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Review Article

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PLANT–ANIMAL INTERACTIONS IN A CHANGING CLIMATE: INTEGRATING BOTANICAL AND ZOOLOGICAL PERSPECTIVES FOR SUSTAINABLE ECOSYSTEM MANAGEMENT

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Abstract

Plant–animal interactions form the structural and functional backbone of terrestrial ecosystems, influencing pollination, herbivory, seed dispersal, and nutrient cycling. Climate change is rapidly altering these interactions through shifts in temperature, precipitation regimes, atmospheric CO₂, and disturbance patterns. These environmental changes affect plant physiology, phenology, chemical defenses, and reproductive strategies, while simultaneously reshaping animal behavior, metabolism, and distribution. Asynchronous phenological shifts-known as mismatches-are becoming increasingly common, threatening mutualistic relationships such as pollination and seed dispersal. At the same time, elevated CO₂ and altered temperatures are modifying herbivore feeding rates and plant defense expression, contributing to cascading ecological and evolutionary consequences. This review synthesizes botanical and zoological perspectives to provide an integrated understanding of how climate change influences plant–animal interactions across multiple ecological levels. It highlights emerging methodologies, including network modeling, long-term phenological monitoring, and experimental climate manipulations, and outlines strategies for sustainable ecosystem management. Emphasizing interdisciplinary approaches, the review underscores the need for adaptive management, restoration practices that account for both plant and animal physiology, and policies that enhance resilience in a rapidly changing climate.

Keywords: Climate change, Plant–animal interactions, Phenological mismatch, Pollination biology, Herbivory, Ecosystem resilience, Global change ecology, Plant physiology, Animal behaviour.

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Introduction

Plant–animal interactions form the ecological foundation for most terrestrial ecosystems, shaping processes such as pollination, seed dispersal, herbivory, and decomposition. These interactions contribute to biodiversity maintenance and ecosystem stability. However, climate change-manifested through rising temperatures, changing precipitation patterns, elevated CO₂, and more frequent extreme events-is increasingly influencing these interactions at physiological, behavioral, ecological, and evolutionary scales [1][2]. Understanding these changes requires integrating botanical and zoological perspectives for more effective ecosystem management.

Impacts of Climate Change on Plant-Animal Interactions

1. Phenological Shifts

Climate change is driving notable advances or delays in key phenological events such as flowering, leaf flushing, insect emergence, and migration. However, plants and animals do not always adjust their timing at the same rate, creating *phenological mismatches* [1]. For example, earlier flowering caused by warming may not align with pollinator emergence, reducing reproductive success for both partners. These mismatches threaten long-term stability in mutualistic networks.

2. Physiological and Behavioral Responses

Climate change alters plant physiology—including nutrient composition, defense chemicals, and growth rates-which can significantly affect how animals interact with plants. For example:

- Elevated CO₂ may increase carbon-rich compounds but reduce nitrogen, lowering leaf nutritional quality [2].
- Warmer temperatures often increase herbivore metabolic rates, influencing feeding frequency and consumption levels [2].

From the zoological perspective, herbivores, pollinators, and seed dispersers adjust behaviors in response to thermal stress, food availability, and habitat shifts. Above- and below-ground herbivores may respond differently to these changes, altering plant-mediated multitrophic interactions [3].

3. Evolutionary and Ecological Consequences

Long-term climate change can drive evolutionary shifts in both plants and animals. Trait modifications—such as changes in plant defense or insect developmental timing—can influence coevolutionary dynamics [2]. Meta-analyses show that increased temperatures generally accelerate herbivore development, while elevated CO₂ often delays it, producing complex outcomes for plant–herbivore interactions [2].

4. Network-Level Changes

Climate-driven shifts in species abundances and behaviors can alter the structure of interaction networks, potentially reducing connectivity or eliminating specialized mutualisms. Pollinator decline, for example, can cause cascading failures within networked ecosystems. Such network disruptions reduce resilience and increase the risk of local extinctions.

3. Integrative Botanical–Zoological Approaches

Sustainable ecosystem management requires methods that bridge plant and animal sciences:

- Mechanistic Integration**
Combining plant physiology (e.g., metabolomics) with animal behavior and thermal biology reveals causal pathways behind climate-driven changes.
- Phenological Monitoring**
Long-term records, remote sensing, and citizen science programs enable tracking species responses across landscapes [1].
- Experimental Manipulations**
Controlled experiments manipulating temperature, moisture, and CO₂ allow researchers to measure direct changes in plant traits and animal responses.
- Network Modeling**
Simulation models predict how interaction networks may rewire in response to climate stress.
- Restoration Ecology Integration**
Restoration plans must consider both plant requirements and the physiological and behavioral needs of pollinators, seed dispersers, and herbivores [4].

4. Implications for Sustainable Ecosystem Management

- Protect Keystone Species**
- Targeting keystone pollinators or seed dispersers helps maintain ecosystem integrity.
- Enhance Habitat Connectivity**

Wildlife corridors facilitate climate-driven range shifts.

- Adaptive Management**
Monitoring ecological changes informs timely management interventions.
 - Promote Biodiversity**
Diverse communities buffer ecosystems against climate-related disruptions.
 - Incorporate Community Engagement**
Local participation improves monitoring and conservation outcomes.
- ### 5. Research Gaps and Future Directions
- Multistressor Experiments:**
Few studies combine warming, drought, CO₂, and nutrient changes simultaneously.
 - Evolutionary Timescales:**
More research is needed on how fast plant and animal populations can adapt.
 - Understudied Systems:**
Tropical and arid ecosystems require more attention.
 - Scaling Up:**
Translating small-scale studies to landscape-level predictions is challenging.
 - Applied Translation:**
More integration between science, policy, and restoration practice is needed.

Conclusion

Plant–animal interactions are highly sensitive to climate change, with impacts ranging from physiological changes to network restructuring. An integrated botanical–zoological framework is essential for predicting these shifts and developing sustainable ecosystem management strategies. Through adaptive management and ecosystem restoration that accounts for both plant and animal responses, it is possible to build resilience in the face of rapid climate change.

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