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A Conceptual Model Linking Environmental Degradation and Social Resilience Thresholds under Climate Stress

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ABSTRACT

Climate change exacerbates environmental degradation, posing profound challenges to social systems worldwide. This conceptual manuscript introduces a novel theoretical framework that elucidates the threshold-based coupling between ecological degradation and social resilience under persistent climate stress. Drawing on recent peer-reviewed literature, we synthesize key concepts from ecology and social sciences to argue that environmental thresholds —points where incremental changes lead to abrupt shifts in ecosystem states —interact dynamically with social resilience thresholds, defined as the limits beyond which communities lose adaptive capacity. The proposed model posits that climate stress acts as a multiplier, accelerating degradation and eroding resilience through feedback loops, such as resource scarcity amplifying social inequities or biodiversity loss undermining cultural adaptive strategies. This coupling can result in cascading failures, where crossing an ecological threshold precipitates a social collapse, or vice versa, leading to regime shifts in socio-ecological systems. Unlike existing models that treat these domains separately, our framework emphasizes their interdependent thresholds, offering a unified lens for analyzing system vulnerabilities. By avoiding empirical analysis, this work focuses on theoretical integration to guide future interdisciplinary research and policy formulation aimed at enhancing systemic stability in a warming world. The implications underscore the need for proactive threshold monitoring to prevent irreversible transitions.

Keywords: *Environmental degradation, Social resilience, Climate stress, Ecological thresholds, Social thresholds, Socio-ecological coupling*

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INTRODUCTION

The escalating impacts of climate change represent one of the most pressing challenges facing humanity in the 21st century. Rising global temperatures, altered precipitation patterns, and increased frequency of extreme weather events are driving widespread environmental degradation, including soil erosion, biodiversity loss, and ecosystem fragmentation (Washington State Department of Ecology, 2025; Zhou *et al*., 2025). These changes not only compromise the integrity of natural systems but also strain the fabric of human societies, particularly in vulnerable regions where adaptive capacities are limited (Graefen *et al*., 2023; Maslin *et al*., 2025). Environmental degradation under climate stress manifests in multiple forms: deforestation accelerates carbon emissions, ocean acidification disrupts marine food webs, and land subsidence from groundwater depletion heightens flood risks (Dhanasekar *et al*., 2022; Santos *et al*., 2022). Such processes are not isolated; they interact with social dynamics, influencing livelihoods, health, and community cohesion (Kemarau *et al*., 2025).

Social resilience, broadly understood as the ability of communities and institutions to withstand, adapt to, and recover from disturbances, has emerged as a critical concept in addressing these challenges (Nguyen & Hoang, 2022; Efremov, 2023; Kharecha *et al*., 2025). It encompasses dimensions such as economic stability, social capital, governance structures, and cultural knowledge systems that enable collective responses to adversity (Nguyen & Hoang, 2022; Puig *et al*., 2025; Yan & Li, 2025). However, under prolonged climate stress—defined here as chronic pressures like heatwaves, droughts, and sea-level rise superimposed on acute events—social resilience can erode, leading to heightened vulnerability (Fletcher *et al*., 2024). For instance, in regions experiencing recurrent droughts, agricultural communities may face food insecurity, migration pressures, and social conflicts, all of which test the limits of resilience (Nguyen & Hoang, 2022; Yan & Li, 2025).

Despite growing recognition of these interconnections, existing theoretical approaches often treat environmental degradation and social resilience as parallel rather than intertwined phenomena. Ecological models frequently emphasize biophysical thresholds, such as tipping points in coral reefs or permafrost thaw, without fully integrating social feedbacks (Trung *et al*., 2022; Huang *et al*., 2023). Conversely, social science frameworks highlight adaptive behaviors and institutional responses but undervalue the constraining role of degraded environments (Ncube *et al*., 2023; Mishra *et al*., 2025). This silos approach limits our understanding of how climate stress mediates the coupling between these domains, potentially overlooking critical junctures where small perturbations trigger large-scale shifts (FigueroaValverde *et al*., 2023; Eriksen & Simon, 2025).

A key gap in the literature is the lack of a unified conceptual model that explicitly links environmental degradation to social resilience through threshold dynamics. Thresholds represent nonlinear transitions: in ecology, they denote points where ecosystems shift from one stable state to another, often irreversibly (Okoro *et al*., 2023; Qi *et al*., 2025). In social systems, thresholds might involve the breakdown of community networks or institutional overload, beyond which recovery becomes improbable (Fitero *et al*., 2023; Mahmood *et al*., 2025). Climate stress amplifies these thresholds by accelerating degradation rates and reducing buffering capacities, creating conditions for coupled failures (Fedele *et al*., 2019; Rutten *et al*., 2022). For example, prolonged heat stress can degrade soil quality, diminishing agricultural yields and pushing rural economies toward collapse thresholds (Siddiqi *et al*., 2022; Morris *et al*., 2025).

This manuscript addresses this gap by proposing a novel conceptual framework: the Eco-Social Threshold Coupling Model. This model theorizes that environmental degradation and social resilience are linked via interdependent thresholds, where crossing one domain's limit cascades into the other under climate stress. Unlike prior frameworks that focus on resilience as a static property or degradation as a linear process, our approach introduces a dynamic coupling mechanism parameterized by recent literature (Menard *et al*., 2021; Xie *et al*., 2023). It posits that climate stress acts as a forcing agent, modulating the proximity to thresholds and the strength of feedbacks between ecological and social spheres (Hultström *et al*., 2023; Fransolet & Laurent, 2024).

The framework's novelty lies in its emphasis on threshold-based interactions, conceptualizing them as coupled oscillators where perturbations in one system resonate in the other. This perspective draws inspiration from complex systems theory but applies it uniquely to socio-ecological contexts under climate change (Cissé *et al*., 2024; Multiple authors, 2025). By synthesizing insights from diverse fields, the model provides a theoretical scaffold for understanding how global stressors like climate change could precipitate widespread regime shifts, informing strategies to bolster systemic robustness (Global Environment Facility Independent Evaluation Office, 2022).

In the following sections, we first review the theoretical background, synthesizing literature on environmental degradation, social resilience, and threshold concepts. We then delineate the proposed framework, describing its components and dynamics. This purely conceptual endeavor avoids empirical validation, focusing instead on logical coherence and literature-grounded parameterization to advance theoretical discourse in sustainability sciences (Baptiste *et al.,* 2024).

Theoretical background & literature synthesis

Environmental degradation under climate stress

Environmental degradation refers to the progressive deterioration of natural resources, ecosystem structures, and ecological functions, largely driven by anthropogenic pressures and increasingly intensified by climate change (Zhou *et al*., 2025). Climate stress operates through multiple, interrelated pathways, including rising mean temperatures, altered precipitation regimes, and the increasing frequency and intensity of extreme climatic events, all of which exacerbate existing degradation processes such as habitat fragmentation, soil salinization, desertification, and freshwater depletion (Mizyed, 2025; Washington State Department of Ecology, 2025). Rather than acting as an isolated driver, climate stress amplifies pre-existing vulnerabilities within socio-ecological systems, accelerating degradation trajectories that were previously constrained by ecological thresholds or adaptive management (Ramanathan & von Braun, 2023).

Empirical evidence from arid and semi-arid regions demonstrates that prolonged drought conditions significantly reduce vegetative cover, disrupt soil microbial communities, and weaken soil structure, thereby increasing susceptibility to wind and water erosion (Chang & Vivekanand, 2024; Puig *et al*., 2025). These processes initiate reinforcing feedback loops in which land degradation further reduces moisture retention and primary productivity, deepening climate sensitivity. Importantly, recent literature emphasizes that degradation under climate stress is not merely cumulative; instead, it is synergistic, with climate-induced pressures interacting with pollution, land-use change, and resource overexploitation to produce nonlinear and often irreversible outcomes (Ramanathan & von Braun, 2023; Thazha *et al*., 2023).

Research published highlights biodiversity loss as a central manifestation of climate-driven environmental degradation (Scordato & Gulbrandsen, 2024; Kharecha *et al*., 2025). Species extinctions, population declines, and shifts in community composition undermine ecosystem integrity and functionality, ultimately reducing the capacity of ecosystems to deliver essential services. These changes are increasingly conceptualized through an ecosystem services framework, wherein degradation results in diminished provisioning services such as food and water supply, regulating services such as carbon sequestration and flood control, and cultural services linked to identity, heritage, and well-being (Santos *et al*., 2022). In coastal ecosystems, sea-level rise, saltwater intrusion, and intensified storm surges contribute to the degradation of mangroves and wetlands, weakening their role as natural buffers against erosion and extreme weather events (International Fund for Agricultural Development, 2025).

These dynamics are frequently interpreted through resilience theory, which frames environmental degradation as a process that erodes the absorptive, adaptive, and transformative capacities of ecosystems (Malhi *et al*., 2020; Huang *et al*., 2023). As resilience declines, ecosystems become increasingly vulnerable to regime shifts, where gradual environmental change triggers abrupt transitions to alternative, often less productive and less reversible states. Such shifts underscore the importance of understanding degradation not only as a gradual loss of quality but also as a precursor to critical thresholds with profound ecological and social consequences.

Concepts of social resilience

Social resilience encompasses the capacity of individuals, communities, and institutions to anticipate, absorb, adapt to, and recover from disturbances while maintaining core functions and structures (Maslin *et al*., 2025; Scolozzi *et al*., 2025). Contemporary resilience frameworks emphasize its multidimensional nature, recognizing that resilience is shaped by economic factors such as livelihood diversification, social dimensions including networks and collective identity, and institutional attributes such as governance flexibility and policy responsiveness (Kemarau *et al*., 2025; Zhou *et al*., 2025).

Climate stress challenges social resilience through both chronic pressures, such as prolonged drought or heat stress, and acute shocks, including floods, storms, and sudden resource shortages, which can overwhelm existing coping mechanisms (Fletcher *et al*., 2024; Washington State Department of Ecology, 2025).

Recent scholarship increasingly explores the interaction between social resilience and environmental conditions, arguing that strong social capital—defined by trust, shared norms, and dense networks—can mitigate the impacts of environmental degradation by facilitating cooperation, information exchange, and collective action (Maslin *et al*., 2025; Yan & Li, 2025). Communities with robust social cohesion are often better positioned to mobilize resources, implement adaptive strategies, and engage with external support systems. However, resilience is unevenly distributed, and structural inequalities significantly shape adaptive capacity. Marginalized populations frequently experience heightened exposure to climate stress while lacking access to financial capital, political influence, and technological resources necessary for effective adaptation (Santos *et al*., 2022; Mishra *et al*., 2025).

The literature documents a range of adaptive strategies, including participatory governance, local ecological knowledge sharing, and community-based resource management (Kemarau *et al*., 2025; Mahmood *et al*., 2025). Nevertheless, it also cautions that sustained or intensifying climate stress can erode social resilience over time. Prolonged hardship may deplete social capital, strain institutions, and foster maladaptive responses such as unsustainable resource extraction, social fragmentation, or conflict, thereby pushing social systems closer to critical thresholds of breakdown.

Thresholds in ecological systems

Ecological thresholds represent critical points at which incremental environmental change leads to abrupt, nonlinear shifts in ecosystem structure and function (Fedele *et al*., 2019; Qi *et al*., 2025). Climate change is widely recognized as a factor that lowers these thresholds by modifying fundamental abiotic conditions, such as temperature and moisture regimes, thereby reducing the buffering capacity of ecosystems. For example, sustained warming and drying trends can push forest ecosystems beyond resilience limits, facilitating transitions toward savanna-like states or degraded shrublands (Kharecha *et al*., 2025; Morris *et al*., 2025).

Conceptual and mathematical models describe ecological thresholds as bifurcations in system dynamics, where feedback mechanisms amplify initial disturbances and lock systems into alternative stable states (Fransolet & Laurent, 2024; Puig *et al*., 2025). In polar and high-latitude regions, feedbacks such as ice–albedo interactions accelerate warming and contribute to rapid ecosystem transformation. research increasingly integrates climate projections and remote sensing data to identify early indicators of threshold proximity, such as critical aridity indices associated with dryland desertification (Global Environment Facility Independent Evaluation Office, 2022; Fletcher *et al*., 2024). These studies emphasize that thresholds are highly context-dependent, shaped by historical land use, disturbance regimes, and cumulative stressors, reinforcing the importance of early warning signals and adaptive management strategies (Mizyed, 2025; Yan & Li, 2025).

Thresholds in social systems

Social thresholds refer to limits beyond which social systems experience abrupt losses in functionality, cohesion, or legitimacy, potentially resulting in systemic transformation or collapse (Huang *et al*., 2023; Eriksen & Simon, 2025). Under conditions of climate stress, such thresholds may manifest as tipping points in migration flows, livelihood viability, or institutional capacity. For instance, declining agricultural productivity can reach a point where remaining adaptation options are no longer viable, prompting large-scale displacement or economic restructuring (Menard *et al*., 2021; Mishra *et al*., 2025).

Analytical frameworks conceptualize social thresholds as resilience boundaries, where the exceedance of adaptive capacity leads to fundamental changes in social organization, governance arrangements, or conflict dynamics (Eriksen & Simon, 2025; Multiple authors, 2025). Increasingly, the literature highlights the coupled nature of social and ecological thresholds, demonstrating how environmental tipping points, such as water scarcity or land degradation, can trigger social unrest, political instability, or humanitarian crises (Baptiste *et al*., 2024; Qi *et al*., 2025). Equity considerations are central to this discussion, as thresholds are not uniform across populations. Low-income and marginalized groups often encounter social thresholds earlier due to limited buffers and constrained adaptive options, underscoring the need for inclusive and anticipatory resilience-building strategies (Scordato & Gulbrandsen, 2024; Mahmood *et al*., 2025).

Synthesis: interactions and couplings between ecological and social domains

Integrating the preceding bodies of literature reveals an increasingly recognized pattern of emergent couplings between ecological degradation and social resilience under conditions of climate stress (Fedele *et al*., 2019; International Fund for Agricultural Development, 2025). Rather than operating as parallel or weakly linked processes, ecological and social systems are dynamically intertwined, with changes in one domain actively reshaping trajectories in the other. Environmental degradation alters the material and institutional foundations upon which societies depend, while social responses and governance structures, in turn, influence the rate, direction, and reversibility of ecological change (Malhi *et al*., 2020; Morris *et al*., 2025).

A central feedback identified in recent syntheses involves the erosion of ecosystem services—such as food production, water regulation, and climate buffering—reducing livelihood options and economic security, thereby constraining social adaptive capacity (Malhi *et al*., 2020; Morris *et al*., 2025). As households and communities lose access to stable resource bases, social resilience becomes increasingly strained, manifesting in weakened institutions, declining social cohesion, and heightened vulnerability to shocks. Climate stress acts as a critical modulator in this relationship, intensifying both ecological degradation and social stress while compressing the distance to critical thresholds in each domain (Menard *et al*., 2021; Scolozzi *et al*., 2025). This compression effect implies that systems may transition more rapidly from relative stability to collapse, with limited opportunity for incremental adaptation.

Despite growing recognition of these linkages, substantial gaps persist in how socio-ecological couplings are conceptualized and modeled. Much of the existing literature relies on linear or incremental representations of interaction, which inadequately capture nonlinear dynamics, feedback amplification, and cascading effects across domains (Fransolet & Laurent, 2024; Zhou *et al*., 2025). As a result, current frameworks often underestimate the risk of abrupt, systemic change. This synthesis underscores the need for an alternative analytical approach that explicitly treats ecological and social thresholds as interdependent rather than independent phenomena, thereby enabling a more realistic understanding of socio-ecological dynamics under accelerating climate stress (Multiple authors, 2025; Washington State Department of Ecology, 2025).

Proposed conceptual model

The Eco-Social Threshold Coupling Model is proposed as a novel theoretical framework for examining the reciprocal interactions between environmental degradation and social resilience in climate-stressed systems. This model conceptualizes socio-ecological systems as composed of dynamically linked domains, with thresholds functioning as critical interfaces that govern system stability and transformation. In contrast to existing models that analyze resilience or degradation in isolation, the proposed approach introduces a coupling mechanism grounded in threshold interdependence and informed by synthesized insights from ecological resilience, social systems theory, and climate science (Qi *et al*., 2025; Scolozzi *et al*., 2025; Zhou *et al*., 2025).

The framework comprises three core components: the ecological domain, the social domain, and the climate stress modulator. The ecological domain encompasses processes of environmental degradation, including biodiversity loss, soil deterioration, and resource depletion, which evolve toward critical thresholds where incremental pressures generate disproportionate and often irreversible ecosystem shifts, such as collapse or regime change (Fedele *et al*., 2019; Kharecha *et al*., 2025). The social domain captures dimensions of social resilience, including community networks, livelihood diversity, institutional capacity, and governance effectiveness, which similarly approach thresholds beyond which adaptive limits are exceeded and systemic breakdown becomes likely (Huang *et al*., 2023; Eriksen & Simon, 2025). Climate stress operates as an exogenous but interacting forcing agent, accelerating degradation trajectories and eroding resilience buffers through mechanisms such as intensified droughts, heatwaves, and extreme weather events (Mizyed, 2025; Washington State Department of Ecology, 2025).

The defining innovation of the model lies in its threshold-based coupling logic. Ecological and social thresholds are treated not as isolated endpoints but as mutually influential through bidirectional feedbacks. Crossing an ecological threshold—for example, irreversible soil degradation—can cascade into the social domain by undermining agricultural livelihoods, weakening economic security, and accelerating the approach toward social thresholds such as community disintegration or mass outmigration (Huang *et al*., 2023; Maslin *et al*., 2025). Conversely, the transgression of social thresholds, such as governance failure or institutional collapse, can exacerbate ecological degradation by enabling unsustainable resource extraction, reducing regulatory enforcement, and diminishing collective stewardship (Kemarau *et al*., 2025; Qi *et al*., 2025). These interactions are conceptualized as resonant feedbacks, wherein disturbances in one domain propagate into the other and amplify overall system instability, potentially producing synchronized regime shifts across ecological and social systems (Fedele *et al*., 2019; Fransolet & Laurent, 2024).

Formally, the model represents ecological state as E (degree of degradation), social resilience as S, and climate stress intensity as C. Critical thresholds are denoted as E_t and S_t, beyond which system states shift toward alternative and less desirable equilibria. The coupled dynamics are expressed conceptually as $dE/dt = f(C) + g(S)$ and $dS/dt = h(C) + i(E)$, where the functions f and h represent direct climate-driven stress effects, and g and i capture cross-domain feedbacks between social and ecological states (Global Environment Facility Independent Evaluation Office, 2022; Fletcher *et al*., 2024). Importantly, proximity to thresholds increases system sensitivity; as E approaches E_t, the feedback term $i(E)$ intensifies, accelerating the movement of S toward S_t, and vice versa (Malhi *et al*., 2020; Menard *et al*., 2021).

This framework highlights the existence of socio-ecological vulnerability hotspots, where high baseline degradation or low initial resilience predispose systems to rapid and cascading transitions (Eriksen & Simon, 2025; Yan & Li, 2025). It also emphasizes the strategic importance of preventive interventions, such as threshold monitoring, early warning indicators, and integrated governance approaches, aimed at interrupting feedback loops before critical transitions are triggered (Baptiste *et al*., 2024; Multiple authors, 2025). By foregrounding threshold interdependence, the Eco-Social Threshold Coupling Model advances theoretical understanding and provides a foundation for more effective policy and management responses in an era of escalating climate stress.

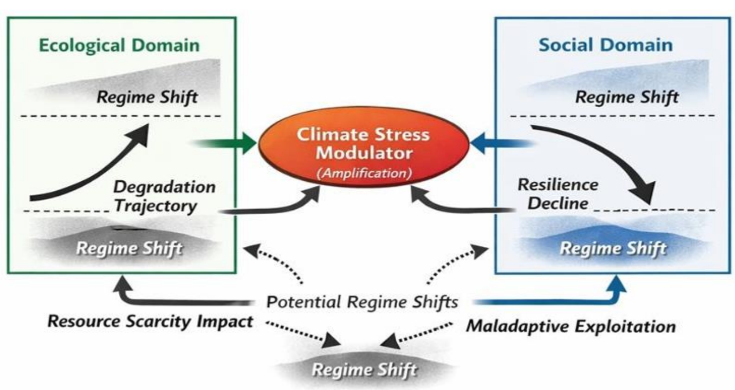

Figure 1. Coupled Ecological–Social Cascade Model with Climate Stress Amplification

This textual description captures the framework's logic without visual aids, emphasizing theoretical novelty in threshold coupling for socio-ecological analysis.

Propositions

Building on the Eco-Social Threshold Coupling Model, this study advances a set of propositions that articulate the theoretical implications of threshold-based interactions between environmental degradation and social resilience under climate stress. These propositions are logically derived from the synthesized literature and the internal dynamics of the proposed framework. Collectively, they function as analytically testable hypotheses that can guide future conceptual development, comparative case analysis, and empirical investigation.

Proposition 1

Climate stress intensity moderates the strength of coupling between ecological and social thresholds, such that increasing levels of climate stress reduce the distance to both thresholds and heighten the probability of synchronized regime shifts. Under elevated climate forcing—such as prolonged heatwaves or recurrent droughts—feedback mechanisms intensify, compressing adaptive buffers and accelerating joint transitions across ecological and social domains (Qi *et al*., 2025; Washington State Department of Ecology, 2025).

Proposition 2

Low baseline social resilience amplifies rates of environmental degradation, thereby pushing ecological systems closer to critical thresholds through mechanisms such as resource overexploitation, weakened governance, and short-term coping strategies during periods of stress. Conversely, high baseline social resilience delays ecological threshold crossing by enabling collective action, institutional learning, and sustainable resource management, indicating an asymmetric but decisive influence of social capacity on ecological stability (Fedele *et al*., 2019; Eriksen & Simon, 2025).

Proposition 3

The crossing of an ecological threshold induces a nonlinear decline in social resilience, characterized by intensified social inequities, erosion of livelihoods, and diminished adaptive capacity, particularly in resource-dependent and marginalized communities. This cascade effect reflects the interdependent nature of socio-ecological systems, wherein ecological disruptions—such as biodiversity loss—undermine economic, cultural, and institutional dimensions of resilience (Kharecha *et al*., 2025; Yan & Li, 2025).

Proposition 4

Targeted interventions focused on threshold monitoring and early warning signals can weaken or temporarily decouple ecological–social feedbacks, thereby enhancing overall system stability. By enabling anticipatory adjustments before feedback amplification occurs, such interventions expand adaptive space and reduce the likelihood of cascading failures, consistent with resilience theory's emphasis on proactive and flexible governance structures (Fletcher *et al*., 2024; Mahmood *et al*., 2025).

Proposition 5

Threshold coupling dynamics are scale-dependent in heterogeneous socio-ecological systems. At local scales, couplings are tighter due to direct dependencies between ecosystems and livelihoods, while at regional and global scales, threshold interactions exhibit delayed or mediated effects through mechanisms such as trade, migration, and institutional redistribution. This spatial differentiation implies that climate stress disproportionately intensifies localized vulnerabilities, underscoring the necessity of scale-sensitive and context-specific policy responses (Ramanathan & von Braun, 2023; Scolozzi *et al*., 2025).

Table 1. Summary of Propositions Derived from the Eco-Social Threshold Coupling Model

Proposition	Core Theoretical Claim	Direction of Coupling	Dominant Mechanism	Indicative Conceptual Signals
Proposition 1	Climate stress intensity moderates the strength of coupling between ecological and social thresholds, compressing adaptive buffers and increasing the likelihood of synchronized regime shifts.	Bidirectional (E ↔ S)	Threshold compression and feedback amplification under external forcing	Increasing frequency of extreme events, reduced recovery time, convergence of ecological and social stress indicators
Proposition 2	Low baseline social resilience accelerates environmental degradation, while high social resilience delays ecological threshold crossing through governance and collective action.	Social → Ecological (S → E)	Asymmetric influence of social capacity on ecological stability	Governance effectiveness, resource management practices, institutional continuity
Proposition 3	Crossing an ecological threshold precipitates a nonlinear decline in social resilience, disproportionately affecting resource-dependent and marginalized communities.	Ecological → Social (E → S)	Cascading failure and loss of ecosystem services	Livelihood collapse, increased inequality, erosion of cultural and economic assets
Proposition 4	Threshold monitoring and early warning interventions can weaken or temporarily decouple ecological–social feedbacks, enhancing system stability.	Bidirectional (E ↔ S)	Anticipatory governance and feedback dampening	Early warning indicators, adaptive policy responses, preventive institutional action
Proposition 5	Threshold coupling dynamics are scale-dependent, with tighter couplings at local scales and lagged or mediated effects at regional and global scales.	Scale-mediated coupling	Spatial heterogeneity and cross-scale interactions	Local resource dependence, trade flows, migration dynamics

Taken together, these propositions encapsulate the model's central contribution by framing threshold coupling as a dynamic, process-oriented phenomenon rather than a static condition. They emphasize the importance of interdisciplinary analytical lenses for understanding and governing socio-ecological systems under accelerating climate stress, and they provide a structured foundation for future theoretical extensions and empirical validation (Kemarau *et al*., 2025).

RESULTS AND DISCUSSION

The Eco-Social Threshold Coupling Model advances a nuanced understanding of the interplay between environmental degradation and social resilience by explicitly integrating threshold dynamics under conditions of climate stress. In doing so, it addresses a critical gap in existing socio-ecological frameworks, which often acknowledge interactions between ecological and social systems but insufficiently theorize how nonlinear thresholds and feedbacks jointly shape system trajectories. By conceptualizing thresholds as interdependent rather than isolated, the model highlights climate stress as a systemic multiplier that accelerates coupled dynamics and increases the likelihood of irreversible socio-ecological regime shifts. This reconceptualization carries significant implications for both theoretical development and applied policy design.

From a theoretical standpoint, the model challenges reductionist approaches that compartmentalize ecological and social domains, instead advancing a systems-oriented perspective in which feedbacks generate emergent vulnerabilities and path-dependent outcomes (Santos *et al*., 2022; Zhou *et al*., 2025). This aligns with and extends scholarship on planetary boundaries, which demonstrates that transgressing ecological limits—such as those related to biodiversity integrity or climate regulation—can precipitate social tipping points, including forced migration, food insecurity, and institutional destabilization (Fransolet & Laurent, 2024; Kharecha *et al*., 2025). The present framework builds on these insights by explicitly parameterizing the coupling between ecological and social thresholds, framing them as resonant processes in which climate stress synchronizes the approach to critical limits. This conceptualization draws analogies to coupled oscillators in complex systems theory, where external forcing aligns system dynamics and amplifies transitions (Scordato & Gulbrandsen, 2024; Washington State Department of Ecology, 2025). The principal theoretical contribution lies in rejecting linear assumptions and instead foregrounding nonlinear cascades that intensify under climate stress, thereby enriching and extending contemporary resilience discourse (Fedele *et al*., 2019; Puig *et al*., 2025).

From a policy and governance perspective, the model underscores the urgency of adopting threshold-oriented strategies rather than incremental or sectorally isolated interventions. The identification and monitoring of early warning indicators—such as soil moisture or vegetation indices for ecological thresholds, and measures of social capital, institutional trust, or livelihood diversity for social resilience limits—could support anticipatory governance and reduce the likelihood of cascading failures (Fletcher *et al*., 2024; Scolozzi *et al*., 2025). In highly vulnerable contexts, particularly arid and semi-arid regions experiencing accelerated degradation, policies that strengthen social equity and institutional capacity may serve as indirect yet powerful buffers against ecological collapse, given that structural inequities frequently intensify threshold couplings (Eriksen & Simon, 2025; Maslin *et al*., 2025). Such insights suggest that social policy is not merely complementary to environmental management but integral to maintaining ecological stability under climate stress.

Nevertheless, several limitations warrant consideration. The model remains conceptual and does not provide quantitative estimates of coupling strength or threshold proximity, relying instead on literature-based parameterization that may obscure context-specific dynamics and empirical variability (Fletcher *et al*., 2024; Yan & Li, 2025). Additionally, while the framework emphasizes interdependence, it does not yet account for the full complexity of multi-scale interactions, including cross-regional spillovers mediated by trade, migration, and geopolitical dynamics. Future research could address these limitations by operationalizing the model through comparative case studies, longitudinal data analysis, or simulation-based approaches such as agent-based modeling, which may capture emergent couplings even in data-scarce environments (Ramanathan & von Braun, 2023; Kemarau *et al*., 2025).

Beyond analytical and policy considerations, the framework foregrounds important ethical and equity dimensions. Coupled threshold dynamics are rarely socially neutral; they tend to disproportionately burden marginalized populations that already face constrained adaptive capacity due to historical exploitation, governance exclusion, and environmental degradation legacies (Malhi *et al*., 2020; Fransolet & Laurent, 2024). By explicitly rejecting assumptions of uniform resilience, the model calls for inclusive and justice-oriented approaches that recognize differentiated vulnerabilities and responsibilities across social groups and regions (Kemarau *et al*., 2025; Mahmood *et al*., 2025).

In sum, the Eco-Social Threshold Coupling Model contributes a theoretically integrative and policy-relevant lens for understanding socio-ecological change in an era of intensifying climate stress. By bridging ecological science and social theory through the concept of interdependent thresholds, it fosters interdisciplinary dialogue and provides a foundation for guiding more equitable and sustainable transitions in increasingly fragile socio-ecological systems (Kharecha *et al*., 2025; Qi *et al*., 2025).

CONCLUSION

In summary, this manuscript presents the Eco-Social Threshold Coupling Model as a novel theoretical construct linking environmental degradation and social resilience through interdependent thresholds under climate stress. By synthesizing recent literature, we demonstrate how climate acts as a forcing agent, intensifying feedbacks and heightening risks of regime shifts. The propositions delineate key dynamics, offering a scaffold for understanding systemic vulnerabilities.

This framework advances conceptual discourse by emphasizing coupling mechanisms, departing from siloed analyses to highlight nonlinear interactions. Its implications extend to policy, advocating threshold monitoring and equitable interventions to enhance stability. While purely theoretical, it paves the way for future integrations, urging scholars to explore these couplings in diverse contexts.

As climate stress escalates, recognizing threshold interdependencies is paramount to fostering resilient socio-ecological futures.

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