17(4) 529-542, Winter 2025

Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: http://www.aejournal.ir

## Original Research Paper

# Adaptive Co-Management Frameworks for Protected Areas Integrating Local Livelihoods and Wildlife Conflict Mitigation

***Dr.R. Thyagarajan[1*], Dr. Varsha Agarwal[2], Dr. Gaurav Kumar Ameta[3], Hoshiyar Singh[4], Uma Bhardwaj[5], Dr. Samarendra Kumar Mohanty[6], Dinesh Goyal[7]***

*[1*]Associate Professor, Department of Biotechnology, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India. Email: thyagarajan.biotech@sathyabama.ac.in,*
*ORCID: https://orcid.org/0000-0002-1653-9276*
*[2]Director, ISME, ATLAS SkillTech University, Mumbai, India. Email: varsha.agarwal@atlasuniversity.edu.in, ORCID: https://orcid.org/0000-0001-8406-9213*
*[3]Associate Professor, Department of Computer Science and Engineering, Faculty of Engineering and Technology, Parul Institute of Technology, Parul University, Vadodara, Gujarat, India.*
*Email: gaurav.ameta24442@paruluniversity.ac.in, ORCID: https://orcid.org/0000-0002-7463-2583*
*[4]Professor, Department of Agriculture, Vivekananda Global University, Jaipur, India.*
*Email: hoshiyar.singh@vgu.ac.in, ORCID: https://orcid.org/0000-0001-8993-9185*
*[5]Professor, Department of Biotechnology and Microbiology, Noida international University, Noida, Uttar Pradesh, India. Email: vc@niu.edu.in, ORCID: https://orcid.org/0000-0002-6414-9731*
*[6]Assistant Professor, Department of Livestock Production Management, Institute of Veterinary Science and Animal Husbandry, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, Odisha, India. Email: samarendrakuamarmohanty@soa.ac.in, ORCID: https://orcid.org/0009-0000-4202-7410*
*[7]Quantum University Research Center, Quantum University, Roorkee, Uttarakhand, India. Email: dinesh.ca@quantumeducation.in, ORCID: https://orcid.org/0009-0004-3157-0695*

**Key Words**

Adaptive co-management, Conflict mitigation, Human–wildlife conflict, Livelihood resilience, Protected areas, Socio-ecological systems, Vegetation condition.

**Abstract**

In human-dominated habitats, human-wildlife conflict is a challenge that is frequently observed to affect the existence of protected areas that serve as important in conserving biodiversity. This paper set out to advance and test the adaptive co-management framework, which combines local livelihoods in a way that supports conflict mitigation to improve socio-ecological resilience. The data were gathered under the mixed-method socio-ecological systems approach, through the various protected areas that differ in governance regimes, livelihood dependence, and conflict intensity. Human-wildlife conflict data were based on the incident records, participatory mapping, and household survey, and the ecological indicators such as habitat condition and fragmentation obtained using the multi-temporal Landsat and Sentinel. Composite indices of livelihood resilience and participation in governance included income diversity, adaptive capacity, institutional access, and stakeholder engagement. The findings indicated that strong co-managed sites had the lowest levels of conflict ($HWC_i = 2.1 \pm 0.3$), highest resilience livelihood ($LRI_i = 0.74 \pm 0.05$), and better habitat condition ($VCI = 0.68 \pm 0.04$), and weakly managed sites had the highest levels of conflict ($HWC_i = 5.2 \pm 0.6$), low resilience ($0.39 \pm 0.07$). The involvement of governance positively affected livelihood resilience ($\beta = 0.62$, $p < 0.001$) and indirectly decreased the intensity of conflict ($\beta = -0.48$, $p < 0.01$), with adaptive learning having a further positive impact on institutional effectiveness ($\beta = 0.55$, $p < 0.001$). The researchers summarize the research by concluding that adaptive co-management, which provides a structured feedback-driven learning and livelihood assistance, can reduce HWC, enhance community resilience, and ecological performance all at the same time. Further research must aim at expanding the framework to various socio-ecological settings and implement technological assistance in monitoring and mitigation of proactive conflicts.

* Corresponding Author's email: thyagarajan.biotech@sathyabama.ac.in
Received: 17 September 2025; Reviewed: 23 October 2025; Revised: 01 December 2025; Accepted: 29 December 2025
**(DOI): 10.70102/AEJ.2025.17.4.41**

## Introduction

The core element of global biodiversity conservation is protected areas, but human pressures and changes in land-use, as well as climate change, increasingly question these conservation methods (Ullah et al., 2022; Ma et al., 2023). The majority of the regions harbor protected areas encircled by human-architectural landscape where people tend to rely on forest resources as their sources of livelihoods, including agriculture, grazing, non-timber forest product harvesting, and ecotourism (da Silva et al., 2025; Chakanyuka & Utete, 2022). Such a close spatial and socio-economic association frequently leads to the Human Wildlife Conflict (HWC) in the form of crop raiding, livestock depredation, property damage, and human safety threats (Kilonzi & Ota, 2023). These wars weaken conservation and destroy domestic sponsorship of the management of the protected areas. Traditional models of protected area governance were predominantly based on centralization and top-down models that focus on the ecological goals and pay little attention to the local livelihood issues (Baten, 2024; Senghor et al., 2023). Such approaches have frequently proven inadequate in addressing dynamic socio-ecological interactions and escalating wildlife conflicts. Conversely, adaptive co-management has become one of the promising governance paradigms that integrates the principles of iterative learning associated with adaptive management, as well as the collaborative decision-making of co-management (Galappaththi et al., 2022; Ma et al., 2023). Adaptive co-management structures aim to address institutional flexibility, integration of knowledge, and shared responsibility, harmonizing conservation objectives and human welfare as well as limiting conflicts through active involvement of local communities, state agencies, and other stakeholders (Kilonzi & Ota, 2023; Chowdhury et al., 2022).

The main aim of this research is to design and test an adaptive co-management system of the protected areas that would, at the same time, sustain the local livelihood and reduce the human-wildlife conflict. Specifically, the study aims to assess how participatory governance, local ecological knowledge, and adaptive learning mechanisms can be integrated into protected area management to reduce conflict incidence while sustaining biodiversity conservation (Baten, 2024; Galappaththi et al., 2022). Additionally, the study seeks to identify governance structures, livelihood interventions, and conflict mitigation strategies that enhance resilience and long-term coexistence between human and wildlife populations.

Although the adaptive approach to co-management in conservation discussions has received increased attention, a number of important gaps still exist. One, there are limited empirical research investigations that clearly identify adaptive co-management processes as defined by quantifiable resources in matters concerning human-wildlife conflict reduction. Second, most of the current frameworks consider livelihoods and conflict mitigation as complementary and not interdependent entities within a coupled socio-ecological system. Third, the mechanisms of adaptive feedback, including

learning in conflict events, livelihood monitoring, and management interventions adjustment, are not well understood in varying institutional and ecological settings. Lastly, not many works provide working frameworks that can be directly applied and expanded to the secured regions of the Global South, where the reliance on livelihood and the level of the conflict is the most significant (Ullah et al., 2022; Karim et al., 2024).

The hypothesis guiding this study is that, when areas are managed by protecting them through the adaptive co-management frameworks, there will be lower rates of human-wildlife conflict than areas managed through the traditional centralized methods, owing to the enhanced stakeholder involvement and context-based decisions. The hypotheses further postulate that participation of livelihood-support mechanisms in adaptive co-management will improve community tolerance to wildlife, resulting in the minimization of retaliation and conservation success. Lastly, it is assumed that through the repetition of learning and feedback, the institutional capacity of management systems to be responsive to the changing ecological and socio-economic conditions will be enhanced (Galappaththi et al., 2022; Chowdhury et al., 2022).

This research has some important contributions to conservation science and governance of the protected areas. First, it suggests a combined adaptive co-management model that clearly attaches livelihood sustainability and mitigation of wildlife conflicts. Second, it offers empirical data on the value of the participatory and adaptive mode of governance in lessening HWC. Third, the research develops a socio-ecological systems (SES) viewpoint by showing the combined effects of local knowledge, institutional learning, and adaptive interventions on conservation and livelihood results. Lastly, the results provide some practical policymaking insights and implementation recommendations to the managers of protected areas and the policy-makers pursuing the promotion of resilient, inclusive, and conflict-sensitive conservation measures.

The article starts with an Introduction that describes the problem of human-wildlife conflict (HWC) in the protected areas and how adaptive co-management can be used to incorporate conservation and livelihoods. The Literature Review presents the synthesis of the world's evidence about co-management, conflict mitigation, and socio-ecological resilience. The description of the mixed-methods socio-ecological systems approach, the site selection, data gathering regarding the HWC, livelihoods, governance, and ecological metrics, and analytical methods (GLM, SEM, and spatial analyses) are described in Materials and Methods. Findings provide the trends in conflict, livelihood resilience, participation in governance, and ecological outcomes. The socio-ecological linkages are discussed, the effectiveness of the framework is marked in the Conclusion, and practical implications and future research directions are identified.

## Literature Survey

Governance Adaptive co-management has emerged as one of the most popular governance

mechanisms that would manage to balance conservation of biodiversity with local livelihood requirements in and around the areas of protection. An extensive amount of literature is explicit that traditional top-down conservation models tend to distance local communities, creating livelihood instability, loss of trust, and enhanced HWC (Muchapondwa & Ntuli, 2024; Kang et al., 2025). As a reaction to this, co-management systems, which focus on joint decision-making, involvement of stakeholders, and institutional learning, have been implemented more and more in a variety of socio-ecological settings.

In South and Southeast Asia, empirical studies have shown that co-management has the potential to positively impact the forest cover, restoration success, and landscape integrity. Research in Bangladesh demonstrates that the state of the forest and decreased deforestation in co-managed protected areas are better than in the strictly state-controlled systems, and yet, the results are diverse regarding the power relations and the degree of actual participation (Ullah et al., 2022; Chowdhury et al., 2022; Karim et al., 2024). Nevertheless, skeptical evaluations warn that the effectiveness of co-management is frequently limited by unequal power relations, lack of community empowerment, and elite capture, which can contravene livelihood gains and long-term conservation targets (Baten, 2024; Islam et al., 2022).

In addition to the condition of the forest, a number of studies focus on adaptive co-management as a measure to curb HWC. Africa and Asian case studies enable us to understand that locally implemented adaptive methods, including participatory monitoring, conflict-responsive governance, and the diversification of livelihoods, can improve coexistence with wildlife species as diverse as crocodiles or leopard cats (Chakanyuka & Utete, 2022; Nguyen et al., 2024; Nguyen et al., 2025). These works point to the relevance of iterative learning and locally situated knowledge systems as a way of responding to dynamic conflict situations.

Adaptive co-management is being increasingly presented in a resilience and socio-ecological systems perspective in the global arena. Latin American, arctic, and marine protected region research studies highlight that adaptive co-management based on resilience enhances flexibility of the system, cross-scale learning, and enhances the ability to adapt to change (Neira et al., 2022; Galappaththi et al., 2022; Senghor et al., 2023). Integrating local and Indigenous knowledge has also been identified as a critical factor for legitimacy, compliance, and long-term stewardship (Nishima-Miller, 2025; Gatlewar, 2025).

In spite of these developments, literature is always citing a lack of trade-offs among conservation goals, livelihood security, and conflict concerns. Although co-management has the potential to enhance perceptions and participation, a positive ecological and social outcome is not invariably achieved and requires institutional design, adaptive capacity, and context-sensitive implementation (Ma et al., 2023; Wang & Li, 2025; Nchanji et al., 2023). As a result, an increasing demand is being made to have integrative adaptive co-management

models that clearly tie livelihoods, governance, and wildlife conflict mitigation in the management of the protected areas.

## Materials and methods

### Study Design and Conceptual Framework

This study adopted a mixed-methods, SES approach to evaluate adaptive co-management frameworks in protected areas, with explicit integration of local livelihoods and HWC mitigation. This research design was a combination of quantitative ecological and socio-economic evaluation with qualitative institutional and governance evaluation. An adaptive co-management conceptual framework was formed based on the combination of the principles of co-management (shared authority, participation, and equity) and adaptive management (learning-by-doing, feedback loops, and iterative decision-making). Livelihood resilience and conflict dynamics were treated as interlinked components within the SES framework.

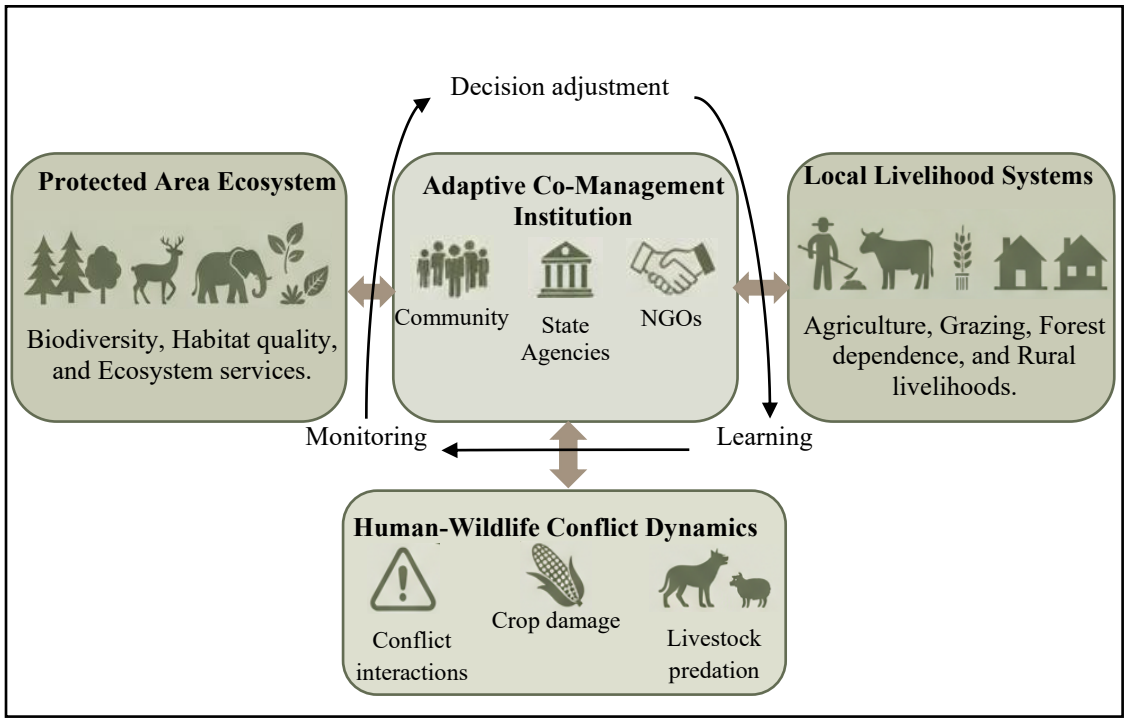


Figure 1: Conceptual Framework Of Adaptive Co-Management Integrating Protected Area Ecosystems, Local Livelihoods, And Human–Wildlife Conflict Mitigation

The present study is based on a socio-ecological systems approach that is mixed, i.e., it will study adaptive co-management in the selected areas, directly connecting the governance systems to the local livelihoods and the dynamics of human-wildlife conflict. The conceptual framework that informs the research (Figure 1) is a scenario of how the ecosystems of the protected areas, the livelihood systems of the local communities, and the conflict processes interact with one another through adaptive co-management institutions and through the feedback loops of monitoring, learning, and decision adjustment.

## Study Area Selection

A purposive sampling strategy was used to select protected areas to be able to capture the variation in governance regimes, livelihood dependence, and conflict intensity. The criteria of selection were as follows: (i) official implementation of co-management or participatory systems of governance, (ii) the presence of nearby human settlements that are livelihood-dependent on the resources within the area, and (iii) the presence of documented human-wildlife conflict. The spatial spillover effects were captured by integrating buffer zones and community land that were directly neighboring the zone. Various seasons were used to conduct the study to ensure that the temporal fluctuations in livelihood activities and the occurrence of conflict were taken into consideration.

## Data Collection

### *Ecological and Conflict Data*

The data used in HWC were gathered using a mixture of official incidents, participatory conflict mapping, and household-based reporting. The frequency of crop raiding, livestock depredation, property damage, and human injury or mortality was the indicator of conflict. Multi-temporal remote sensing data were used to calculate ecological indicators like change in land-cover, fragmentation of habitats, and the condition of the vegetation (e.g., Landsat and Sentinel imagery), and were verified in the field.

### *Livelihood and Socio-Economic Data*

Household questionnaires were conducted at a randomized sampling method, which was stratified in communities surrounding the protected areas. The livelihood portfolios, the sources of income, the reliance on the resources, the perception of the wildlife, the degree of tolerance, and the status of involvement in the co-management institutions were represented by the survey tools. Composite indices that included income diversity, adaptive capacity, and access to institutional support were used as the measure of livelihood resilience.

### *Governance and Institutional Data*

The qualitative data were gathered based on key informant interviews, focus group discussions, and document analysis. These participants were the representatives of the community, the managers of the protected areas, the government officials of the local government, and the non-governmental organizations. This information is centered on the decision-making processes, power-sharing systems, conflict settlement mechanisms, and adaptive learning systems in co-management systems.

### *Data Analysis*

Multivariate statistical methods were applied in order to test the relationship between governance participation and livelihood outcomes and the occurrence of conflicts. Linkages among hypothesized adaptive co-management attributes and socio-ecological outcomes were tested using generalized linear models and structural equation modeling. The spatial analyses were done within a GIS setting in order to determine conflict hotspots and land-use patterns.

### *Framework Evaluation and Validation*

A multi-criteria assessment, including ecological effectiveness, livelihood sustainability, conflict reduction, and governance inclusiveness, was used to evaluate the proposed adaptive co-management framework. The stakeholder validation workshops were carried out to fine-tune the framework and give it a relevant context. The data collection was carried out with ethical approval, and informed consent was obtained from all participants.

## Results

### Human–Wildlife Conflict Intensity and Spatial Patterns

HWC intensity varied substantially across protected areas and governance contexts. To quantify conflict pressure in a standardized manner, a composite Human–Wildlife Conflict Index ($HWC_i$) was calculated for each site by aggregating multiple conflict types, weighted by their perceived severity:

$$HWC_i = \sum_{j=1}^{n} w_j \times F_{ij} \qquad (1)$$

In equation (1), $F_{ij}$ represents the recorded frequency of conflict type $j$ (crop raiding, livestock depredation, property damage, and human injury or mortality) at site or household $i$, and $w_j$ denotes severity weights derived through stakeholder consultation. Higher $HWC_i$ values, therefore, indicate both more frequent and more socially severe conflict events.

Analysis of $HWC_i$ revealed significantly lower conflict intensity in sites characterized by strong co-management arrangements. Spatial analysis also revealed that hotspots of conflicts were centred in buffer zones and the community surrounding lands, with the exception of habitat boundaries and corridors of wildlife movement. The seasonal dynamics revealed that $HWC_i$ values were high during the peak agricultural seasons and dry seasons, indicating high levels of wildlife invasions in agricultural works.

### Livelihood Resilience and Household Adaptive Capacity

Communities had a significant difference in livelihood resilience, which was closely linked to governance participation. Livelihood results were measured in terms of a Livelihood Resilience Index ($LRI_i$), which is an equal-weight composite of income diversity, adaptive capacity, and institutional access:

$$LRI_i = \frac{D_i + A_i + I_i}{3} \qquad (2)$$

In equation (2), $D_i$ denotes livelihood income diversity, $A_i$ will be the household adaptive capacity (education, skills, livelihood flexibility), and $I_i$ will be the access to institutional support mechanisms, including compensation schemes, extension services, and co-management institutions. Every part was scaled to 0-1 in order to make them similar.

The findings showed that the households in co-management institutions had a much better $LRI_i$ value, which has a more diversified livelihood and coping mechanisms. Notably, an increased livelihood resilience relied on a greater tolerance towards wildlife and a lesser perceived susceptibility to the impacts of conflict. Contrastingly, conflict sensitivity was

disproportionately greater in households with low $LRI_i$ values, especially those depending on single household incomes, like rain-fed agriculture.

Table 1: Human–Wildlife Conflict and Livelihood Resilience Across Governance Contexts

| Governance context | HWC Index (mean ± SE) | Livelihood Resilience Index | Tolerance toward wildlife |
|---|---|---|---|
| Strong co-management | 2.1 ± 0.3 | 0.74 ± 0.05 | High |
| Moderate co-management | 3.6 ± 0.4 | 0.58 ± 0.06 | Moderate |
| Weak co-management | 5.2 ± 0.6 | 0.39 ± 0.07 | Low |

The relationship between $HWC_i$, $LRI_i$, and wildlife tolerance is illustrated in Table 1, which presents HWC and LRI with wildlife tolerance together across governance contexts. The negative correlation between livelihood resilience and conflict level is very apparent. This table demonstrates the inverse relationship between livelihood resilience and conflict intensity across governance regimes.

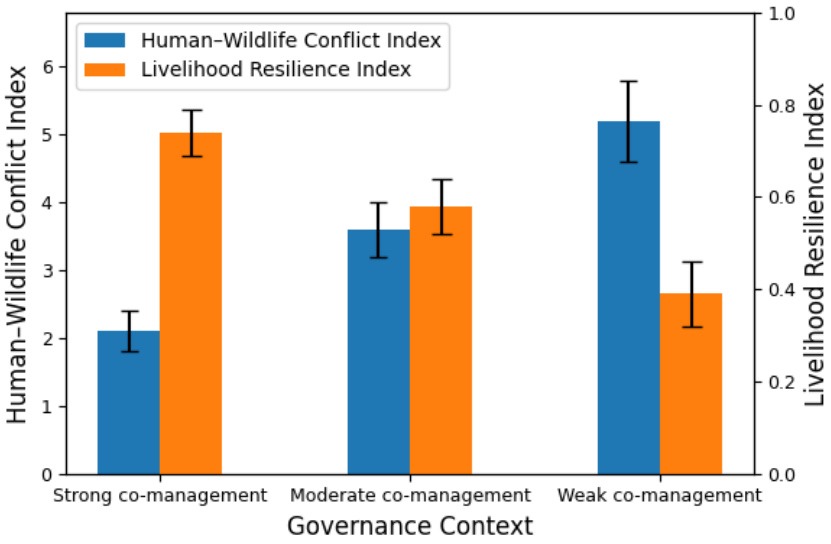


Figure 2: Contrasting Human–Wildlife Conflict Intensity and Livelihood Resilience Across Governance Contexts

Figure 2 demonstrates a different trend between the intensity of the human-wildlife conflict and livelihood resilience in each of the governance settings. Strong co-management sites have the lowest level of conflict index and the greatest resilience to livelihoods compared to weak co-management sites, which have the greatest level of conflict and the lowest resilience. The conflicting patterns along the governance gradient reflect the inverse relationship between livelihood resilience and the intensity of conflict, and it is important to note the importance of good governance in reducing human-wildlife conflict.

## Governance Participation and Institutional Effectiveness

The level of governance engagement was measured through a Governance Participation

Score $GPS_i$ that made an effort to capture the level of household/community participation in co-management processes:

$$GPS_i = \frac{P_i + S_i + E_i}{3} \quad (3)$$

$P_i$ in equation (3) represents the frequency of participation in the meetings and decision-making forums; $S_i$ is perceived power-sharing between the authorities and the communities; and $E_i$ is equity and inclusiveness in the governance systems. The increased $GPS_i$ values, therefore, indicate more substantive and meaningful participation.

Communities that exhibited greater $GPS_i$ ions tended to exhibit more adaptive learning behaviors (such as frequent monitoring, incorporation of feedback, and revision in policies after conflict situations). Qualitative data demonstrated that institutional legitimacy and trust were strengthened by good decision-making and conflict resolution systems, which were local and entrenched, strengthening compliance and cooperation.

## Ecological Condition and Habitat Dynamics

Remote sensing was used to measure ecological outcomes based on indicators derived through remote sensing, and habitat quality was measured by a Veget

ation Condition Index (VCI):

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (4)$$

Multi-temporal Landsat and Sentinel images were used to estimate the NDVI values in equation (4). The VCI is a normalized estimate of vegetation health, with high indicating a high level of habitat health.

Table 2: Ecological Indicators Across Governance Contexts

| Indicator | High participation sites | Low participation sites |
|---|---|---|
| Vegetation Condition Index | 0.68 ± 0.04 | 0.42 ± 0.05 |
| Habitat fragmentation | Low | High |
| Conflict hotspot density (events km$^{-2}$) | 1.9 | 4.7 |

The sites of good governance involvement showed much larger VCI values and reduced habitat fragmentation, which indicated that adaptive co-management had an effect on better ecological results. On the other hand, sites that had weak governance characterized vegetation degradation and fragmentation, which were spatially related to the high conflict hot spots. These ecological contrasts are presented in Table 2, highlighting the linkage between governance effectiveness and habitat condition.

## Integrated Socio-Ecological Linkages

Generalized linear models and structural equation modeling (SEM) were used to examine causal relationships among governance participation, livelihood resilience, and conflict intensity. SEM results demonstrated that governance participation had both direct and indirect effects on conflict reduction. In particular, greater $GPS_i$ values promoted livelihood resilience ($LRI_i$), which subsequently had a great impact in minimizing $HWC_i$.

Table 3: Structural Equation Model Results Linking Governance, Livelihoods, and Conflict

| Pathway | Standardized coefficient | p-value |
|---|---|---|
| Governance participation → Livelihood resilience | 0.62 | <0.001 |
| Livelihood resilience → HWC index | −0.48 | <0.01 |
| Governance participation → HWC index (direct) | −0.31 | <0.05 |
| Adaptive learning → Governance effectiveness | 0.55 | <0.001 |

Table 3 quantifies these relationships, showing that standardized path coefficients, both the effect of governance on livelihood resilience is strong and negative, and the effect of livelihood resilience on conflict intensity is also significant. The resulting adaptive learning mechanisms enhanced the effectiveness of governance, thus the need to value the significance of the feedback-based institutional processes.

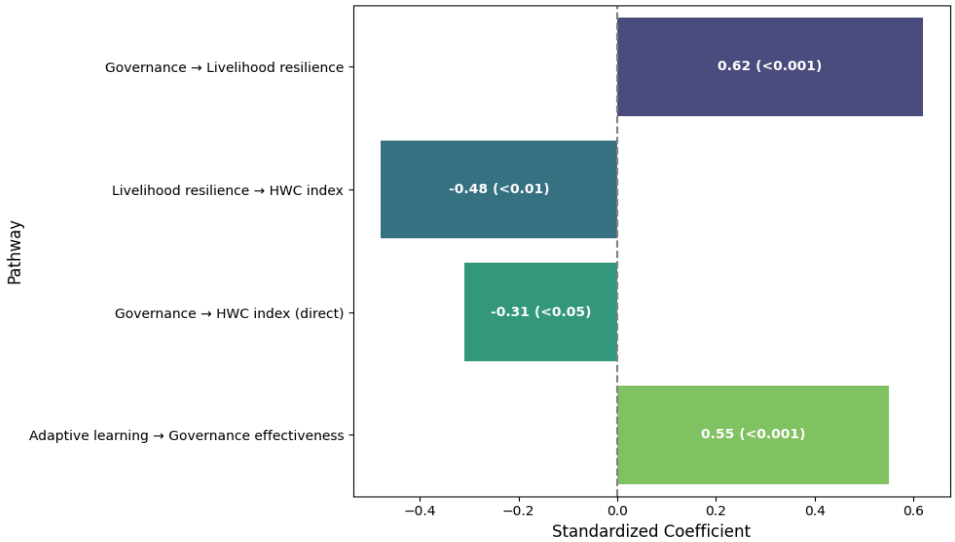


Figure 3: Structural Equation Model Pathways Linking Governance, Livelihoods, and Human–Wildlife Conflict

The standardized coefficients of the most important SEM pathways are visualized in Figure 3, which demonstrates how the participation of governance, adaptive learning, and livelihood resilience affect the intensity of human-wildlife conflict (HWC). Positive coefficients indicate enhancing effects, whereas negative coefficients represent conflict-reducing influences. The coefficients and the statistical significance (p-values) are also presented within the bars so that it is easy to see the relationship in terms of strength and trustworthiness of each of the pathways.

## Framework Performance and Validation

The adaptive co-management system was measured with a multi-criteria measurement that incorporates conflict minimization, livelihood sustainability, ecological efficacy, and governance inclusivity. Sites with a high result on governance and adaptive learning always ranked higher in all areas. These findings were

supported by stakeholder validation workshops, and the respondents stressed the practical applicability of the framework and its suitability across different socio-ecological settings.

## Discussion

Comparison of HWC in the protected areas demonstrated that there was a considerable discrepancy in conflict intensity and space allocation that was closely associated with the governance systems. An overall $HWC_i$ as frequency and severity of crop raiding, livestock depredation, property damage, and human injury showed that sites with high co-management had the lowest level of conflict ($HWC_i = 2.1 \pm 0.3$), and those with poor co-management had the highest conflict ($HWC_i = 5.2 \pm 0.6$). The spatial mapping revealed that the hotspots of conflicts were observed along habitat edges, wildlife corridors, and buffer zones with seasonal peaks related to agricultural seasons and dry seasons. A Livelihood resilience, measured using an $LRI_i$, which is a combination of income diversity, household adaptive capacity, and access to institutional support, had a positive correlation with governance participation. Strong co-managed households were more resilient ($LRI_i = 0.74 \pm 0.05$) and more tolerant of wildlife, and low-resilience households ($LRI_i = 0.39 \pm 0.07$) were more sensitive to conflicts, especially when the livelihood source relied on rain-fed agriculture. The negative correlation between $LRI_i$ and $HWC_i$ in the governance settings highlights the importance of diversified livelihood and institutional facilitation in reducing conflict.

The participation in governance as a measure through a Governance Participation Score ($GPS_i$) had a direct impact on adaptive learning and institutional effectiveness. $GPS_i$ communities were high-commitment communities that undertook the practice of repetitive monitoring, open decision making, and balanced distribution of power, which promoted trust and compliance. Multi-temporal Landsat and Sentinel vegetation photography revealed that high-participation sites exhibited improved habitat characteristics ($VCI = 0.68 \pm 0.04$), less fragmentation, and less intense hotspots (1.9 events $km^{-2}$) than low-participation sites $VCI = 0.42 \pm 0.05$; hotspot density = 4.7 events $km^{-2}$).

The socio-ecological interrelationships were further supported by structural equation modeling: the engagement of governance positively influenced the resilience of livelihood ($\beta = 0.62$, $p < 0.001$) which consequently had a significant effect of reducing the intensity of conflicts ($\beta = -0.48$, $p < 0.01$) although there was a direct effect of governance on conflict reduction ($\beta = -0.31$, $p < 0.05$). A governance enhanced with adaptive learning was found to be more effective ($\beta = 0.55$, $p < 0.001$), thus the need to incorporate an iterative, feedback-oriented co-management process. In general, the performance of the sites with strong governance and adaptive learning was higher than that of sites with weak governance and inadequate adaptation, which is supported by the stakeholder validation workshops, and this indicates relevance to the adaptive co-management framework.

## Conclusion

The researchers prove that adaptive co-management is an effective way to reduce the level of human-wildlife conflict and increase the resilience of livelihoods and the ecological performance of the landscape of the protected areas. The high level of governance participation was associated with lower conflict level ($HWC_i$ = 2.1 ± 0.3), better livelihood resilience ($LRI_i$ = 0.74 ± 0.05), and better habitat state (VCI = 0.68 ± 0.04) with the synergistic advantage of inclusive and participatory management. The negative association between livelihood resilience and conflict intensity highlights the importance of diversified income approaches, institutional support, and household adaptive capacity in managing vulnerability to wildlife. The structural equation model also indicated the direct and indirect influence of governance participation on conflict reduction through increased livelihood and adaptive learning, which promotes the critical role of feedback-based decision-making and local systematic conflict management systems. The ecological analysis revealed that high-participation locations were associated with less habitat fragmentation and hotspots of conflict, and thus the effectiveness of social governance was connected to physical environmental performance. Further research needs to be done on scaling of the adaptive co-management framework to different socio-ecological systems and integration of dynamic modeling of seasonal and climatic-induced changes in conflict patterns. Policy refinements can be informed by longitudinal studies that determine the maintenance of governance effects and livelihood adaptation strategies. Moreover, the application of technological resources, including remote sensing, wildlife tracking, and active participation reporting, may be integrated with monitoring and decision-making, which will allow for the minimization of conflicts more actively. Adaptive co-management offers an adaptable, evidence-based model of harmonizing livelihoods, conservation of wildlife, and the sustainability of ecosystems by aligning human development objectives with conservation priorities.

## References

[1] Baten, Mohammed Abdul. "Revisiting the success of co-management in forest protected areas of Bangladesh: untangling the interplay of power, participation, and Community empowerment." *Environmental Policy and Governance* 34, no. 6 (2024): 649-662. https://doi.org/10.1002/eet.2114

[2] Chakanyuka, Tafadzwa, and Beaven Utete. "Adaptive co-management, co-existence or just wildlife conservation? Case study of the human and Nile crocodile (Crocodylus niloticus) conflicts in Ngezi Dam, Mashonaland West, Zimbabwe." *African Journal of Ecology* 60, no. 3 (2022): 759-768. https://doi.org/10.1111/aje.12974

[3] Chowdhury, Faqrul Islam, Kamrul Islam, Mohiuddin Al Faroque, Kazi Nazrul Islam, Md Farhadur Rahman, Md Tanjimul Alam Arif, Tapan Kumar Nath, and Mohammed Jashimuddin. "Assessing the impacts of

co-management on protected area landscape under socio-imagery lens: evidence from Bangladesh." *Journal of Sustainable Forestry* 41, no. 7 (2022): 553-572. https://doi.org/10.1080/10549811.2020.1747497

[4] da Silva, Achilem E., Kettrin FB Maracajá, André CS Batalhão, Viviane F. Silva, and Igo MS Borges. "Ecotourism and Co-Management: Strengthening Socio-Ecological Resilience in Local Food Systems." *Sustainability* 17, no. 6 (2025): 2443. https://doi.org/10.3390/su17062443

[5] Galappaththi, Eranga K., Marianne Falardeau, Les N. Harris, Juan C. Rocha, Jean-Sébastien Moore, and Fikret Berkes. "Resilience-based steps for adaptive co-management of Arctic small-scale fisheries." *Environmental Research Letters* 17, no. 8 (2022): 083004. https://doi.org/10.1088/1748-9326/ac7b37

[6] Gatlewar, D. (2025). Community-Based Conservation: Integrating local knowledge for biodiversity protection. *Zenodo (CERN European Organization for Nuclear Research)*. https://doi.org/10.5281/zenodo.17475570

[7] Islam, Kazi Nazrul, Mohammed Jashimuddin, Kazi Jamil Hasan, Md Ismail Khan, Md Kamruzzaman, and Tapan Kumar Nath. "Stakeholders' perception on conservation outcomes of forest protected area co-management in Bangladesh." *Journal of Sustainable Forestry* 41, no. 3-5 (2022): 240-256. https://doi.org/10.1080/10549811.2021.1899941

[8] Kang, Yuan, Haolian Luan, Xiao Zhao, and Chengzhao Wu. "Conceptual Evolution, Governance Transformation, and Spatial Planning Approaches for Protected Area–Community Conservation–Livelihood Trade-Offs." *Land* 14, no. 9 (2025): 1797. https://doi.org/10.3390/land14091797

[9] Karim, Md Rezaul, Md Abdul Halim, Imrul Kayes, Wenxi Liao, Sharif A. Mukul, HM Tuihedur Rahman, and Sean C. Thomas. "Co-Management effects on forest restoration in protected areas of Bangladesh: a remote sensing and GIS-based analysis." *Land* 13, no. 10 (2024): 1709. https://doi.org/10.3390/land13101709

[10] Kilonzi, Francisca Mutwa, and Takahiro Ota. "Application of the 4Rs framework towards effective co-management of protected forests: case of aberdare forest in central Kenya." *Environment, Development and Sustainability* 25, no. 8 (2023): 8561-8584. https://doi.org/10.1007/s10668-022-02412-5

[11] Ma, Ting, Brent Swallow, J. Marc Foggin, Linsheng Zhong, and Weiguo Sang. "Co-management for sustainable development and conservation in Sanjiangyuan National Park and the surrounding Tibetan nomadic pastoralist areas." *Humanities and Social Sciences Communications* 10, no. 1 (2023): 1-13. https://doi.org/10.1057/s41599-023-01756-1

[12] Muchapondwa, Edwin, and Herbert Ntuli. "Managing trade-offs between communities' welfare and nature conservation: the case of wildlife management systems in and outside protected areas in Africa." *Annual Review of Resource Economics* 16 (2024). https://doi.org/10.1146/annurev-resource-101623-103802

[13] Nchanji, Yvonne Kiki, Sabaheta Ramcilovic-Suominen, Eileen Bogweh Nchanji, William Armand Mala, and Juha Kotilainen. "Tackling conflicts, supporting livelihoods: Convivial conservation in the Campo Ma'an National Park." *Conservation and Society* 21, no. 1 (2023): 61-72. https://doi.org/10.4103/cs.cs_30_22

[14] Neira, Francisco, Santiago Ribadeneira, Estefania Erazo-Mera, and Nicolas Younes. "Adaptive co-management of biodiversity in rural socio-ecological systems of Ecuador and Latin America." *Heliyon* 8, no. 12 (2022). https://doi.org/10.1016/j.heliyon.2022.e11883

[15] Nguyen, Linh Bao, Hsing-Chih Chen, Timothy Bernd Wallace Seekings, Nabin Dhungana, Chi-Cheng Chen, and Chun-Hung Lee. "Integrated adaptation strategies for human–leopard cat coexistence management in Taiwan." *Sustainability* 16, no. 10 (2024): 4031. https://doi.org/10.3390/su16104031

[16] Nguyen, Linh Bao, Timothy Bernd Wallace Seekings, and Chun-Hung Lee. "Developing local-driven adaptive management for coexistence between humans and leopard cats." *Global Ecology and Conservation* 58 (2025): e03436. https://doi.org/10.1016/j.gecco.2025.e03436

[17] Nishima-Miller, Jeffrey. "Transformative frameworks and strategic planning for wildlife stewardship, co-management, and Indigenous-led conservation." PhD diss., University of British Columbia, 2025. https://doi.org/10.14288/1.0451063

[18] Senghor, Khadidiatou, Stefan Partelow, Cesar Giraldo Herrera, and Isimemen Osemwegie. "Conflicting governance realities: Aligning historical and cultural practices with formal marine protected area co-management in Senegal." *Marine Policy* 155 (2023): 105706. https://doi.org/10.1016/j.marpol.2023.105706

[19] Ullah, SM Asik, Masakazu Tani, Jun Tsuchiya, M. Abiar Rahman, and Masao Moriyama. "Impact of protected areas and co-management on forest cover: A case study from Teknaf Wildlife Sanctuary, Bangladesh." *Land Use Policy* 113 (2022): 105932. https://doi.org/10.1016/j.landusepol.2021.105932

[20] Wang, Changhai, and Ao Li. "Analysis of Perceptions of Community Co-Management by Households in the Surrounding Communities of Protected Areas: Empirical Study of Xishuangbanna National Nature Reserves in China." *Land* 14, no. 6 (2025): 1181. https://doi.org/10.3390/land14061181