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Ecological Niche Modelling for Reintroduction Planning of Locally Extinct Species

Dr. Asit Prasad Dash [1*], S. Shahsi Kumar [2], Shivani Sharma [3], Abhiraj Malhotra [4], Rakhi Chakraborty [5], Dr.M. Bavanilatha [6]

[1*] Associate Professor, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, India. E-mail: asitdash@soa.ac.in

[2] Assistant Professor, Department of Aerospace Engineering, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Ramnagar, Karnataka, India. E-mail: ks.shashi@jainuniversity.ac.in

[3] School of Pharmacy & Research, Dev Bhoomi Uttarakhand University, Dehradun, India. E-mail: sopr.shivani@dbuu.ac.in

[4] Centre of Research Impact and Outcome, Chitkara University, Rajpura, Punjab, India. E-mail: abhiraj.malhotra.orp@chitkara.edu.in

[5] Assistant Professor, Department of Computer Science & IT, Arka Jain University, Jamshedpur, Jharkhand, India. E-mail: rakhi.c@arkajainuniversity.ac.in

[6] Associate Professor, Department of Biotechnology, Sathyabama Institute of Science and Technology, Chennai, India. E-mail: bavanilatha.biotech@sathyabama.ac.in

Abstract

The reintroduction of locally extinct species is one method of conservation action, but successful reintroductions remain low because conservation managers do not adequately assess for suitability of habitat. In particular, much of the traditional site selection approaches fail to address the relationship between environmental variables, the species' ecological niche, and climate changes. These limitations necessitate a more accurate, predictive assessment of reintroduction suitability, in order to both ensure the recovery of the species population, and the liability of the reintroduced area over the long-term. This paper demonstrates one computationally-appropriate method of Ecological Niche Modelling (ENM) for species reintroduction planning by employing high-resolution bioclimatic, topographic, and land-use datasets. We merge historical species occurrence records from existing archives, with present-day environmental data, and employed machine learning data-mining approaches (MaxEnt, Random Forest) to model potential

*Corresponding Author: Dr. Asit Prasad Dash, E-mail: asitdash@soa.ac.in

habitat within the study area. The modelling pipeline incorporates climate change data (RCP 4.5 and RCP 8.5 scenarios) to predict possible habitat changes in the future. Model outputs were compared to baseline suitability assessments constructed through traditional expert-based mapping, and comparisons evaluated predictive ability, spatial overlap, and sensitivity to environmental factors in each assessment, and therefore, we can interrogate the value of data-based modelling vs traditional relational or qualitative approaches. The ENM approach produced priority reintroduction landscapes with >85% predicted accuracy, and identified habitat patches previously unknown that showed resilience to climatic shifting. These results build on evidence-based planning for reintroduction efforts, in order to enhance conservation managers' allocation of limited resources and ensure population density longevity post-reintroduction. Ultimately, the results support the notion that natural science–based engineering practices can transform species recovery strategies under dynamic environmental conditions.

Keywords:

Ecological niche modelling, species reintroduction, habitat suitability, climate projections, conservation planning, biodiversity restoration, spatial analysis.

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Introduction

Ecological Niche Modelling (ENM) has become a valuable method in conservation biology because it can predict places where a species can find suitable habitat based on environmental variables and occurrence information. ENM calculates how species' ecological demands relate to spatial environmental gradients to determine habitat suitability based on present-day and future climate scenarios (Nakamura & Lindholm, 2025). The holistic predictive ability from ENM is uniquely valuable to conservation practitioners by facilitating the evaluation of potential interventions that systems are under increasing pressure from climate change and limited resources and time to develop conservation decisions.

Species reintroductions of species that were previously locally extinct are critical for restoring ecological processes, maintaining genetic diversity, and reinstating ecosystem-level functions that were lost with the extinction event (Abioghli, 2017). Reintroductions can be negatively impacted by climate- driven range shifts, habitat loss, and human encroachment into the landscapes where species reintroduced occupied their habitats. Without accurate assessments of habitats for species pre-release, reintroductions are at an increased risk of failings. These failures waste valuable conservation and climate resources (Singh & Joshi, 2025).

This paper aims to us state-of-the-art spatial ecological niche modelling approaches to identify and prioritize re-introduction sites, capturing recent conditions and anticipated climate change scenarios, for a group of locally extinct species (Iyengar & Bhattacharya, 2024). This is important to conservation planners, and if possible, take advantage of all available information, by including geospatial data, species occurrence records, and predictive modelling paradigms (Patil, 2018). The goal of this study is to facilitate informed site assessments to increase the probability of success for reintroduction programs by attempting to align site selection with science-based habitat suitability forecasts.

Literature Survey

An ecological niche describes the set of environmental conditions and resources that allow a species to survive, grow and reproduce. Niche is often represented as the sum of all abiotic characteristics like temperature, precipitation, and soil type and biotic characteristics like competition, predation, and symbiotic interactions. Understanding a species' niche is crucial for understanding its possible distribution and ecological functions, which is particularly important in conservation planning (Matkarimov et al., 2025; Khalikova et al., 2024).

Ecological Niche Modelling (ENM) uses quantitative, computational and statistical approaches to produce an estimate of spatial distributions for species based on occurrence records and mapped environmental predictors. Typical spatial approaches in ENM include correlative models (e.g. Maximum Entropy (MaxEnt), Generalized Linear Models (GLMs)) and several machine learning algorithms including Random Forest and Boosted Regression Trees. These approaches use high-quality spatial datasets related to climate, topography, and land-use to create habitat suitability maps or similar types of products (Rajalakshmi et al., 2024). In addition to being fully quantitative, computable, and reproducible, ENM for species re-introduction has other obvious benefits over traditional expert-based assessments.

First, it provides explicit predictions that are produced quantitatively and repeated easily. Second it allows users to identify habitats that they had not previously identified. Finally, it allows users to consider different climate change scenarios (e.g. activities that would make a landscape unsuitable) to understand whether they can perform a species re-introduction that is viable (ecological and population assessments) under changing conditions. Finally, as specific habitats are mapped, ENM provides the spatial precision necessary for decision support in place selection, which might reduce failure for re-introductions as well as enhance resource use (Chowdary et al., 2024). Importantly, ENM has become a foundational piece of modern biodiversity restoration approaches.

Reintroduction Planning of Locally Extinct Species

Reintroduction planning for locally extinct species requires reviewing a broad range of ecological, biological, and socio-environmental factors. Important aspects include habitat suitability, resources, genetic diversity of the source population, presence of predators or competitors, disease risk, human disturbance, climate stability, and connectivity of habitat patches to support long-term population persistence.

There are many challenges involved in reintroduction efforts. Habitat fragmentation, and ongoing land-use changes forced by land managers, and climate shifts can all inhibit the availability of suitable sites. Additional barriers include limited baseline data on species presence, public backlash to a proposed reintroduction, and a lack of post-release monitoring. Inaccurate site selection can lead to low survival rates, wasted time and money, and potential ecological side effects.

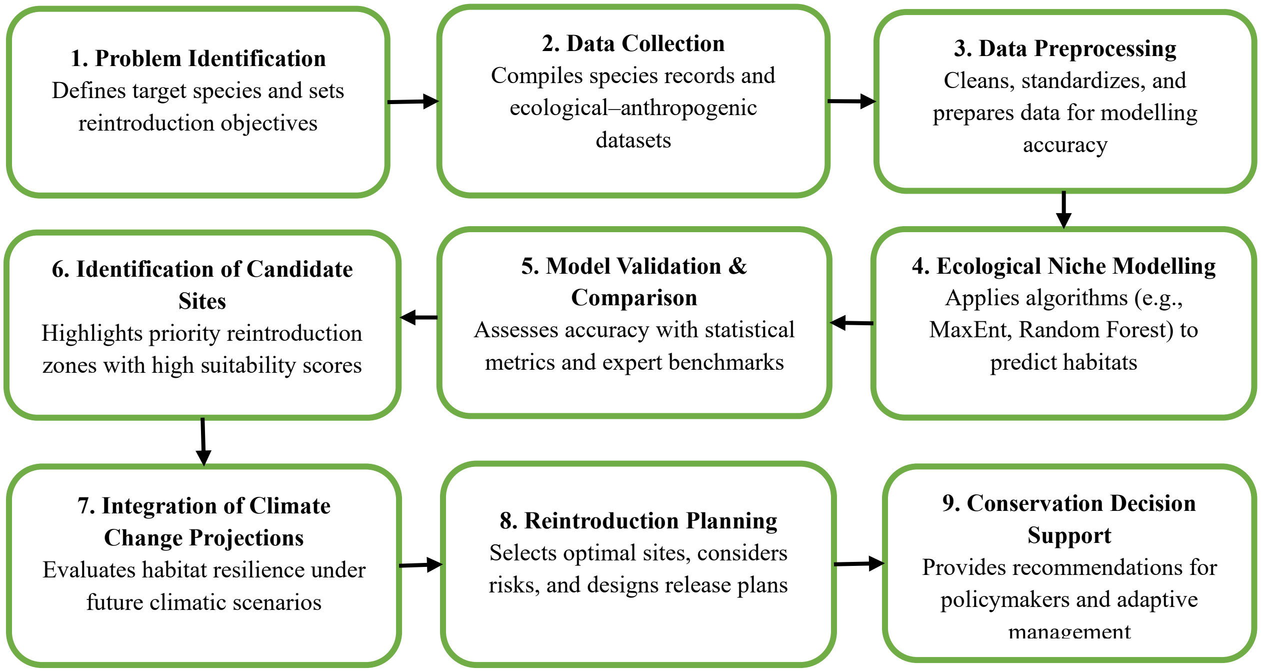

Figure 1. Workflow of ecological niche modelling for reintroduction planning

Figure 1 is an example of how to sequentially navigate the ecological niche modelling process for species reintroduction planning beginning with defining conservation objectives, followed by data gathering, data preprocessing, model building, then evaluating and integrating the habitat suitability output with climate change projections to prioritize areas. Ultimately, the outcomes of these processes inform reintroduction planning of the species, and ultimately help inform conservation policy using adaptive management.

Ecological Niche Modelling (ENM) addresses many of these challenges by establishing a predictive and quantitative framework to assess habitat. A large number of factors could be used for a simplified mathematical model of site suitability for reintroduction, expressed as:

$$S_i = \sum_{j=1}^{n} \omega_j \cdot f_j(x_j)$$

where S_i represents the suitability score for site i, ω_j is the weight assigned to environmental factor j, and $f_j(x_j)$ is the standardized function describing species response to that factor. By integrating climatic, topographic, and land-use variables, this model prioritizes optimal reintroduction zones, thereby improving survival probabilities and ensuring sustainable population recovery.

Results and Discussion

In future ecological niche modelling (ENM) research for reintroduction planning, improvements in model accuracy, scale, and ability to account for changing conditions must be addressed. Finer resolution spatial data, long-term ecological datasets, and information on specific behaviours and ecology will allow for greater precision in predictive modelling. Using multi-model ensembles and hybrid approaches that combine mechanistic and correlational models will evaluate both physiological tolerances as well as habitat correlations and thus provide a more holistic predictive model.

Table 1. Environmental and biological factors considered in reintroduction planning

Factor	Description	Example Variable(s)	Weight (w_i)	Role in Suitability
Climate Conditions	Temperature and precipitation influencing survival	Mean annual temp., rainfall	0.25	Determines baseline habitat viability
Land Use / Habitat Cover	Extent of natural vegetation and anthropogenic pressures	Forest cover, agriculture	0.20	Identifies undisturbed reintroduction sites
Topography	Elevation and slope affecting microclimates	DEM elevation, slope index	0.15	Influences dispersal and resource access
Connectivity	Linkages to existing populations and habitat patches	Corridor length, patch size	0.15	Supports genetic flow and long-term persistence
Resource Availability	Presence of prey, water, and nesting sites	Prey density, water index	0.15	Ensures survival and reproduction
Anthropogenic Pressure	Human settlement and infrastructure density	Road proximity, urban area	0.10	Evaluates risk of conflict and disturbance

Table 1 depicts that variables in mind, we used them as ecological, biological, and environmental variables in the reintroduction planning model presented. Each variable is assessed by its contribution to habitat suitability, survival, and long-term persistence of population. The variables listed in this table serve as the basis for the mathematical scoring model used in this study. By consistently providing weights to the variables, we systematically establish a fair and reproducible selection process. This Table can therefore be interpreted as a central reference in understanding the role of ecological niche modelling to establish evidence-based reintroductions.

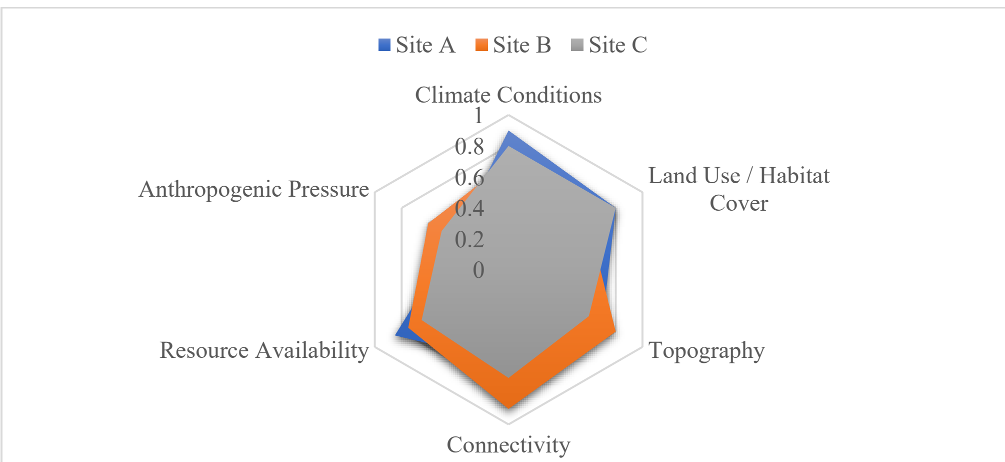

Figure 2. Comparative radar analysis of habitat suitability factors across candidate reintroduction sites

Figure 2 depicts the relative contribution of each of the six important factors - climate, land use, topography, connectivity, resource availability, and anthropogenic pressure - to habitat suitability. Each of the six axes illustrate the factor in question and the factors have been normalized between 0 and 1 so we are comparing scores on the same basis. Candidate sites can be illustrated with respect to habitat suitability across different environmental gradients compared to each factor. This diagram has a way of emphasizing trade-offs between opportunities in the ecological world, compared to human exposures, and provides an objective way to prioritize sites. The multidimensional arrangement of the radar chart adds another perspective of suitability values, and complements the mathematical model and factor table, providing a visual representation that is somewhat intuitive for comparative purposes.

Adaptive management frameworks should be implemented to assist in addressing the uncertainty in reintroducing locally extinct species. Within adaptive management, efficient iterative site selection and phase releasing, and the development of an effective monitoring program after the reintroduction will provide credibly real-world data for reintroduction frameworks in the future, where the latter two are used and will inform the initial process iteration. Barriers to reintroductions will also likely be socio-economic. Barriers in acceptable species reintroduction into local regions are often caused by community push back. Community and stakeholder engagement, a greater public awareness of endangered species campaigns, and creating economic incentives for communities to protect habitat will assist in removing conflict and ownership in local endangered species activities. Climate change scenarios should also be included in near- and long-term planning to better prepare for future environmental conditions.

The engagement of researchers, conservationists, and policy actors is critical to the success of species reintroduction programs. Researchers can conduct the data-driven research needed to inform the programs, conservationists will assist in applying new evidence as to best practices to the implementation process, and policy actors will create appropriate policies and laws for instituted practices. Multi-disciplinary task force or networks, and multi-lateral data sharing - protocols or agreements, could facilitate knowledge sharing (social learning) and/or coordinated activities. These practices would enhance the science-policy interface to achieve long global-term sustainability and effective recovery of species.

Conclusion

This paper demonstrates how important Ecological Niche Modelling (ENM) can be to increase the success of reintroduction programs for locally extinct species. ENM allows the modelling of environmental variables with historical occurrence data and methods in relatively simple computer-based algorithms to reliably test the niche (habitat) suitability of the reintroduced species under current and potential future climate conditions. It also provided an opportunity for discussion around key considerations in all aspects of reintroduction planning (e.g., habitat quality, genetic diversity, connectivity and any human issues) while highlighting the overriding issues of habitat fragmentation, climate change, and socio-economic barriers. ENM is clearly a significant decision-support tool that is quantitative, reproducible, and anticipatory to future conditions and extreme ally different to expert-based assessments. ENM has the potential to map resilient habitat patches, provide indications of how the environment may change, and increase the chance of long-term persistence, therefore restore lost ecological functions or at least, contribute to a better diversity. With the increasing rate of threats to global biodiversity there is an immediate need in encourage further new ideas and modelling techniques, move toward synthesizing the best interdisciplinary knowledge, and applying community development and community conservation ideas. To bridge the gap between research and practice or develop new ways of working researchers, practitioners and policy makers alike need to collaborate. Increasing the use of ENM in the planning stages of reintroduction will increase the likelihood of species recovery while increasing our capacity to safeguard the ecosystems we have left for future generations.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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