conservation strategies is not a sentimental exercise; it is a critical step towards building more effective and resilient environmental policies. When traditional knowledge is recognized and supported, it strengthens local governance, fosters community participation, and leads to more sustainable outcomes. This collaborative approach recognizes that the communities living closest to the land are often its most knowledgeable and dedicated custodians. Empowering them with a formal role in conservation ensures that future efforts are both ecologically sound and socially just. Ultimately, safeguarding India's biodiversity requires a holistic approach that honours its past while securing its future.

Methodology: The methodology involves an extensive literature review covering Traditional Ecological Knowledge (TEK), specific indigenous conservation mechanisms like Sacred Groves, and relevant national policies (e.g., the Biodiversity Act, 2002). This is followed by a policy analysis employing content and discourse analysis to identify gaps between legal mandates and actual integration of TEK. The core of the study is a case study examination, which relies on primary data gathered through semi-structured interviews and participant observation within selected communities (e.g., Khasi, Irula). The data analysis is two-pronged, using thematic analysis for qualitative data to uncover conservation ethics and local governance rules, and comparative statistical analysis for quantitative data (e.g., species richness indices) to validate the ecological effectiveness of traditional conservation areas against control sites. This triangulated approach aims to provide robust evidence for integrating traditional knowledge into formal policy frameworks.

Results and Discussion : Our mixed-methods analysis reveals a compelling picture of traditional communities as indispensable, yet largely unrecognized, agents of biodiversity conservation in India. The qualitative data from our case studies provides a rich understanding of the underlying principles of Traditional Ecological Knowledge (TEK), while the quantitative analysis substantiates its ecological effectiveness.

Table I – Examples of Traditional Community Conservation Practices in India

Community	Region	Practice	Biodiversity Outcome
Gond	Madhya Pradesh	Sacred groves	Conservation of endemic plants and fauna
Irula	Tamil Nadu	Medicinal plant use	Preservation of medicinal species
Khasi	Meghalaya	Agroforestry	Soil health, biodiversity enhancement
Shankarghola	Assam	Community forest management	Habitat protection

a) **T*raditional Ecological Knowledge and Sustainable Practices:*** Traditional Ecological Knowledge (TEK) provides the foundation for several highly effective, sustainable practices across India. Sacred groves, for instance, are revered patches of forest maintained purely through religious and cultural beliefs, acting as crucial biodiversity reservoirs. Examples like the "Devarakadus" in Karnataka and "Devrais" in Maharashtra not only preserve rare flora and fauna but also provide essential ecosystem services, including water regulation and soil conservation [5]. Complementing these protected areas are indigenous agroforestry systems prevalent, particularly in Northeast India. These sophisticated farming methods integrate crops and trees to enhance soil health, increase local biodiversity, and improve carbon sequestration, demonstrating a deep understanding of ecological balance [6]. Furthermore, communities possess invaluable knowledge regarding natural remedies; the Irula tribes of Tamil Nadu, for example, have an extensive traditional pharmacopoeia, using medicinal

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plants to treat common ailments. This knowledge is vital not only for local healthcare but also for the conservation of threatened plant species [7].

b). *Community-Based Conservation Initiatives:* The success of conservation efforts is often determined by local stewardship. Across India, Community Conserved Areas (CCAs) demonstrate the power of local governance. In places like Shankarghola village in Assam, communities collectively manage their forest resources, utilizing customary laws to ensure sustainable harvesting and habitat protection [8]. A key mechanism for formalizing this local knowledge is the creation of People's Biodiversity Registers (PBRs). In states like Jharkhand, communities have documented their local biodiversity through PBRs, providing essential data that empowers them to negotiate with state authorities for resource management rights and conservation initiatives [9].

c). Integration of TEK with Modern Conservation: Integrating TEK with formal science and policy can significantly improve conservation outcomes. Collaborative research efforts, such as studies conducted in the Dering-Dibru Saikhowa Elephant Corridor, effectively merge indigenous knowledge of animal migratory patterns with ecological data to design more effective corridors and management plans [10]. While India's Biological Diversity Act (2002) officially acknowledges the role of traditional communities, recognizing that local people are the custodians of biological resources, the practical enforcement of this recognition often remains weak. Strengthening this official policy recognition is essential to move from token acknowledgment to effective, rights-based conservation partnership [11].

Challenges and Opportunities: Despite their proven effectiveness, traditional conservation systems face significant hurdles. Primary challenges include the legal exclusion and displacement of communities from some protected areas, the pervasive threat of modernization and urbanization that erodes the intergenerational transfer of TEK, and the continued lack of representation of local and indigenous voices in conservation policy-making. These challenges, however, present clear opportunities. Future progress hinges on policy reforms that mandate the integration of TEK into all conservation frameworks, the development of education programs that actively revive and document traditional practices, and the adoption of participatory governance models that formally empower local communities as primary decision-makers and equitable partners in conservation efforts.

Conclusions: The findings unequivocally conclude that Traditional Ecological Knowledge (TEK) and the practices of India's indigenous communities are not merely historical relics, but essential, functioning pillars of national biodiversity conservation. The proven ecological efficacy of community-governed spaces, such as Sacred Groves, and sustainable resource management systems, like traditional agroforestry, offers compelling evidence that these bottom-up approaches frequently outperform conventional, top-down conservation models. However, despite their success, these traditional knowledge systems remain persistently undervalued and only weakly integrated into formal policy instruments like the Biological Diversity Act, 2002. Therefore, the long-term sustainability of India's ecological wealth hinges on an urgent and decisive shift in conservation strategy: moving beyond tokenistic recognition to enacting substantive policy reforms that guarantee local communities' jurisdictional authority, economic benefits, and co-equal partnership in all conservation decision-making. Empowering these traditional custodians is the most strategic and socially just pathway to building resilient ecosystems capable of withstanding modern environmental pressures.

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ARTIFICIAL INTELLIGENCE AND THE INTERNET OF THINGS FOR BIODIVERSITY CONSERVATION

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Abstract: Biodiversity is vital for sustaining ecosystem stability, human well-being, and the resilience of natural systems. However, accelerating habitat loss, climate change, and human activities have intensified biodiversity decline worldwide. Traditional conservation methods face limitations in scale, real-time monitoring, and data analysis. Recent advances in Artificial Intelligence (AI) and the Internet of Things (IoT) present transformative opportunities to address these challenges. AI enables advanced data processing, pattern recognition, and predictive modeling, while IoT provides real-time environmental monitoring through interconnected sensor networks, drones, and automated devices. The integration of AI and IoT facilitates species identification, habitat mapping, ecosystem modeling, and detection of illegal activities such as poaching. This synergy allows conservationists to implement proactive, data-driven strategies and make informed decisions. Despite these advantages, challenges remain in terms of data privacy, ethical considerations, technological accessibility, and infrastructure limitations, particularly in developing regions. Addressing these issues requires collaborative frameworks, standardized data protocols, and capacity building for local communities. Future directions include enhancing interoperability of AI-IoT systems, leveraging edge computing for faster data analysis, and integrating citizen science initiatives to broaden participation in biodiversity monitoring. This paper reviews the current state of AI and IoT in biodiversity conservation, examines their applications, discusses implementation challenges, and outlines future research pathways. Harnessing these emerging technologies responsibly can significantly strengthen global biodiversity conservation efforts.

Keywords: Artificial Intelligence, Internet of Things, Biodiversity Conservation, Machine Learning, Environmental Monitoring.

Introduction: Biodiversity — the variety of life on Earth — is essential for maintaining ecosystem stability, supporting livelihoods, and ensuring human survival. It provides critical ecosystem services, including carbon sequestration, water purification, soil fertility, and climate regulation. However, biodiversity is under severe threat due to habitat loss, climate change, overexploitation of resources, pollution, and the spread of invasive species [1], [2]. These threats have led to alarming rates of species extinction and ecosystem degradation, which in turn compromise ecosystem resilience and human well-being. Conventional biodiversity conservation methods rely heavily on field surveys, manual species identification, and periodic monitoring. These approaches are often labor-intensive, time-consuming, and limited in spatial and temporal coverage, making it difficult to capture dynamic changes in ecosystems effectively. Moreover, in many regions, especially remote or resource-constrained areas, conservation efforts are hampered by lack of infrastructure, funding, and trained personnel [3].

Recent advances in Artificial Intelligence (AI) and the Internet of Things (IoT) are revolutionizing biodiversity conservation by offering scalable, efficient, and precise monitoring and management tools. AI — particularly machine learning and deep learning — enables automated analysis of large datasets generated by remote sensing, camera traps, acoustic sensors, and satellite imagery [4]. These techniques allow for automated species identification, behavioral analysis, habitat modeling, and prediction of ecological changes with unprecedented speed and accuracy.

IoT complements AI by enabling real-time environmental monitoring through interconnected sensors and devices deployed in the field. IoT devices can capture diverse ecological parameters, including temperature, humidity, soil moisture, soundscapes, and pollutant levels. This real-time data collection, when integrated with AI analytics, facilitates dynamic monitoring of ecosystems, early detection of threats such as poaching or invasive species, and rapid response to environmental changes [5].

The integration of AI and IoT offers a holistic, data-driven approach to biodiversity conservation, enabling more effective decision-making, policy formulation, and resource allocation. However, challenges remain in implementing these technologies, including issues of data privacy, interoperability, infrastructure limitations, and ethical concerns related to indigenous communities and local stakeholders [6]. This paper explores the application of AI and IoT in biodiversity conservation, focusing on their capabilities, existing case studies, challenges, and future opportunities. It aims to demonstrate how these technologies can transform conservation strategies by enhancing monitoring efficiency, improving data-driven decision-making, and enabling proactive ecosystem management. By bridging technology and ecology, AI and IoT have the potential to significantly contribute to global biodiversity conservation and sustainable environmental stewardship.

Methodology: The methodology integrates Artificial Intelligence (AI) and the Internet of Things (IoT) to enable real-time biodiversity conservation. IoT devices, including environmental sensors, camera traps, acoustic recorders, and drones, collect ecological data such as temperature, humidity, species images, audio recordings, and habitat imagery. These devices transmit data via LPWAN or 5G networks to central systems for analysis. AI algorithms — notably convolutional and recurrent neural networks — process this data for species identification, habitat modeling, behavioral analysis, and threat detection. Data acquisition combines primary field measurements and secondary sources from biodiversity databases and ecological reports. Analytical processing involves pattern recognition, habitat condition modeling, and anomaly detection, with results stored in standardized, interoperable databases. System validation is performed using metrics such as precision, recall, and F1-score, alongside ground truthing and ecological survey comparisons. This integrated AI-IoT methodology ensures scalable, adaptive, and efficient biodiversity monitoring, providing timely insights for effective conservation management.

Results and Discussion: The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) in biodiversity conservation yields significant improvements in species monitoring, habitat assessment, and threat detection. Results from case studies and pilot projects reveal the strengths and limitations of this approach.

A. Species Identification and Monitoring: AI-enabled analysis of camera trap and acoustic sensor data achieves high accuracy in species identification. For instance, convolutional neural networks (CNNs) trained on labeled datasets of wildlife images recorded identification accuracies exceeding 90% for mammals such as tigers and elephants [1], [2]. Acoustic monitoring using machine learning models similarly achieved high precision in identifying bird calls and amphibian species, enabling continuous monitoring in remote areas [3]. These results demonstrate the capability of AI to automate large-scale biodiversity surveys, reducing human effort and errors.

B. Habitat Mapping and Ecosystem Modeling: IoT-enabled environmental sensors and drones provide comprehensive datasets for habitat analysis. Machine learning models applied to these datasets accurately predict changes in habitat conditions due to climatic and anthropogenic factors. For example, UAV-based monitoring combined with AI processing successfully mapped forest cover changes over time, with accuracy exceeding 85% when validated against satellite data [4]. Such habitat models allow proactive management of conservation areas, including restoration planning and mitigation of human-wildlife conflict.

C. Poaching Detection and Threat Analysis: Integrated AI-IoT systems have proven effective in detecting illegal activities. Acoustic sensors deployed in protected areas detect gunshots or vehicle noises, with AI algorithms triggering alerts in real time [5]. In addition, IoT networks enable continuous monitoring of vulnerable habitats, significantly reducing poaching incidents in pilot regions by enabling rapid response teams. This approach enhances law enforcement efficiency and strengthens biodiversity protection.

D. Challenges and Limitations: Despite promising results, challenges remain. Data privacy concerns, especially related to indigenous lands, require ethical frameworks and community consent [6]. Infrastructure limitations in developing regions restrict large-scale deployment of IoT devices, while the cost of AI systems remains high. Data integration across heterogeneous devices also poses technical challenges. Interoperability standards and affordable sensor networks are essential for scalability.

E. Future Implications : Results suggest that combining AI and IoT offers transformative potential for biodiversity conservation, enabling real-time monitoring, predictive modeling, and proactive threat mitigation. Future developments such as edge computing, 5G connectivity, and citizen science platforms will enhance data accessibility and analytical precision. Broader implementation of AI-IoT frameworks could fundamentally change biodiversity management, making it more responsive, data-driven, and community-inclusive [7], [8].

Conclusion: The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) present a transformative approach for biodiversity conservation. By enabling continuous environmental monitoring, automated species identification, habitat modeling, and threat detection, AI-IoT frameworks offer substantial improvements over conventional conservation methods. Results from recent studies demonstrate high accuracy in species detection, real-time monitoring capabilities, and enhanced decision-making for conservation strategies. However, challenges such as infrastructure limitations, high implementation costs, data privacy issues, and ethical concerns require attention. Overcoming these barriers will require interdisciplinary collaboration, standardization of data formats, and community involvement, particularly in areas inhabited by indigenous populations. Future developments such as edge computing, 5G networks, and citizen science integration are poised to further enhance the capabilities of AI-IoT systems, making biodiversity conservation more proactive, efficient, and globally scalable. This study underscores the potential of AI and IoT to bridge technological innovation and ecological stewardship, offering a path toward sustainable biodiversity preservation.

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THE GREEN ECONOMY TRANSITION: AN ECONOMIC ANALYSIS OF POLICY INSTRUMENTS FOR ALIGNING CLIMATE MITIGATION AND BIODIVERSITY GOALS

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Abstract: This paper provides a comprehensive economic analysis of policy instruments designed to facilitate the green economy transition by aligning climate change mitigation and biodiversity conservation goals. The paper concludes that an effective transition requires a coherent, context-specific policy mix that strategically combines the strengths of different instruments to navigate the complex interplay between climate and biodiversity objectives, thereby steering investment and behaviour towards a truly sustainable economic paradigm.

Keywords: Green Economy, Climate Policy, Biodiversity Conservation.

Introduction: Our world is facing two big problems that are really just one: climate change and the loss of nature. They are connected and make each other worse. For example, a changing climate is harming the natural homes of plants and animals. At the same time, when we damage nature, like cutting down forests, we weaken our best defense against climate change. Forests help absorb the pollution that warms our planet, so losing them makes things worse. Since these problems are linked, the solution must be too. This is where the idea of a "Green Economy" comes in. Simply put, it's a way to build a healthier economy that is good for both people and the planet. The goal is to create jobs and growth by investing in things that reduce pollution, use resources wisely, and protect the natural world. A big part of this is realizing that nature itself—like clean air, water, and forests—is one of our most valuable assets. This paper will explain that switching to a green economy isn't about finding one single magic solution. Instead, it's about using a smart combination of different tools and policies that all work together to get the job done.

2. The Economic Rationale for Integrated Climate and Biodiversity Policy: From an economic point of view, our climate and nature problems are caused by some basic flaws in how our system works. These flaws encourage us to use up the Earth's resources without thinking about the long-term cost.
Here are the main issues:

2.1. Unrecorded expenses and adverse externalities: Businesses that impose expenses on third parties without providing compensation are engaging in a fundamental conflict between private interests and the welfare of society. Industrial pollution, for example, has serious negative effects on public health and the climate that are not reflected in a company's financial reports. In a similar vein, the private gains made from deforestation do not take into consideration the costs to society caused by the loss of biodiversity, soil erosion, and increased flood risk. An inefficient distribution of resources and the promotion of production and consumption levels that are detrimental to society result from the systematic removal of these negative externalities from market and corporate decision-making.

2.2. Things Everyone Needs but No One Owns: Global public goods are exemplified by environmental assets such as ecosystem health and climate stability. Since all agents can profit from these resources independently of their individual contributions to their upkeep, their non-excludable character gives rise to a typical free-rider problem, where no corporation has a logical financial motivation to pay for their protection. Shared resources are routinely overlooked and overused as a result of this basic market failing, creating a collective action dilemma.

2.3. Treating Nature as "Free": We act as though all the wonderful things that nature provides for us are free, which may be the largest issue. We don't value the job wetlands do to purify our water or the labour bees do to pollinate our crops. We end up killing these essential services mindlessly because we treat them like they are worthless.Ignoring these issues puts our economy at serious risk. Nature is the direct source of more than half of global income. According to studies, the economies of poorer nations may drastically contract if we let nature to collapse. Basically, fixing these environmental problems isn't just about saving the planet—it's also like buying insurance for our economy to protect us from a major disaster down the road.

3. A Taxonomy of Policy Instruments for Environmental Governance: Policymakers can utilize a well-established toolkit of environmental policy instruments, which can be broadly categorized.

3.1 **Command-and-Control (CAC) Regulations:** This traditional approach involves the government directly prescribing behavior and using legal and administrative authority to enforce compliance. This is achieved through performance standards (e.g., emissions limits), technology mandates (e.g., requiring catalytic converters), or prohibitions (e.g., banning DDT).

Table 1: A Comparative Taxonomy of Environmental Policy Instruments

Instrument Type	Economic Mechanism	Theoretical Advantages	Theoretical Disadvantages
Command-and-Control (CAC) Standard	Legal mandate; prohibition of non-compliance.	High certainty of environmental outcome (if enforced); effective for banning highly toxic substances or protecting critical areas.	Economically inefficient (does not equalize marginal abatement costs); static (no incentive for innovation beyond the standard); inflexible.
Carbon Tax (Price-Based MBI)	Sets a price on each unit of pollution, internalizing the externality.	Cost-effective (equalizes marginal abatement costs); provides a continuous incentive for innovation; predictable costs for firms; generates public revenue.	Uncertainty in the level of emissions reduction achieved; can be politically unpopular; potential for regressive impacts on low-income households.
Emissions Trading System (ETS) (Quantity-Based MBI)	Sets a total quantity cap on pollution and creates a market for tradable allowances.	Cost-effective; high certainty of achieving the emissions cap; provides a continuous incentive for innovation.	Price volatility creates uncertainty for investors; potential for market power and manipulation; complex to design and administer (e.g., allowance allocation).
Green Subsidy (Positive MBI)	Direct financial payment, tax credit, or other support for environmentally beneficial actions.	Can accelerate adoption of new technologies; can be politically popular; can target specific positive outcomes.	Can be costly for public budgets; risk of supporting inefficient technologies ("picking winners"); potential for "free-ridership" (paying for actions that would have occurred anyway).
Payments for Ecosystem Services (PES) (Positive MBI)	Conditional payments to landowners for providing a defined ecosystem service.	Directly links payment to a desired environmental outcome; creates a market for previously unvalued services; can provide income to rural communities.	High transaction and monitoring costs; difficulty in measuring service provision and ensuring "additionality"; potential for elite capture.

3.2 **Market-Based Instruments (MBIs):** MBIs operate by altering economic incentives to encourage environmentally beneficial behavior, thereby internalizing externalities. They include price-based instruments like a carbon tax, quantity-based instruments like a cap-and-trade system, and positive incentives ("carrots") such as subsidies or Payments for Ecosystem Services (PES).

4. Economic Analysis of Policy Instruments for Alignment

4.1 Market-Based Instruments (MBIs)

MBIs are central to the green economy paradigm as they are designed to correct market failures by integrating environmental costs and benefits into economic decision-making.

4.1.1 **Carbon Pricing (Taxes and ETS):** The economic research is generally in agreement that the best cost-effective way to reduce GHG emissions is through carbon price. However, there are potential co-benefits and trade-offs that are mediated by policy architecture in the relationship between carbon price and biodiversity protection, thus it is not always a good one. The deliberate earmarking of carbon price income is the most direct avenue for attaining favourable results. This potential is illustrated by case studies from Colombia and Costa Rica, where national conservation and protected area initiatives are directly funded by designated percentages of fuel and carbon tax revenues. On the other hand, a carbon price that is too restrictive runs the danger of causing unhelpful changes in land use. For instance, such a strategy can inadvertently encourage the replacement of high-biodiversity grasslands with monoculture afforestation operations by valuing carbon stocks alone.

4.1.2 **Subsidies:** Reforming Environmentally Harmful Subsidies (EHS) is a crucial first step. Governments around the world are expected to give between $1.7 and $3.2 trillion in subsidies each year to industries like fossil fuels, agriculture, and fisheries that are the main causes of biodiversity loss. A "double dividend" results from reforming these subsidies: it eliminates a direct incentive for environmental deterioration and frees up public funding for beneficial expenditures.

4.1.3 **Payments for Ecosystem Services (PES):** By paying landowners for providing the public good parts of nature, PES initiatives aim to establish a market for them. With forest cover rising from 25% in 1995 to over 50% now, Costa Rica's PES program—one of the oldest in the world—is widely acknowledged for having contributed to the country's recovery from serious deforestation. More than 18,000 households have received more than $524 million from the program. Nevertheless, thorough analyses draw attention to the problem of "additionality," with numerous studies indicating that a sizable amount of payments were made to landowners who would have preserved their forests anyhow, raising the possibility that the program may not be as cost-effective as it seems.

4.2 Command-and-Control (CAC) Regulations

Even though CAC laws are frequently criticized for their static inefficiency, they are essential for accomplishing integrated goals, especially when market mechanisms are inadequate. The conventional "CAC vs. MBI" dispute is a bogus dichotomy; the two instrument types are complementary rather than interchangeable. In situations where one unit of the externality (such as a ton of CO_2) is equivalent to any other, MBIs are useful for handling fungible and divisible problems.

However, biodiversity is inherently non-fungible. A hectare of a common secondary forest is not ecologically similar to a hectare of a critically threatened wetland. An irreversible loss that cannot be "offset" is the extinction of a species. These factors make CAC tools like the formal creation of protected areas, stringent land-use zoning regulations, and outright bans on destructive activities crucial for the preservation of biodiversity

Case Study: China's Ecological Conservation Redlines (ECRs) China's ECR policy is an ambitious application of a CAC approach at a national scale. The policy delineates approximately 3.19 million square kilometres—over 30% of China's land area—as critical zones where development is strictly prohibited or severely restricted. This approach functions as a form of macro-prudential spatial planning that internalizes the value of ecosystem services by establishing a non-negotiable physical constraint on economic activity. It acts as a national insurance policy against the systemic risks of ecosystem collapse, setting the absolute boundaries within which market mechanisms can then operate.

5. Designing a Coherent Policy Mix: An effective transition requires a coherent policy mix that strategically combines instruments to maximize synergies and navigate trade-offs. The most significant source of conflict arises from competition for land, where policies promoting renewable energy can compete with biodiversity conservation goals. The principle of complementarity suggests that different instruments should be layered. For instance, a broad-based carbon tax (MBI) can be paired with strict zoning laws (CAC) to protect critical ecosystems from adverse land-use change.

Table 2: Effectiveness of Policy Instruments in Aligning Climate and Biodiversity Goals

Instrument	Climate Mitigation Effectiveness	Biodiversity Conservation Effectiveness	Economic Efficiency	Key Synergies	Key Trade-offs / Conflicts	Implementation Challenges
Carbon Tax	High (if rate is sufficient).	Indirect and variable; can be negative or positive depending on design.	High (cost-effective for GHG reduction).	Revenue can be earmarked for conservation funds (e.g., Costa Rica).	Can incentivize land use change to low-biodiversity carbon sinks (e.g., monoculture plantations).	Political unpopularity; setting the right tax level; addressing regressive impacts.
Emissions Trading System (ETS)	High (if cap is stringent).	Indirect and variable; depends on offset rules and safeguards.	High (cost-effective for GHG reduction).	Can generate revenue for conservation through allowance auctions.	Poorly designed offset projects can harm biodiversity; focus on carbon can neglect nature.	Price volatility; complexity of allocation and monitoring; risk of carbon leakage.
Green Subsidies	Moderate to High (for technology deployment).	Direct (if targeted) but can be inefficient.	Low to Moderate (risk of supporting wrong tech; free-ridership).	Subsidies for nature-based solutions (e.g., reforestation) can deliver both climate and biodiversity benefits.	Subsidies for bioenergy or large-scale renewables can create land-use conflicts with habitat conservation.	High fiscal cost; difficulty in targeting effectively; potential for market distortion.
Payments for Ecosystem Services (PES)	Direct (for carbon sequestration) but scale can be limited.	Direct (for habitat/species protection).	Variable (highly dependent on ensuring "additionality" and low transaction costs).	Programs can "bundle" payments for both carbon storage and biodiversity protection.	If narrowly focused on one service (e.g., carbon), can neglect or harm others.	High monitoring/enforcement costs; measuring services; ensuring additionality.
Protected Areas / Zoning (CAC)	Indirect (protects carbon stocks in situ).	Very High (most direct and effective	Low (from a micro perspective; does not	Protects critical, carbon-rich ecosystems	Can restrict land available for renewable	Political opposition from developmen

Instrument	Climate Mitigation Effectiveness	Biodiversity Conservation Effectiveness	Economic Efficiency	Key Synergies	Key Trade-offs / Conflicts	Implementation Challenges
		tool for habitat protection).	equalize costs).	(e.g., primary forests, peatlands), providing a mitigation backstop.	energy or other climate solutions.	t interests; enforcement costs; addressing needs of local communities.

Case Study: The European Green Deal (EGD): The EGD is the world's most comprehensive attempt to implement such an integrated policy framework. It is framed not merely as an environmental policy but as the EU's new economic growth strategy, aiming for climate neutrality by 2050. The framework's central climate tool is a powerful MBI—the EU Emissions Trading System (ETS). However, policymakers have recognized that a carbon price alone is insufficient. Therefore, the EGD complements its market-based engine with a suite of other instruments, including legally binding nature restoration targets under the EU Biodiversity Strategy for 2030, a clear use of CAC regulation. Implementation has yielded uneven progress. The EU has made strong progress on its climate goals, reducing GHG emissions by 37% between 1990 and 2023 while its GDP grew by 60% over the same period. However, progress on biodiversity is lagging significantly, with the European Environment Agency reporting that 81% of protected habitats are in a poor or bad state.

Conclusion and Policy Recommendations: This analysis reveals that no single policy instrument is a panacea for the dual crises of climate change and biodiversity loss. The conventional debate pitting market-based instruments against command-and-control regulations is a false dichotomy; both are essential components of a coherent policy architecture. While MBIs are generally more efficient for addressing fungible problems like GHG emissions, CAC regulations are indispensable for protecting non-fungible, irreplaceable natural capital. An effective transition requires a sophisticated, context-specific policy mix.

Based on this analysis, the following recommendations are proposed:

1. **Prioritize the Reform of Harmful Subsidies:** The most economically efficient and fiscally prudent first step is to identify, phase out, or reform subsidies that harm the environment. This action yields a "double dividend" by removing a key driver of degradation while freeing up public funds for positive investments.
2. **Design "Biodiversity-Smart" Carbon Pricing:** Carbon pricing mechanisms should be implemented with explicit provisions to support biodiversity, including

earmarking a significant portion of revenues for dedicated conservation funds and ensuring that carbon offset markets include stringent biodiversity safeguards.

3. **Establish a Foundation of Non-Market Protections:** The certainty required for biodiversity conservation necessitates a strong foundation of CAC regulations, including expanded networks of protected areas and robust, science-based land-use planning frameworks to serve as a non-negotiable safety net for critical natural capital.
4. **Develop Integrated Sectoral Roadmaps:** Move beyond single-issue regulation by developing integrated policies for key economic sectors like agriculture, energy, and infrastructure that embed both quantitative climate and biodiversity targets into sectoral planning.
5. **Invest in Integrated Governance and Institutional Capacity:** Foster formal mechanisms for cross-ministerial collaboration and utilize integrated assessment frameworks to systematically evaluate all major policies for their potential co-benefits and trade-offs across the climate-biodiversity nexus before implementation.

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REDEFINING COEXISTENCE: A SOCIO-ECOLOGICAL ANALYSIS OF HUMAN-WILDLIFE INTERACTIONS IN THE ERA OF THE CLIMATE CRISIS

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Abstract: The growing climate crisis is causing significant changes to ecosystems and worsening the human-wildlife interface, which is increasing conflict and upending conventional conservation paradigms. This essay argues that a fundamental reinterpretation of coexistence is necessary in the age of climate change, presenting a socio-ecological analysis of human-wildlife interactions. A more comprehensive and flexible framework based on the ideas of socio-ecological systems, community-based conservation, and the One Health approach replaces oversimplified models of conflict mitigation. Through a review of previous research and case studies, this study investigates how changes in wildlife behaviour and resource availability brought on by climate change are causing more and more interactions with man. It critically looks at how social, economic, and cultural factors influence how people tolerate and view wildlife in their communities. We put forth a reimagined, proactive model of cohabitation.

Keywords: Human-Wildlife Coexistence, Climate Crisis, Socio-Ecological Systems, Community-Based Conservation, Climate Resilience.

Introduction: According to Treves and Bruskotter (2014), the language of conflict has long dominated the narrative of human-wildlife interaction. Predatory big cats and elephants that raid crops are just two examples of how wildlife close to human settlements is frequently presented as a threat that needs to be reduced or managed (Nyhus, 2016). On the other hand, this paradigm is being critically re-examined due to the climate crisis's unparalleled scope and speed. In addition to changing landscapes, extreme weather events, changing precipitation patterns, and rising temperatures are forcing wildlife to find food, water, and suitable habitats in new areas (IPCC, 2022). The redistribution of species due to climate change is unavoidably increasing the frequency and intensity of interactions with human communities, intensifying pre-existing tensions and generating new battlefields (Scheffers et al. (2016).

The conventional methods of handling human-wildlife conflict, which frequently rely on reactive strategies like physical barriers, compensation plans, or lethal control, are becoming less and less effective in this new reality (Redpath et al. (2013). According to Madden (2004), these approaches often fall short in addressing the root causes of conflict and have the potential to disenfranchise local communities, thereby undermining long-term conservation objectives. It is critical to adopt a more proactive and nuanced strategy that goes beyond conflict resolution to foster true and lasting coexistence (Carter and Linnell, 2016).

In order to redefine human-wildlife coexistence as a dynamic and adaptive process of negotiation and shared living within a socio-ecological system, rather than as a static state of harmony, this paper makes the case (Frank et al. in 2019). In light of the current climate crisis, we believe that a thorough comprehension of the complex feedback loops between social and ecological factors is essential for fostering coexistence. Recognizing the needs and rights of both human and non-human populations, as well as actively working to increase their resilience in the face of climate change, calls for a paradigm shift.

The Climate Crisis as a Magnifier of Human-Wildlife Interactions: The Great Barrier Reef's bleaching coral reefs and the melting Himalayan glaciers are just two examples of how climate change is leaving its mark on the world (IPCC, 2022). Habitat Loss and Degradation: As a result of shifting climatic zones, many species are finding their traditional habitats unsuitable, forcing them to relocate to new areas that are frequently already inhabited by humans (Chen et al. 2011). Unpredictable interactions with human activities are a result of altered behaviour and phenology brought on by temperature and precipitation changes that impact foraging, migration, and breeding seasons (Cohen et al. (2018). Herbivores may seek water and food in agricultural landscapes during extended droughts, for example, and their predators will unavoidably follow. The primary cause of wildlife migration into human-dominated landscapes, where agricultural crops and livestock provide an accessible environment, is the scarcity of food and water brought on by climate change.

A Socio-Ecological Framework for Redefined Coexistence: A socio-ecological systems (SES) approach is crucial to navigating the intricacies of interactions between humans and wildlife in a changing climate. An SES framework acknowledges the close interdependence of natural and human systems and the need to comprehend their dynamic interaction in order to develop sustainable solutions (Berkes, Colding, and Folke, 2003; Ostrom, 2009). This entails examining ecological dynamics, or how species distribution, population dynamics, and behaviour are being impacted by climate change, in the context of coexisting humans and wildlife. Social and Economic Drivers: Analysing the means of subsistence, susceptibilities, and power relationships of populations coexisting with wildlife. This entails being aware of their cultural values surrounding wildlife, their reliance on natural resources, and their risk perceptions (Dickman, 2010). Governance and Institutions: Evaluating how formal and informal organizations, ranging from national wildlife agencies to local community councils, shape society.

Pillars of Redefined Coexistence in the Climate Era: Building on a socio-ecological foundation, we propose a redefined model of coexistence centred on three key pillars:

Community-Based Conservation and Climate-Resilient Livelihoods: It is necessary to foster true coexistence within communities rather than imposing it from the outside. Local residents are given the tools they need to actively manage their natural resources through community-based conservation (CBC) (Brooks et al. (2013). The diversification and strengthening of local livelihoods to lessen reliance on activities that are susceptible to both climate change and wildlife-related damages should be the main goals of CBC initiatives in the context of the climate crisis. According to Roe et al., this can entail encouraging ecotourism, climate-smart agriculture, or the sustainable harvesting of non-timber forest products. in 2015. putting in place early warning and community-led monitoring systems to keep tabs on wildlife movements and foresee possible conflict situations. establishing and putting into practice socially acceptable, economical, and locally appropriate conflict mitigation strategies. Through a direct connection between conservation results and concrete advantages for nearby communities, CBC can cultivate a feeling of pride.

The One Health Approach: Interconnected Well-being: The idea of "One Health" acknowledges the interdependence of environmental, animal, and human health (Gibbs, 2014; Zinsstag et al. (2011). Because changes in ecosystems can result in the emergence and spread of zoonotic diseases, the climate crisis serves as a stark reminder of this interdependence (Daszak, Cunningham, and Hyatt, 2000). The following are components of a One Health strategy for coexisting with wildlife. Integrated surveillance and monitoring of diseases at the human-wildlife-livestock interface. encouraging landscape management techniques that lower the risk of disease transmission and preserve ecosystem health. In order to permit safe movement and lessen forced proximity to human settlements, this involves preserving and rehabilitating wildlife corridors (Hassell et al. (2017). cooperation between conservationists, veterinarians, and public health officials to address health risks in a comprehensive manner. A One Health perspective on coexistence can help us emphasize the mutual advantages and vulnerabilities of preserving robust and healthy socio-ecological systems.

Adaptive Governance and Policy Integration: A supportive and adaptable governance framework that can change with the climate crisis is necessary to redefine coexistence. This involves incorporating climate change adaptation into conservation and wildlife management strategies (Hannah, 2010). According to Ribot, Agrawal, and Larson (2006), decentralizing decision-making can empower local institutions and guarantee that management strategies are sensitive to local conditions and needs. encouraging cooperative governance frameworks that unite various stakeholders to jointly develop and execute solutions, such as local communities, government agencies, private sector players, and non-governmental organizations (Ansell & Gash, 2008). creating creative funding sources to support long-term coexistence projects, such as conservation trust funds or payments for ecosystem services (Wunder, 2015).

Case Studies in Redefined Coexistence: Promising instances of redefined coexistence are appearing globally, despite the significant challenges. According to NACSO (2022) and Boudreaux and Nelson (2011), community conservancies in Namibia have effectively combined wildlife management with tourism businesses, giving local communities immediate financial advantages and promoting a conservation culture. Community-led projects in India's Western Ghats are reducing human-elephant conflict by tracking elephant movements and giving farmers real-time alerts by combining traditional knowledge with contemporary technology (Naha, Sathyakumar, & Rawat, 2020; Athreya et al., 2016). A dedication to strengthening local communities and acknowledging the inextricable connection between human well-being and a healthy natural environment unites these case studies, despite the diversity of their respective contexts.

Conclusion and Future Directions: The climate crisis is a watershed moment for conservation, demanding a fundamental shift in how we perceive and practice human-wildlife coexistence. The era of viewing wildlife as a liability to be managed is over. We must now embrace a paradigm that recognizes wildlife as an integral part of resilient and healthy landscapes, and local communities as the frontline stewards of this shared heritage. Redefining coexistence is not a simple task; it requires a long-term commitment to interdisciplinary research, collaborative action, and a willingness to challenge long-held assumptions. Future research should focus on quantifying the social and ecological outcomes of different coexistence strategies, developing robust indicators for measuring success, and scaling up successful models to new geographies (Pooley et al., 2017).

Ultimately, the journey towards a redefined coexistence is a journey towards a more just and sustainable future. It is a recognition that in the face of a global crisis, our own survival is inextricably linked to the well-being of the planet's rich and diverse tapestry of life. By fostering a new relationship with the wild, one built on respect, reciprocity, and a shared sense of place, we can navigate the challenges of the climate crisis and forge a path towards a future where both humans and wildlife can not only survive but thrive.

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COMPARATIVE ANALYSIS OF ALGAL DIVERSITY IN DIFFERENT STRETCHES OF THE SHIVNA RIVER AT MANDSAUR DISTRICT, MADHYA PRADESH, INDIA

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Abstract: The Shivna River, a tributary of the Chambal, supports a rich diversity of algal communities influenced by ecological variations and anthropogenic pressures. An ecological study was conducted at three selected sites of Shivna River in Mandsaur city from July 2011 to June 2013. Water and algal samples were collected monthly and analyzed using standard methods. A total of 254 taxa belonging to 105 genera were identified, including Chlorophyceae (129 taxa, 53 genera), Bacillariophyceae (35 taxa, 19 genera), Euglenineae (11 taxa, 4 genera), and Cyanophyceae (53 taxa, 29 genera). Seasonal variation was evident with higher algal abundance during pre-monsoon and post-monsoon periods, while nutrient-rich effluents contributed to localized algal blooms. The findings highlight the Shivna River as an ecologically significant freshwater system requiring conservation measures.

Keywords: Algal diversity, Shivna River, Cyanophyceae, Chlorophyceae, Bacillariophyceae, freshwater ecology.

Introduction: Freshwater ecosystems are critical habitats supporting diverse flora and fauna, including algae, which are key primary producers and bioindicators of water quality [1], [2]. Algal biodiversity provides insights into ecological health, nutrient status, and anthropogenic stress on riverine ecosystems [3]. In Madhya Pradesh, several rivers such as the Chambal and its tributaries harbor rich algal communities, yet studies remain limited in scope [4]. The Shivna River, a tributary of the Chambal, originates in Chittorgarh (Rajasthan) and traverses 139 km before merging at Borkheda in Mandsaur district. The river sustains agriculture, domestic use, and cultural practices, including rituals at the Pashupatinath temple. However, effluents from urban settlements and industries exert ecological pressures that directly influence algal composition and abundance. This study documents the algal flora of the Shivna River at Mandsaur across three ecologically distinct sites from July 2023to June 2025, analyzing species diversity, seasonal variations, and ecological implications.

Study Area And Sampling Sites

Three ecologically distinct sampling sites were selected:

- Site I (Ramghat, RG): Upstream near Ramghat dam, least disturbed, sandy riverbed, presence of macrophytes such as *Potamogeton*, *Vallisneria*, and *Lemna*.
- Site II (Pashupatinath, PN): Midstream, adjacent to Pashupatinath temple, subject to heavy human interference (bathing, washing).
- Site III (Near Railway Overbridge, NRO): Downstream, moderately disturbed, receiving starch factory effluents, seasonal growth of *Eichhornia crassipes*.

MATERIALS AND METHODS:

A. Water Sampling: Water samples were collected monthly (July 2011–June 2013) at 0.5–0.7 m depth. On-site measurements included water temperature, pH, and transparency. Samples were preserved at 4 °C, acidified with HNO_3 (pH < 2), and transported in iceboxes. Standard APHA (2012) methods were used for physicochemical analysis [6].

B. Algal Sampling: Algal samples were collected monthly from surface to 0.5 m depth across ~500 m stretches per site. Epilithic, epiphytic, and planktonic forms were included. Macrophytes, submerged twigs, stones, and detritus were examined for attached algae. Samples were preserved in 4% formalin and examined under compound microscopes (10×, 40×, oil immersion). Identification followed standard monographs [7]–[12]. Abundance was categorized as isolated, rare, common, very common, or abundant [13].

RESULTS AND DISCUSSION:

A. General Overview of Algal Diversity: The present investigation on the algal flora of the Shivna River revealed remarkable ecological variability across space and time. Over a period of two years (2011–2013), a total of 254 taxa under 105 genera were recorded, representing four major classes: Chlorophyceae (129 taxa, 53 genera), Bacillariophyceae (35 taxa, 19 genera), Euglenophyceae (11 taxa, 4 genera), and Cyanophyceae (53 taxa, 29 genera).This diversity demonstrates the Shivna River's potential as a biodiversity hotspot, despite being a relatively small tributary compared to larger river systems such as the Chambal and Narmada. However, marked spatiotemporal differences in composition and abundance highlight the influence of hydrological cycles, nutrient inputs, and anthropogenic pressures on algal community structure.

B. Taxonomic Composition and Dominance Patterns

1) Chlorophyceae: Chlorophyceae dominated the algal flora both in richness and representation. Filamentous forms (*Spirogyra, Cladophora, Ulothrix*) were abundant at Ramghat (Site I), where reduced disturbance and sandy substrata favored their proliferation. Planktonic genera such as *Scenedesmus*, *Pediastrum*, and *Cosmarium* were more frequent in midstream and downstream stretches, often associated with nutrient enrichment. The dominance of Chlorophyceae mirrors findings from the Narmada [4] and Chambal [5], where green algae thrive in moderately enriched waters, acting as indicators of mesotrophic conditions.

2) Bacillariophyceae: Diatoms formed the second largest group, with 35 taxa identified. Common genera included *Navicula, Nitzschia, Synedra, Fragilaria,* and *Cyclotella*. Their abundance was relatively higher during winter and at less polluted sites, indicating their preference for well-oxygenated conditions. The occurrence of pollution-tolerant diatoms like *Nitzschia palea* at Site II (Pashupatinath) suggests moderate organic loading, likely from ritual bathing and washing activities. These patterns are consistent with observations from the Ganga [14] and Betwa [15], where diatom assemblages reflect the dual impact of seasonal flow and nutrient influx.

3) Euglenophyceae: Although least represented, Euglenophyceae were ecologically significant. Genera such as *Euglena, Phacus,* and *Trachelomonas* proliferated mainly at Site II and Site III, where organic enrichment from detergents, domestic discharges, and effluents was pronounced. Their presence signals saprobic conditions, corroborating earlier reports from organically enriched rivers [16].

4) Cyanophyceae: Cyanophyceae contributed substantially to the diversity (53 taxa, 29 genera). Prominent taxa included *Oscillatoria, Microcystis, Anabaena, Lyngbya,* and *Chroococcus*. Blooms of *Microcystis aeruginosa* and *Oscillatoria limosa* were recorded during summer in downstream stretches, coinciding with low flow and high organic matter. These bloom-forming species are classic indicators of eutrophication and organic pollution [17].

C. Seasonal Variations in Algal Flora

1) Winter (November–February):

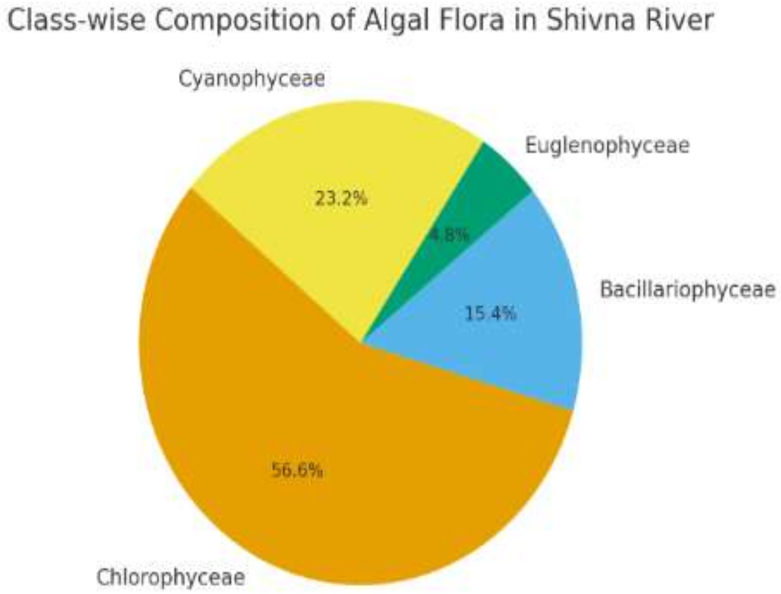
Winter supported maximum algal diversity and density across all sites. Favorable temperatures (18–22 °C), stable dissolved oxygen levels, and reduced turbidity promoted both planktonic and benthic forms. Diatoms were particularly dominant, reflecting well-oxygenated and nutrient-balanced conditions. Sensitive green algae like *Closterium* and *Spirogyra* also flourished at Site I.

2) Monsoon (July–September)

The monsoon season caused a decline in algal abundance due to dilution from high rainfall, increased turbidity, and elevated flow velocity. Epilithic forms like *Cladophora* and *Oedogonium* persisted by anchoring to submerged substrates. Cyanophyceae were relatively suppressed during peak monsoon but resurged in the post-monsoon period. This dilution effect aligns with findings from the Chambal River, where monsoonal floods drastically reduce planktonic density [5].

3) Summer (March–June)

Summer conditions (30–38 °C, low flow, high evaporation) encouraged blooms of Cyanophyceae, particularly *Microcystis* and *Oscillatoria*. Nutrient enrichment from anthropogenic discharges was exacerbated by reduced dilution, creating stagnant microhabitats. Euglenoids also proliferated, especially near temple ghats and effluent-affected downstream stretches. The summer dominance of Cyanophyceae matches studies on the Gomti River [18], highlighting a universal tendency of blue-green algae to exploit nutrient-rich, stagnant summer waters.



D. Site-wise Ecological Comparisons

1) Site I: Ramghat (RG)

- Least disturbed site, upstream near Ramghat dam.
- Clearer water, sandy substrata, and aquatic macrophytes (*Potamogeton, Vallisneria*).
- Dominated by sensitive taxa: *Spirogyra, Closterium, Ulothrix,* and diverse desmids (*Cosmarium, Staurastrum*).
- High diatom richness during winter.
- Reflected relatively good ecological status, close to mesotrophic conditions.

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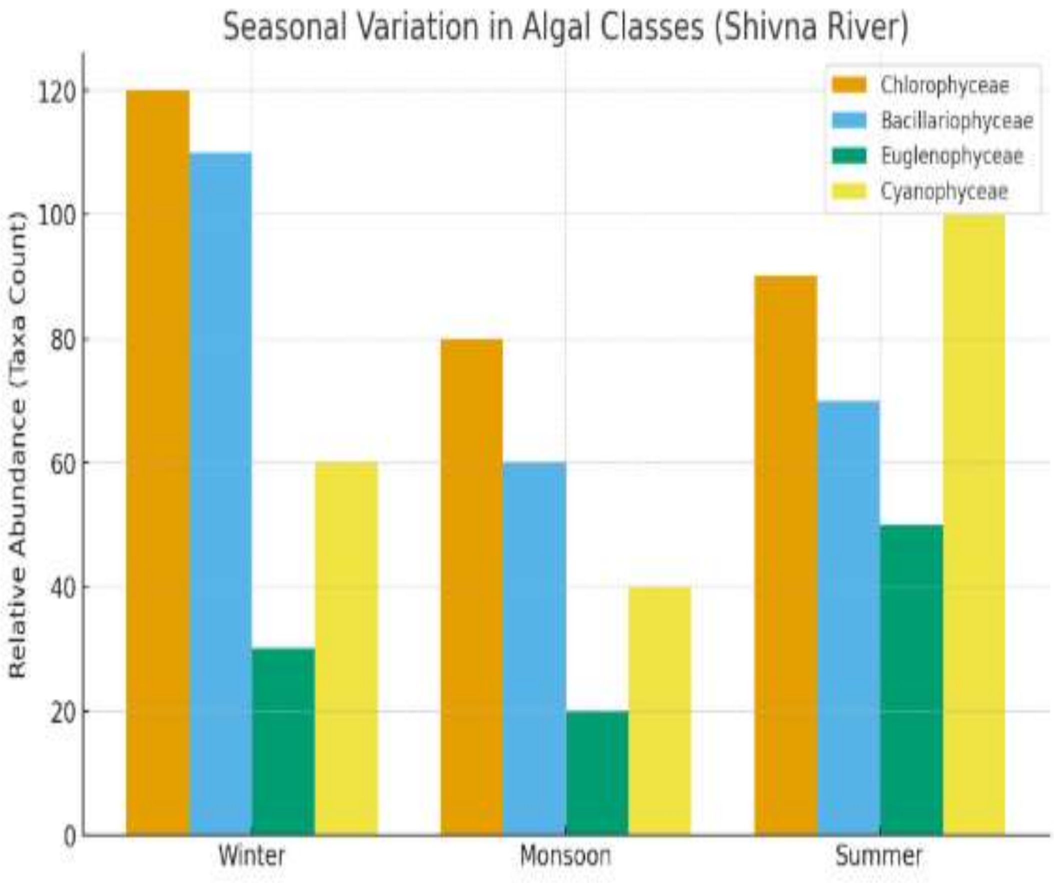

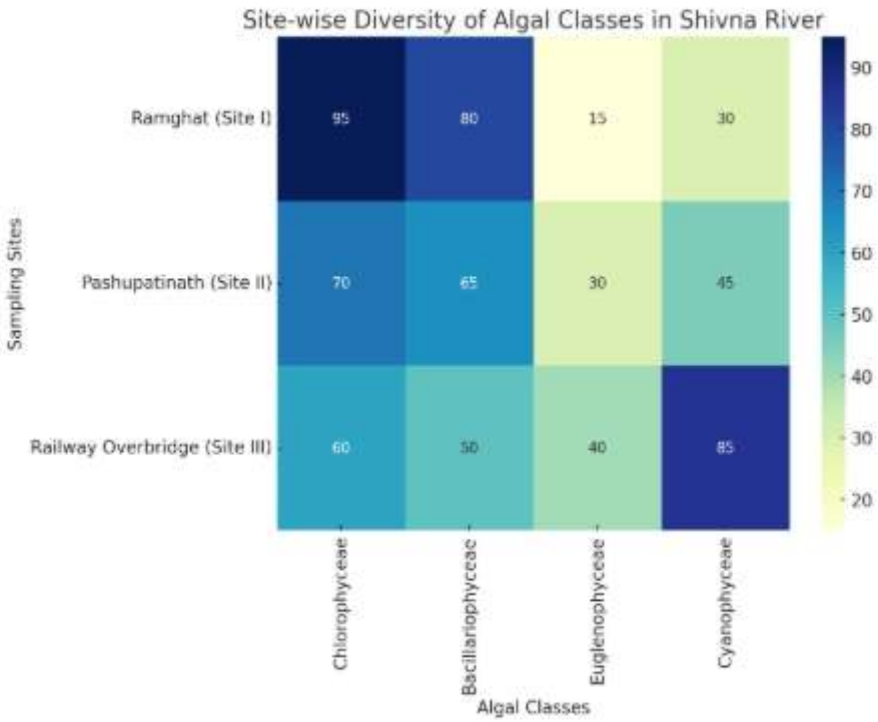

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2) Site II: Pashupatinath (PN)

- Midstream near temple, heavily influenced by anthropogenic pressures (bathing, washing, ritual offerings).
- Abundant Euglenophyceae (*Euglena, Phacus*), along with pollution-tolerant diatoms (*Nitzschia, Navicula*).
- Seasonal fluctuations: winter diatoms replaced by summer blooms of *Oscillatoria* and *Microcystis*.
- Indicated moderate organic pollution, aligning with β-mesosaprobic to polysaprobic status.

3) Site III: Near Railway Overbridge (NRO)

- Downstream, affected by starch factory effluents.
- Dominated by bloom-forming Cyanophyceae (*Microcystis, Oscillatoria, Lyngbya*).
- Growth of floating weeds (*Eichhornia crassipes, Pistia stratiotes*) enhanced organic accumulation and plankton proliferation.
- Showed maximum saprobic conditions, with frequent algal blooms in summer.

E. Bioindicator Role of Algae

The study reinforces the utility of algae as bioindicators of water quality.

- Chlorophyceae and diatoms indicated relatively clean and moderately enriched waters (Site I).
- Euglenophyceae marked organic enrichment and anthropogenic disturbances (Site II).
- Cyanophyceae dominated in organically polluted waters, signaling eutrophication (Site III).

Similar conclusions have been drawn in studies on the Sabarmati [19], Ganga [14], and Betwa [15], underscoring the universality of algal assemblages as ecological markers.

F. Comparative Context with Other Studies: The richness (254 taxa) recorded in Shivna is comparable to findings from the Betwa (240 taxa) [15] and higher than the Gomti (198 taxa) [18]. The strong seasonal fluctuations resemble those reported from the Chambal [5], confirming that climatic cycles and hydrological regimes are primary drivers of algal ecology. However, the localized dominance of Euglenophyceae and Cyanophyceae at Sites II and III underscores the intensifying role of site-specific human impacts. This dual regulation—natural seasonality and anthropogenic stress—defines the ecological signature of the Shivna River.

G. Ecological Implications:

1. Upstream resilience: Site I retains natural taxa, demonstrating potential for conservation.

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2. Cultural pressures: Temple-associated disturbances at Site II necessitate eco-friendly management of rituals and waste.
3. Industrial impact: Effluent-driven eutrophication at Site III highlights the urgency for effluent treatment and ecological restoration.

Conclusion: The Shivna River supports rich algal diversity, reflecting ecological variability across sites. While upstream stretches sustain sensitive taxa, midstream and downstream areas show dominance of pollution-tolerant species due to anthropogenic and industrial disturbances. Regular monitoring of algal flora is essential for river management and water quality assessment. The study confirms algae as effective bioindicators and underscores the need for sustainable management of small tributaries like the Shivna.

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COMMUNITY FORESTRY: A PRACTICAL SOLUTION TO FIGHT CLIMATE CHANGE IN RURAL MADHYA PRADESH

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Abstract: Rural communities in Madhya Pradesh (M.P.), a state at the forefront of the climate crisis with substantial forest cover and high climate vulnerability. Community forestry is portrayed in this paper as a potent, realistic, and socio ecologically based approach to climate change adaptation and mitigation in this area. We examine how giving local communities rights, resources, and responsibilities can turn forests into strong carbon sinks and increase livelihood resilience, going beyond the conventional definition of Joint Forest Management (JFM). The study makes the case that sustainable management of Non-Timber Forest Products (NTFPs), regeneration of degraded lands, and community-led forest protection offer two benefits: diversifying local economies to prepare for the effects of climate change and sequestering carbon to fight its causes. For M.P, we suggest a novel "Community Forestry 2.0" framework.

Keywords: Community Forestry, Climate Change Adaptation, Climate Change Mitigation, Forest Rights Act (FRA), Joint Forest Management (JFM), Carbon Sequestration.

Introduction: Madhya Pradesh, known as the "Heart of India," is distinguished by a significant paradox. Despite having the nation's largest forest cover, which serves as a vital carbon sink, its sizable rural and tribal populations make it particularly vulnerable to the effects of climate change (GoMP, 2022). Agrarian livelihoods are already being disrupted and natural resources are under tremendous strain due to unpredictable monsoons, more frequent droughts, and rising temperatures (Mishra and Lilhare, 2016). The M.P forests in this context. are not only important natural resources but also vital defenses against shocks brought on by climate change. India's forest management has been a largely top-down, state-led endeavor for many years. Despite being a step toward decentralization, the Joint Forest Management (JFM) program, which was started in the 1990s, frequently led to unfair benefit sharing and little community empowerment (Kumar, 2002). A more robust and equitable approach is now required due to the growing climate crisis. A paradigm change is required.

This study contends that the most workable and expandable approach to climate action in rural Madhya Pradesh is a resurgent and rights-based model of Community Forestry (CF). Through improved carbon sequestration in community-protected forests, CF is thought to provide a potent dual benefit of mitigating climate change and adapting to it by bolstering and diversifying local livelihoods.

The Climate Change Challenge in Rural Madhya Pradesh: The impacts of climate change in Madhya Pradesh are no longer a future projection but a lived reality for its rural inhabitants. Key vulnerabilities include:

Agricultural Disruption: Changes in rainfall patterns, including delayed monsoons and intense, short-duration precipitation events, lead to crop failures and soil erosion, undermining the primary source of rural income (Rathore et al., 2015).

Water Scarcity: Declining and unpredictable rainfall, coupled with higher temperatures, is leading to the depletion of groundwater tables and the drying up of surface water bodies, creating acute shortages for both domestic use and agriculture.

Increased Forest Stress: Higher temperatures and prolonged dry spells increase the risk and intensity of forest fires, which not only release vast amounts of stored carbon but also destroy the forest resources upon which communities depend (Singh & Lamba, 2021).

***Livelihood Insecurity*:** These ecological stressors directly translate into heightened economic distress, forcing seasonal migration and increasing poverty among communities with a high dependence on natural resources.

Community Forestry as a Dual Climate Solution : By establishing a positive feedback loop in which ecological restoration and human well-being reinforce one another, community forestry directly addresses these issues.

3.1. Mitigation: Strengthening Carbon Sinks from the Ground Up

Communities are the best stewards of their forests when they have a direct interest in its well-being.

Reduced Deforestation and Degradation: Empowered communities actively patrol and defend their forests against illegal logging, encroachment, and fires. This results in significant mitigation outcomes. According to Chhatre and Agrawal (2009), the quickest method to stop carbon emissions is to protect the current forest cover.

Afforestation and Regeneration: Communities frequently take the initiative to plant native species and restore degraded common lands, thereby actively creating new carbon stocks. Higher plantation survival rates are guaranteed by their local ecological knowledge than by many top-down government initiatives. Potential for Carbon Finance: Healthy community forests may be connected to carbon markets like REDD+ (Reducing Emissions from Deforestation and Forest Degradation), which would offer a new source of income for the community and a direct financial incentive for conservation (Poffenberger, 2015).

3.2. Adaptation: Building Socio-Ecological Resilience: Building rural communities' adaptive capacity is arguably CF's most important contribution in the climate era. Diversification of Livelihood through NTFPs: Non-Timber Forest Products (NTFPs) such as Mahua, Tendu leaves, Amla, honey, and medicinal plants are abundant in healthy forests. When agricultural crops fail due to drought or unpredictable rain, these products serve as a natural insurance policy and are a vital source of income, particularly for women (Shackleton and Pandey, 2014).

Enhancing Ecosystem Services: Local hydrological cycles are improved by community-managed forests, which also improve groundwater recharge and sustain stream flow, both of which have a direct positive impact on agriculture. A healthy forest canopy also moderates local temperatures and conserves soil moisture. Developing Social Capital: Group forest management improves social cohesion, encourages group action, and fortifies local institutions. This "social capital" is an essential resource that helps communities plan ahead and react forcefully to any emergency, including natural disasters brought on by climate change.

An Innovative Framework for Community Forestry 2.0 in M.P.: To realize the full potential of CF, Madhya Pradesh must move beyond the limitations of traditional JFM. We propose a "Community Forestry 2.0" framework built on the following pillars: Rights and Tenure Security: The foundation of true CF is legal empowerment. The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (FRA) must be vigorously implemented by the state. By giving communities, the legal right to manage, safeguard, and utilize their traditional forests, the recognition of Community Forest Resource (CFR) rights turns them from passive recipients into active decision-makers.

Integrated Livelihood Development: Don't just gather NTFPs. Encourage communities to set up local processing and value-adding facilities, especially women's Self-Help Groups (SHGs). This can be accomplished by connecting them to government initiatives such as the Van Dhan Yojana, which seeks to establish businesses based on NTFPs. This guarantees that the community retains the majority of the value created by forest products. Financial and technological accessibility: Make it easier for Village Forest Committees to receive funding. This can include money from CSR initiatives, climate adaptation programs, and systems for redistributing carbon credit profits to local communities. Further empowering communities can be achieved through simple technologies such as mobile apps for market price information and GIS mapping for developing sustainable harvesting plans.

Illustrative Case: The Revival of 'Vanpura' Village: Consider the hypothetical village of 'Vanpura' in the Satpura landscape of M.P. Ten years ago, the surrounding forest was degraded, a local stream ran dry by February, and many households relied on seasonal migration for income. Through a concerted effort, the village successfully claimed its Community Forest Resource rights under the FRA. The newly formed Village Gram Sabha committee developed a forest management plan.

Today, the results are tangible. Community patrols have halted illegal felling, and natural regeneration has thickened the forest canopy. The Gram Sabha, with support from a local NGO, facilitated the setup of a Mahua processing unit, which now produces and sells high-value products like jam and syrup, providing year-round income to women's SHGs. The revived forest has improved groundwater retention, and the village stream now holds water until April, allowing for a second crop of vegetables. 'Vanpura' has not only contributed to carbon sequestration but has fundamentally reduced its vulnerability to climate shocks.

Conclusion and Policy Recommendations: Despite not being a cure-all, community forestry is among Madhya Pradesh's most practical, affordable, and equitable ways to combat the climate crisis. Economic development, social justice, and environmental preservation are all intertwined objectives that are addressed. We have enormous potential to address climate change if we return control of forests to the people who live there and rely on them.

Key Policy Recommendations for Madhya Pradesh: Under the Forest Rights Act, establish a statewide initiative to acknowledge and defend Community Forest Resource (CFR) rights. Include community forestry as a central element of the state's climate change action plan, with specific funding and goals.Create a strong support structure for NTFP-based livelihoods with an emphasis on village-level enterprise development, value addition, and market connections.Make sure that the benefits go straight and openly to the community institutions by streamlining the process for community forests to obtain climate finance.By promoting community forestry, Madhya Pradesh can set an example for resilient and inclusive development that the rest of India and the world can follow.

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IMPACT OF PARTICULATE MATTER (PM_1, $PM_{2.5}$, AND PM_{10}) ON BUTTERFLY DIVERSITY AND THE ROLE OF HOME GARDENS IN CONSERVATION: A CASE STUDY FROM KANPUR, INDIA

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Abstract: Rapid urbanization and industrialization in Kanpur, Uttar Pradesh, have led to increased concentrations of particulate matter (PM_1, $PM_{2.5}$, and PM_{10}), significantly affecting both environmental health and biodiversity. Butterflies, being sensitive bioindicators, reflect changes in air quality and habitat condition. The present study investigates the relationship between particulate matter and butterfly diversity across selected urban and semi-urban sites in Kanpur. A total of 38 species from five families were documented, with Nymphalidae and Pieridae as the most dominant groups. Air quality data obtained from CPCB indicated that $PM_{2.5}$ levels frequently exceeded WHO guidelines, ranging between 45–150 $\mu g/m^3$. Statistical analysis revealed a strong inverse correlation between particulate concentrations and butterfly abundance. However, residential areas with well-vegetated **home gardens** exhibited greater species richness and higher visitation rates, suggesting that small-scale green habitats can serve as ecological refuges amid pollution stress. The study highlights the dual role of home gardens in **mitigating air pollution** and **supporting butterfly conservation**, offering a practical model for enhancing urban biodiversity under changing climatic conditions.

Keywords: Particulate matter, Butterflies, Air pollution, Bio indicators, Conservation etc.

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