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Resilient Wild Framework for Measuring Animal Adaptation Capacity Against Environmental Change

Dr. Deepti Patnaik[1*], Rakshak Bharti[2], Dr. Sunaina Sardana[3]

[1]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*
Email: ku.deeptipatnaik@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0009-6421-5418
[2]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.
Email: ku.rakshakbharti@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0009-6629-7189
[3]Professor, New Delhi Institute of Management, New Delhi, India.
Email: sunaina.sardana@ndimdelhi.org, ORCID: https://orcid.org/0009-0002-1373-0187

Key Words

Adaptation capacity, Behavioral flexibility, Stress resilience, Wildlife conservation, Environmental change, Gut microbiome, Habitat support.

Abstract

Wildlife population performance can vary in its adaptability, capability to adapt, and recovery from disturbances caused by its environment, yet there is no established system to determine capacity for adaptation in the conservation field. Most resilience studies deal with behavioral, physiological, and habitat approaches separately, which makes the study insufficient to understand how contribute as a whole to the persistence of wildlife populations. The article presents the Resilient Wildlife Concept, an innovative theoretical model providing a comprehensive analysis of behavioral flexibility, physiological stress tolerance, and habitat conditions to determine the total capacity for adaptation. The model makes use of the results obtained from research on wildlife behavior during climate-related disease, microbiome adaptability, and climate adaptation strategies, as well as data-driven environmental conservation. Using different sustainability indicators, this model allows comparing the adaptation ability of different species and populations as well as for other situations. Though the model is not tested in a wildlife environment yet, it is a good foundation for future planned conservation efforts.

* Corresponding Author's email: ku.deeptipatnaik@kalingauniversity.ac.in
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Introduction

The different capacities of wildlife to adjust and adapt to environmental modifications such as extreme weather events, disruptions of habitats, or changes in resource availability – all while avoiding degradation – is crucial information for conservation planning nowadays, given the rising occurrence of such environmental impacts. Proposals for developing a conceptual framework for measuring species' behavioral flexibility in response to extreme environmental events point out that such flexibility, which is considered to be the capability of a particular species to change its behavior, habitat use, and social organization in a time of disturbance, changes significantly across species and is possible to measure based on certain behavioral indicators. It is thus possible to create a foundation where adaptive flexibility of species from different ecological niches could be compared (Ameca et al., 2023). The study of the role of gut microbiome as a mediator of stress resilience while using the reactive scope model has proved that the microbial organisms present in the animal organism influence its behavior at times of stress, which indicates that resilience evaluation based on behavioral patterns alone will not provide an accurate picture of adaptation capacity of animals in response to environmental disturbances (Houtz et al., 2022). Studies that have incorporated aspects of ecotourism and resilience features highlight that resilience principles applied in managed wildlife tourism destinations produce useful principles such as redundancy and flexibility of reaction that could also be applied to analyze the adaptive capacity of wildlife (Jones et al., 2024).

The Resilient Wild Framework is presented as an answer to this gap collectively identified by the above studies: behavioral flexibility measures, internal Physiological Resilience Mechanisms, and Resilience-informed Structural Thinking exist independently within respective research disciplines, however a uniform framework uniting these disparate dimensions to create a standardized and interpretable metric of adaptability for organisms to a wide variety of disturbances is lacking.

In summary, the current paper offers three main advancements: first, it offers an overarching framework structure that synthesizes behavioral flexibility, physiological resilience, and habitat support conditions into a composite adaptation capacity index rather than considering these three independently. Secondly, it incorporates internal Physiological Indicators as part of the proposed index, since how capacity to deal with ecosystem change will be dependent on internal physiologically mediated processes as well as the ‘external’ behaviors. And third, it draws from existing resilience frameworks used within wildlife tourism ‘managed’ population scenarios and provides guidance for the adaptation to and application with an ‘unmanaged ‘wild populations broadening resilience theory applications beyond those for which it was conceived.

Hereafter, the paper is organized as follows. Section II surveys current deficiency in adaptation capacity metrics through highlighting pertinent findings of the most recent empirical

literature focusing on wild animal cope strategies for the consequences of a changing climate; climate resilient aquaculture system adaptation planning and climate adaptation utilizing and informing from data. Section III delineates the architecture of the intended resilience measuring framework. Section IV presents on capacity score and best practice use relative to present resilience assessments, and section V is summary and recommendations for future work and Validation.

Shortcomings of Current Adaptation Capacity Metrics

Studies evaluating how conservation management groups should assist wild animals with climate change, particularly looking at the case of Iberian lynx, concluded that assistance in adaptation is frequently developed for each species without efficient system of determining how much help the species needs based on its adaptation ability, which suggests that modern practices tend to utilize case study thinking instead of a systematic approach to assessing adaptation capacity (van Hassel & Bovenkerk, 2023). Reviews of climate change influence on aquaculture production and its sustainable development with the help of climate-adaptive technologies affirm that the adaptation capacity of the animals under cultivation is usually assessed through a systematic multi-directional method. However, similar structured methodologies are less developed in connection to wild animals that experience the same stressors in the natural environment (Yadav et al., 2024). Studies assessing how data analysis can assist in urban climate adaptation and sustainable development demonstrates that the effectiveness of the approach allows to provide insights on the most relevant issues from the collected data thus making a suggestion that a similar approach might enhance adaptation ability of the wild species if environmental and physiological parameters crucial for animal adaptation are analyzed, which, however, has not been explored in environmental resilience study yet (Srivastava & Maity, 2023).

These recent sources highlight a common failure of existing capacity measures of adaptation potential across all three lines of research. Climate coping studies of individual species conclude that support-based decisions about conservation funding do not generally follow from a standardized capacity index but are often ad hoc which makes it difficult to compare. Aquaculture adaptation research suggests that although well-structured, multi-factor assessments of capacity have been developed for managed species that face similar pressures, comparable methods have not been derived for wild populations. Finally, data-driven planning of adaptation suggests that an analytical toolkit exists to find a signal in complex data that have helped in another branch of the Adaptation planning project but have not been used meaningfully to help measure capacity for wildlife adaptation. In combined, the analyses suggest that it is time to establish a wildlife adaptation-planning framework that avoids anecdotal judgement in favor of standardized estimates of adaptive capacity based on the proven multi-factor structured approaches of managed populations and has the capacity to

leverage the powerful data analyses now developing for wildlife-derived data.

Framework Design for Resilience Quantification

Behavioral Flexibility Assessment

This component starts the proposed framework with a behavioral flexibility assessment component; directly using structured behavioral indicator measures to assess species responses to extreme climatic conditions. This part assessing the capability of the population to alter activity timing, behavioral patterns of site and time availability, movement behavior and spatial and social structuring of groups; by ranking populations based on the scope of ability to adjust behaviors historically exhibited and currently attributed to similar species for similar events.

Physiological Stress Resilience Assessment

In conjunction with behavioral assessment, the framework also uses a physiological stress resilience aspect that gauges markers within an animal that suggest its physiological ability to resist internal stressors associated with environmental stress, also including gut microbiome-driven stress-resilience mechanisms that align with the principles of reactive scope models. The approach overcomes the weakness that solely assessing behaviors fails to take into account how animal coping mechanisms are governed by an animal's internal physiologies when responding to prolonged environmental stress and uses relevant indicators of stability in microbial community members and patterns in the secretion of stress hormones.

Habitat Support and Structural Resilience Integration

A third aspect adds design elements related to the provision of habitat based supporting conditions and structural robustness incorporating adaptation principles developed in managed wildlife tourism systems such as the ready availability of “redundant habitat types” and population’s “flexibility of habitat selection” during periods of disturbance. This section assesses whether populations surrounded by habitat are in sufficiently redundant/flexible surroundings to maintain and enable behavioral and physiological adaptive responses discussed in first two sections assuming a behaviorally and physio-gnomically resilient animal might still be hampered in its adaptive capacity if its surrounds are not sufficiently complex to assist new behavioral response styles.

Capacity Scoring and Case-Based Validation

Anticipated Scoring Outcomes

The expected results of the Resilient Wild Framework (RWF) rely on results from previous resilience studies since the framework has not yet been applied to operational conservation applications. The behavioral flexibility section of RWF is predicted to yield similar adaptation scores between species by incorporating standardized behavioral indicators. The results are expected to predict that individuals showing behavioral resilience will have a higher resilience score. The physiological resilience section is hypothesized to assess internally buffered stress response where individuals showing resilience to

environmental stress will maintain stable microbiome and physiological integrity when placed under pressure. This would indicate those species may adapt better to the changes.

Comparison with Existing Resilience Assessment Approaches

The developed approach is a more holistic approach that takes into account behavioral flexibility and physiological resilience at different life stages combined with measures of habitat suitability, compared to single- indicator measures of resilience. Unlike species-specific resilience estimates often based primarily on expert knowledge, such as using questionnaires, the rubric scoring enables comparison between populations subjected to different types of stress and allows for a comparable resilience value among these populations. Also, this is the first framework that builds on principles of multi factor-based system resilience developed in managed environments (eg aquaculture) and applies them to wildlife where robust, measured parameters of adaptation are still often missing. Taking multiple dimensions of resilience into account provides the most accurate measure of a species and its populations capacity to adapt.

Implications and Limitations

By allowing researchers to compare adaptation capacity between populations experiencing a range of environmental stresses, the Resilient Wild framework aids prioritization in conservation decisions, and the summed score can be used to help focus management efforts for particularly vulnerable populations. The framework can also be more seamlessly expanded by combining this scoring approach with model based analytical approaches once large- scale ecological monitoring systems have generated more comprehensive datasets. Future validation of framework, for example by field sites in addition to in situ, adaptation success data for populations subject to distinct challenges may be necessary, though of course the performance of individual resilience scores depend on the consistent generation of behavioral, physiological, habitat, microbiome and stress-related trait information-data that continues to lag behind many species for most aspects.

Conclusion

In this paper, the authors present the Resilient Wild Framework which is a new conceptual paradigm developed to measure the ability of wildlife to adapt to changing ecological environments. This approach combines behavioral flexibility, physiological stress resistance, and ecological constraints to come up with a single, integrated score for capacity to adapt. This framework provides a structured method of measuring adaptation capacity for wildlife populations compared to current single-factor methods that leave room for subjective judgments. Adaptation capacity of various species and the impacts of different disturbances on adaptation readiness are some of the fields of application for the proposed framework.

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