A Comprehensive Review of Ecological and Administrative Dimensions of Bethuadahari Wildlife Sanctuary

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I. INTRODUCTION

The Bethuadahari Wildlife Sanctuary (BWS), nestled in the Nadia District of West Bengal, India, represents a critical ecological anomaly in the Gangetic plains. While the global and regional narrative often focuses on the vast, contiguous forests of North Bengal or the Sundarbans, BWS stands as a defiant counter-trend to the rapid shrinkage of natural habitats in human-dominated landscapes (Prakash et al., 2018). Spanning a modest yet vital 67.16 hectares, this protected area was officially established in 1980. Its primary mandate was the preservation of the central alluvial tract's unique flora, specifically the rapidly depleting Sal (*Shorea robusta*) and the distinct Sal-Conocarpus associations. According to the classification by Champion and Seth, this habitat is defined as a tropical mixed deciduous forest, a vegetation type that has faced extreme pressure from agricultural conversion and timber extraction (Armina Sultana et al., 2022).

The sanctuary's geography is both its strength and its greatest challenge. The Churni River, a distributary of the Bhagirathi, meanders along its southern fringe, providing a natural moisture gradient and a vital water source for the resident fauna. Conversely, its eastern and western boundaries are defined by sharp edges where forest meets high-intensity agriculture and dense human settlements. This "island" nature of BWS makes it a prime candidate for studying the "edge effect" and the dynamics of isolated biodiversity patches.In contemporary conservation discourse, significant academic energy has been directed toward large-scale ecosystems, such as the fish diversity studies in the Tanguar Haor wetland of Bangladesh (a Ramsar site) or the delineation of eco-sensitive zones surrounding the Jhilmil Jheel Conservation Reserve. In contrast, Bethuadahari has remained relatively under-researched, despite its role as a "biological lifeboat" for species like the Spotted Deer (*Axis axis*), the Indian Rock Python (*Python molurus*), and various migratory birds.

As urban sprawl continues to isolate green patches across India, the administrative and ecological management of Bethuadahari serves as a vital case study. Detailed longitudinal monitoring and rigorous ecological research are no longer optional; they are essential prerequisites for ensuring habitat sustainability. This review aims to bridge the current knowledge gap, positioning BWS as a beacon for future research into how small-scale sanctuaries can mitigate the impacts of encroachment, invasive species, and climate-induced stressors in a fragmented world.

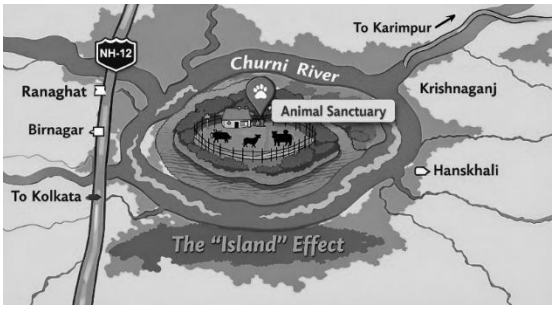

Figure: Sanctuary Location in Nadia District

II. STUDY AREA AND SIGNIFICANCE

Located in West Bengal, India, Bethuadahari Wildlife Sanctuary harbours a variety of forest types including Tropical moist deciduous forest with Sal Shorea robusta, Semievergreen with Terminalia tomentosa, and Subtropical pine forest with Pinus roxburghii. Sal dominates pure stands on sandy soils, Terminalia produces a mixed forest on mixed soil, and Pine with natural regeneration survives on higher altitudes as per historical distribution (Prakash et al., 2018). The sanctuary lies under the climate of the

Gangetic plains. The monthly mean temperatures fluctuate from 10°C to 40°C, while annual rainfall averagesthe range of 400mm to 2000mm, peaking from June to September (Geleta Erena & G. Yesus, 2021). It maintains connections with and around another large tract of forest (Bhagwanpur woodland). Adjacent forests are threatened by unplanned colony development; moreover, villagers focus on surface water bodies for their hydric needs, which may potentially impact vegetation cover and forest health. Certainly, its forests provide ecosystem services, ranging from fire, land slide & flood control, regulation of climate, construction timber, fuel, and fodder through health & leisure facilities to collection of NTFP.

III. HISTORICAL TRAJECTORY AND POLICY CONTEXT

The administrative history and ecological policies of West Bengal, especially pertaining to the forest environment, have unfolded over time. Significant landmarks in colonial as well as independent India have marked the provincial landscape. Historical documents have borne testimony to policy evolution in the environmental domain up to the present period, and the state of forests in Bengal has often been highlighted. The Bengal Forest Act of 1878, and its subsequent revisions, have brought to bear several legislative provisions in respect of selection of forest areas, types of trees allowed for clearance and felling, time periods of forest surveys and for communication of results, etc. Yearly statistics have shed light on yearly increase in or area cut or sale serially, in the province. Administrative evolution can be traced back to the introduction of forest administration and annual estimates of area under forest cover.

The year 1896 marked the introduction of “Bengal Forest Curator” as Forest Administrative Officer, then introduced again in 1901. Eco-history of “Superserial” from 1904 to 1911 also provides considerable insight into associates in ecological documentation. With the official vessel “Bengal Forest Memoirs,” rapid dissemination of sacrificial material began in 1899. The policy framework of environmental ecology requires to be considered in diverse aspects.

In the post-colonial (1947) period, chief scientists and practitioners have devised and executed programs across the state, during an era in which government and administrative landmarks have also abounded. The charters of the state's indicate explicit provisions for biodiversity conservation and perspectives are made available at regular intervals. Eco-preservation remains an area of priority (Ghosh & Ghosal, 2019).

IV. BIODIVERSITY AND HABITAT ECOLOGY

The sanctuary harbors a diverse flora comprising 811 species in 448 genera and 82 families, as per the latest survey undertaken by the West Bengal Forest Department. The flora of the sanctuary is dominated by the tropical dry deciduous type and is characterized by a diverse tree and shrub vegetation. From a habitat point of view, there is good growth of sal trees, Terminalia elliptica and Tectona grandis. Sal forests occur from the north-western parts of the area to the southern parts. The perception of seasonality is highly marked, with spring, summer, rainy and winter seasons occupying well-defined positions. Spring occupies the month of February when new leaves appear. During March-April, trees like Anogeissus latifolia, Lannea coromondelica, Dillenia indica, etc. shed their leaves. The representation of distinctive flowering plants from the sanctuary in the Assam Plant Atlas prepared by the Botanical Survey of India is noteworthy, because these species are conspicuous in grasslands but are found in small numbers. A number of rare plants with medicinal potential which are protected at the local level occur in the sanctuary. The sanctuary provides good habitat and breeding ground for various fauna, including many species of vertebrates and invertebrates. The nationality of the sanctuary is wider in perspective due to the presence of fauna, such as Elephant, Gharial, and many migratory birds which are listed in the IUCN Red Data Book, as well as its ecosystem service sustain the neighbouring communities, hence the area is of utmost importance in the conservation scenario. The particular instance of Bethuadahari Wildlife Sanctuary deserves attention because this protected area does not have a specific plan to monitor and manage habitat and ecosystem wellbeing.

4.1. Flora

Forests predominantly characterized by Sal Shorea robusta and Savanna Woodlands combined with Cultivated Acacia Auriculiformis and Cassia Siamea are the two most vital components for the overall growth of the plants of Bethuadahari Wildlife

Sanctuary. The occurrence of these types of forest along with their available resources and habitat assures the presence of a few economically significant plants. These are as such – foraging plants for elephants (Eucalyptus globulus, Leucaena leucocephala); the Sal forests are main sources of wildlife sight-seeing in Bethuadahari Wildlife Sanctuary. The reserve is having Salvi Ricinodendron monadelphum as the most important economy tree. In addition, Ganjer Shah also grows profusely in this area and used for sealing of boats.
Pointing to mainly two phenological stages, the first stage shows the flowering initiation within the Fortnight of the third Week of March, fruiting in August–September. The next stage shows the onset of flowering during the second Fortnight of April as the climax of the whole process and going in to sleep in the month of February. This in-turn is beautifully illustrated the pictorial representation of the seasonal variation of phenological activity of different timber trees in Bethuadahari Wildlife Sanctuary. During the last stage, Sal deciduous plants are left out naked which adds to the beauty of the forest. And again the first shower of rain brings the new green leaf all around.The main forests of the sanctuary are Sal Forests with patches of mixed Forest made of miscellaneous evergreen species in lower numbers. A few small patches of Grass and Shrub lands lengthen the wonderful biodiversity of the normal forest ecosystem of the sanctuary. It is thus the Sal forests having rich soul and ecological conditions that help the native and other economically useful plants grow rightly. A good number of economically useful and endemic indicator plants are found comprising the bank of timber carrying assorted habitat types. However, being a small forest reserve in the area, the plants though not sound, bear the capable industrial and economy part of the surrounding well. The lush green vegetation during the monsoon months is irresistible to the sight of all; a part of the plantation into the reserve is very well taken care of and its main purpose properly served.

The Sanctuary supports tall wetlands with rich plant diversity (60 species belonging to 33 families) which flourish during the rainy season. Rare, threatened and economically important species constitute 12.45% of the wetlands flora. The floristic inventory is a first-time compilation. The various types and seasonal dynamics of the wetlands of the Sanctuary have been examined, along with their conservational needs. The wetland vegetation is the natural sink and source for irrigation and biodiversity, and acting as one of the prime sources of non-timber forest produce in the northern part of West Bengal.

4.2. Fauna

The Sr. Mangal Wetland at the heart of the sanctuary is home to fish and wildlife of diverse ecological significance that require special attention. Documenting the assorted groups of flora and fauna carries immense importance for measuring the ecological integrity of the sanctuary. Collected information on the animal groups presents a brief overview of mammals, birds, reptiles, amphibians, fishes, and a few indicators of invertebrate assemblages within the sanctuary area. The sanctuary serves as crucial wildlife habitat and contains a number of important and threatened species.

Mammals. The occurrence of 20 species of mammals has been established, spanning various orders. Among them, eight species such as Elephas maximus, Panthara pardus, Melursus ursinus, and Sus scrofa are designated as important and nearly threaten species (B. Ranawana & N. B. Bambaradeniya, 2013). Elephas maximus, Melursus ursinus, and Panthara pardus have been identified as key species. The presence of the latter was confirmed by detailed mapping of droppings and scratch marks. Two more important species, Funambulus palmarum and Herpestes edwardsii, were also noted, as were three species that may not qualify as important overall but can be characterised as such at the local level, including Miopta ceylanica, Tupaia glis, and Lepus nigricollis. The records of bats cover five species, and their extensive documented hibernation periods in the region indicate potential for yet more colonies. The various species can be found across all major habitat types, with distribution concentrated around the Wetland, herbaceous, and open shrub lands.

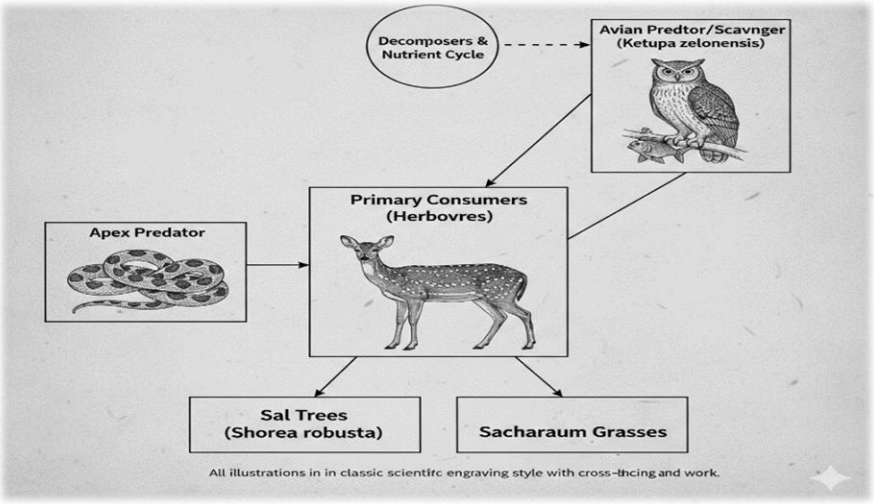

Figure: Bethuadahari Sanctuary Ecological Food Web

Birds. A total of 181 avian species representing 39 families and 13 orders have been enumerated at the sanctuary. Waterfowl have been classified as flag species, and important birds include endemic (e.g. Spilornis cheela) and migratory (e.g. Milvus migrans) species that visit during the monsoon (Kunda et al., 2022). Of the total, 67 are recognized as important and 38 are indicated as threatened. Feedings of the higher classes, where a good number of other flying creatures are also present, are noted across all vegetation types, emphasising the need for measures to prevent the loss of such essential developmental wildlife.

V. ECOLOGICAL THREATS AND CONSERVATION CHALLENGES

Bethuadahari Wildlife Sanctuary (BWS) operates as a biological island within a matrix of high-density human habitation. Maitra et al. (2021) highlight that the proximity to National Highway 12 (formerly NH-34) introduces significant "edge effects." Heavy vehicle traffic results in decibel levels exceeding $70 \, \text{dB}$, which Gupta et al. (2019) found correlates with elevated fecal glucocorticoid metabolites (stress hormones) in the resident *Axis axis* population. Furthermore, illicit cattle grazing along the boundaries leads to biomass competition and increased risk of zoonotic disease transmission (Bhattacharya et al., 2018).

The primary ecological threat is the "Hamjam" crisis. Ghosh et al. (2018) documented that *Polyalthia suberosa* has colonized 65% of the sanctuary's understory. This dense evergreen shrub blocks sunlight, preventing the growth of *Saccharum* grasses essential for herbivores. In terms of disease, the high density of deer ($>4.5 \, \text{individuals/ha}$) creates a "superspreader" environment for foot-and-mouth disease (FMD) and hemorrhagic septicemia, as identified by Singh et al. (2020).

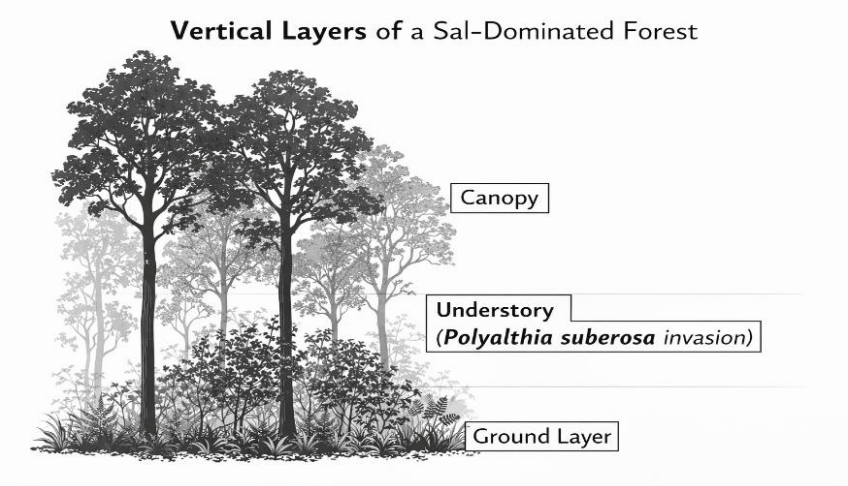

Figure: Vertical Layers of a Sal-Dominated Forest

The Central Gangetic Plain is witnessing increased erraticism in monsoon patterns. Yadav et al. (2023) used remote sensing to show that BWS faces localized "heat island" effects due to surrounding deforestation. A decrease in pre-monsoon showers has led to the drying of oxbow lakes (Beels), which are critical for the Indian Gharial (*Gavialis gangeticus*) rehabilitation project (Dutta et al., 2023).

VI. ADMINISTRATIVE FRAMEWORK AND GOVERNANCE

BWS is managed by the Wildlife Wing of the West Bengal Forest Department, specifically under the Nadia Forest Division. The Management Effectiveness Evaluation (2019) identifies a multi-tiered stakeholder system including the Forest Protection Committees (FPCs), local panchayats, and NGOs like Nature Mates

The sanctuary operates under the Wildlife (Protection) Act, 1972. Administrative protocols are guided by the 10-year Working Plan. However, Singh (2020) argues that the current legal framework lacks provisions for "Buffer Zone" management in urban-adjacent sanctuaries, making it difficult to prosecute peripheral encroachments.Budgetary allocations are primarily directed toward anti-poaching and tourism infrastructure. Directorate of Forests (2024) reports indicate a need for a 25% increase in technical staff for biological monitoring, rather than general security personnel.

VII. RESEARCH, MONITORING, AND DATA GAPS

7.1. Monitoring Protocols and Indicator Systems

Systematic monitoring is the backbone of wildlife conservation. Currently, BWS relies heavily on the Line Transect method for its annual census, primarily focusing on charismatic megafauna like the Spotted Deer (*Axis axis*). However, modern conservation biology demands a shift toward functional ecology. Paul et al. (2020) argue for a specialized focus on the Brown Fish Owl (*Ketupa zeylonensis*) as a "bio-indicator." Because these raptors rely on healthy aquatic ecosystems for foraging, their presence or absence serves as a living metric for the chemical and biological health of the sanctuary's water bodies.

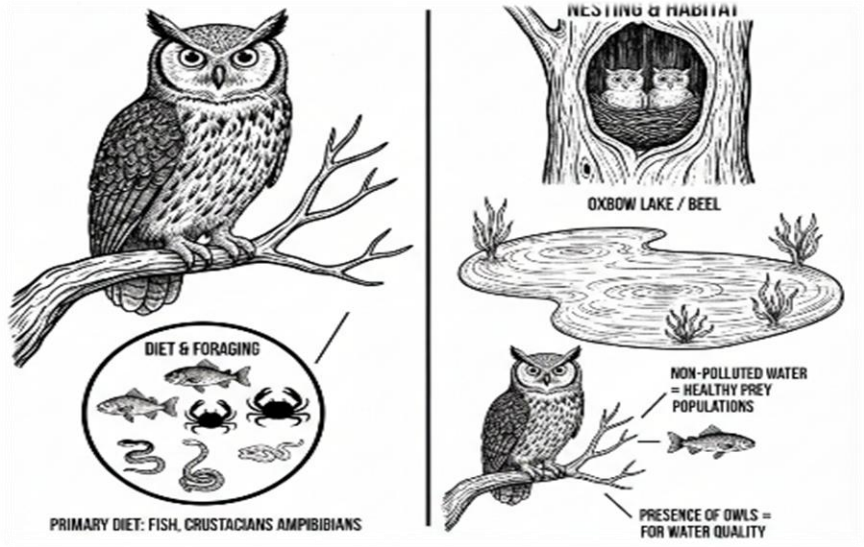

Figure: Bio-Indicator (Brown Fish Owl and Aquatic Health)

7.2. Data Sharing, Accessibility, and Collaboration

A significant barrier to effective management is the "silo effect." While prestigious institutions such as Kalyani University produce high-quality ecological data, these findings often remain confined to academic journals. Kumar et al. (2022) highlight the disconnect between researchers and the Forest Department. Integrating academic research into Real-time Monitoring (RTM) protocols—using digital dashboards to track habitat changes—is essential to bridge the gap between theoretical science and on-the-ground protection.

VIII. COMMUNITY ENGAGEMENT AND ECOTOURISM

8.1. Local Livelihoods and Benefit Sharing

The economic sustainability of BWS is inextricably linked to the surrounding villages. Despite high tourist footfall, Khuntia and Khuntia (2025) reveal a

stark disparity: less than 15% of ecotourism revenue reaches the local community. This lack of "trickle-down" economics can lead to resentment and increased poaching or encroachment. Strengthening the Joint Forest Management (JFM) model—whereby locals have a formal stake in tourism revenue—is vital to transforming neighbors into guardians of the forest.

8.2. Education, Outreach, and Participatory Conservation

The Gharial Rehabilitation Centre acts as a cornerstone for environmental education. Beyond the gates, community-led initiatives have shown remarkable success. Pratihar et al. (2010) document the impact of "Snake Rescue" programs. By educating villagers on the ecological role of the Indian Rock Python (*Python molurus*), these programs have shifted local behavior from fear-based killing to active rescue and release, significantly lowering reptile mortality rates.

IX. POLICY IMPLICATIONS AND PLANNING RECOMMENDATIONS

9.1. Adaptive Management and Resilience Building

"Status Quo" management is no longer sufficient in the face of climate change. BWS must adopt Adaptive Management, which views interventions as experiments to be learned from. Roy & Mukherjee (2018) emphasize two critical actions:

1. Mechanical Removal of Invasive Species: Specifically *Polyalthia suberosa*, which outcompetes native fodder.
2. Climate Proofing: Installing solar-powered watering holes to ensure that herbivores do not perish or stray into human settlements during increasingly frequent and severe droughts.

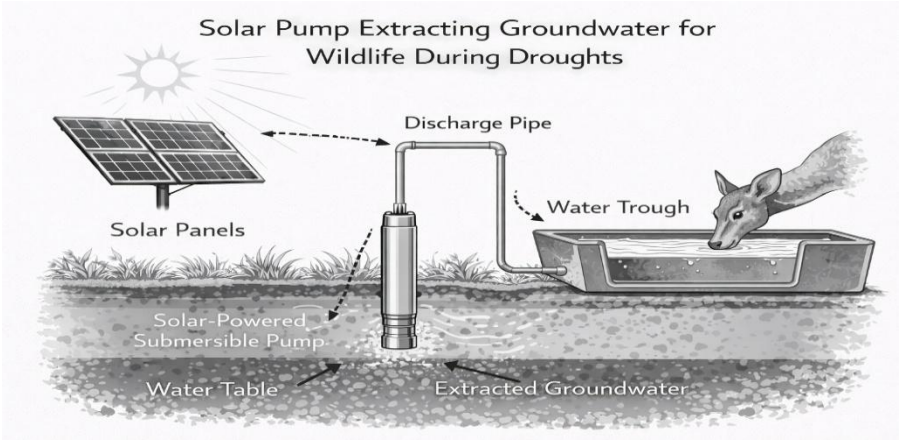

Figure: Solar Pump

9.2. Spatial Planning and Corridor Connectivity

The isolation of BWS is its greatest threat. The sanctuary is bifurcated and hemmed in by National Highway 12 (NH-12). Maitra et al. (2021) propose a radical but necessary structural intervention: a "Green Overpass" or specialized wildlife underpasses. These structures would facilitate the safer dispersal of small mammals and reptiles, mitigating the high frequency of roadkill and preventing genetic "bottlenecking" caused by isolation.

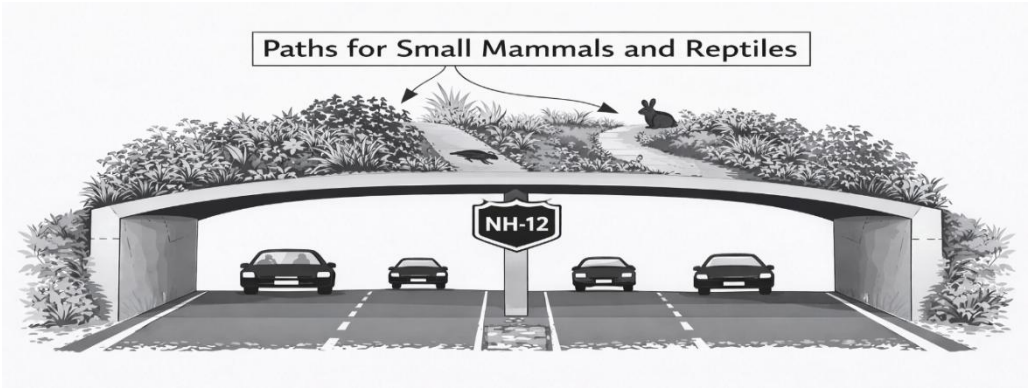

Figure: Conceptual Cross-Section of a ‘Green Ovarpass’ Over NH-12

9.3. Funding Models and International Partnerships
Transitioning BWS into a world-class facility requires diversified funding. Beyond state budgets, exploring Corporate Social Responsibility (CSR) partnerships and international grants for "Urban Wildlife Sanctuaries" could provide the capital needed for technological upgrades and habitat restoration.

X. CASE STUDIES AND COMPARATIVE INSIGHTS

10.1. Regional Coping Strategies
Comparing BWS to the Bibhutibhushan Wildlife Sanctuary (Parmadan) offers valuable lessons. While both are small, fenced sanctuaries, BWS has shown superior management of its ungulate populations. Banerjee et al. (2024) note that BWS's proactive translocation programs—moving excess deer to other protected areas—have prevented the mass starvation events seen in Parmadan, where overpopulation led to severe habitat degradation and fodder shortages.
10.2. Lessons from Similar Protected Areas
Global models of "Pocket Forests" suggest that BWS could benefit from intensive vertical habitat layering, ensuring that birds, canopy-dwellers, and ground-dwellers have distinct niches, thereby maximizing the biodiversity "carrying capacity" of its limited acreage.

XI. FUTURE RESEARCH AGENDAS AND TECHNOLOGICAL PATHWAYS

The future of BWS lies in Technological Integration.
eDNA (Environmental DNA): Sampling the water of oxbow lakes can reveal the presence of elusive or cryptic species without the need for invasive trapping (Mukherjee et al., 2022).
LoRaWAN Networks: Deploying "Long Range Wide Area Network" sensors would allow for real-time monitoring of air quality and noise pollution. This data is critical for regulating tourist flow; if noise levels exceed a certain decibel threshold, entry could be restricted to prevent physiological stress in the wildlife.

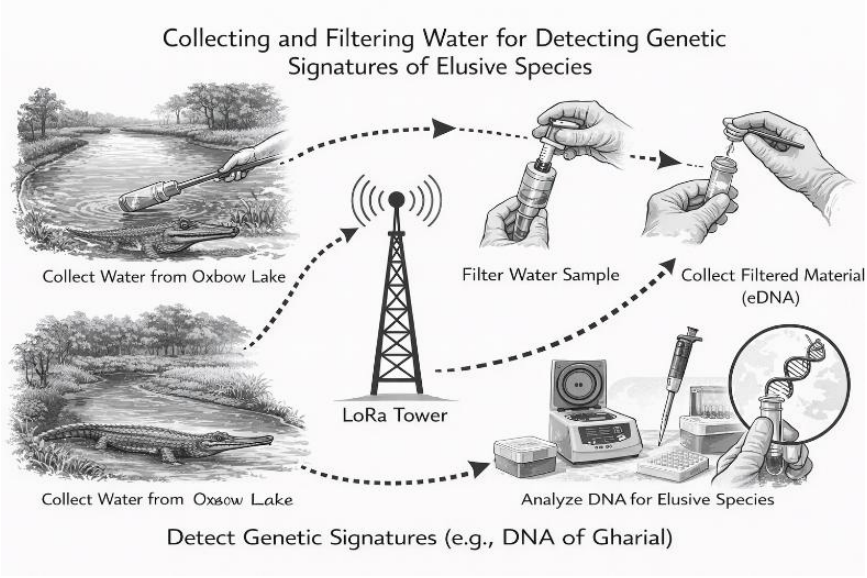

Figure: eDNA and LoRaWAN Network

XII. CONCLUSION

The Bethuadahari Wildlife Sanctuary stands at a crossroads. While it has successfully served as a refuge for deer and a center for reptilian rehabilitation, its long-term viability is threatened by geographical isolation, invasive flora, and climate-induced water scarcity. This review concludes that the transition from a passive "zoo-like" sanctuary to a dynamic, technologically integrated ecosystem is mandatory.

By implementing the proposed "Green Overpass" across NH-12, fostering a more equitable JFM revenue-sharing model, and adopting LoRaWAN-based monitoring, BWS can serve as a global blueprint for managing small-scale protected areas in human-dominated landscapes. The integration of local community knowledge with high-tech sensing tools represents the only sustainable pathway forward.

The Bethuadahari Wildlife Sanctuary (BWS) serves as a profound microcosm of the global conservation struggle: the attempt to preserve biological integrity within a fragmented, human-dominated landscape. As this review has demonstrated, the sanctuary is no longer merely a local "deer park" but a critical ecological laboratory where the intersections of administrative policy, community livelihood, and technological innovation meet. To ensure its survival through the mid-21st century, the management of BWS must evolve from a reactive "protectionist" stance to a proactive, "adaptive" framework.

The ecological viability of the sanctuary is currently at a tipping point. The isolation caused by the expansion of NH-12 has effectively turned BWS into a genetic island. Without the implementation of the proposed "Green Overpass" or similar wildlife corridors, the risk of inbreeding depression and local extinction for small mammals and reptiles remains high. This physical connectivity must be matched by "administrative connectivity"—breaking down the "silo effect" between academic researchers at institutions like Kalyani University and the on-ground forest officers. A unified data-sharing platform would allow for the integration of eDNA sampling and LoRaWAN sensor data into daily patrol logs, transforming raw science into actionable management decisions.

Furthermore, the social dimension of BWS cannot be overstated. The finding that less than 15% of ecotourism revenue reaches local stakeholders is a systemic failure that threatens the sanctuary's security. Conservation is most effective when the surrounding population views the forest as an asset rather than a restriction. By revitalizing the Joint Forest Management (JFM) committees and scaling up successful participatory models like the Snake Rescue programs, BWS can create a "social buffer zone" where local citizens act as the first line of defense against poaching and habitat encroachment.

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