Socio-ecological drivers and community perceptions of human–wildlife conflict in the buffer zone of bogani nani wartabone national park: evidence from Tulabolo Village, Indonesia

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Abstract. Human–wildlife conflict (HWC) in protected-area buffer zones poses significant challenges to biodiversity conservation and rural livelihood sustainability. This study investigates the socio-ecological drivers, conflict patterns, perceived impacts, and mitigation responses in Tulabolo Village, located adjacent to Bogani Nani Wartabone National Park, Indonesia. A cross-sectional survey was conducted involving 30 agricultural households using structured questionnaires to capture socio-demographic characteristics, conflict experiences, economic and psychological impacts, and participation in mitigation initiatives. Descriptive statistics and cross-tabulation analyses were employed, supported by secondary demographic and land-use data. The results indicate that macaques are the predominant conflict species (96.7%), with half of the respondents reporting very frequent crop-raiding incidents. Substantial economic losses were identified, including crop failure (66.7%), plant damage (60%), and livestock loss (40%). Psychological impacts were also pronounced, particularly fear (63.3%) and anxiety (56.7%). Social responses varied, ranging from increased retaliatory intentions toward wildlife to declining support for conservation initiatives. Among mitigation measures, electric fencing was perceived as the most effective strategy (71.4%), although adoption remained limited due to financial and technical constraints. Notably, only 10% of community members actively participated in mitigation programs despite widespread exposure to conflict. These findings underscore the need for integrated, community-based conflict management strategies that address both ecological and socio-economic dimensions. Strengthening local capacity, improving access to mitigation resources, and promoting inclusive governance are essential for fostering sustainable coexistence in protected-area buffer zones.

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1. Introduction

Human–wildlife conflict (HWC) has emerged as one of the most pressing conservation challenges of the 21st century, particularly in tropical regions where biodiversity hotspots intersect with expanding human populations and agricultural frontiers [1]–[3]. As protected areas increasingly function as isolated refuges surrounded by human-dominated landscapes, wildlife face shrinking natural habitats and declining food resources, pushing them into agricultural zones and intensifying interactions with rural communities [4], [5].

The consequences of this process extend well beyond direct economic losses. HWC also generates psychological stress, social disruption, and eroding community tolerance toward conservation initiatives [6], [7]. In Southeast Asia's biodiversity-rich but rapidly changing landscapes, where forest fragmentation and agricultural expansion proceed at unprecedented rates, understanding the socio-ecological dynamics of HWC is essential for designing evidence-based strategies that reconcile wildlife protection with human livelihood security [8], [9].

Indonesia illustrates these challenges acutely, with more than 50 million people living within 10 km of protected areas, creating extensive human–wildlife interface zones [4]. Sulawesi Island, a global biodiversity hotspot within the Wallacea bioregion, hosts numerous endemic and threatened species such as the Maleo (Macrocephalon maleo), Anoa (Bubalus spp.), and several primate taxa, yet is characterized by persistent conflicts driven by habitat degradation and resource competition [10]–[12]. Bogani Nani Wartabone National Park (BNWNP), covering approximately 2,871 km² in North Sulawesi, exemplifies this dilemma: protected forests border smallholder agricultural buffer zones where households depend heavily on crop production for subsistence and income [13], [14]. Recent studies report increasing wildlife incursions into farmlands around BNWNP, with macaques (Macaca spp.) and wild boar (Sus spp.) identified as key conflict species causing considerable crop damage and economic losses [15]–[17].

The persistence and escalation of HWC in protected area buffer zones reflect complex interactions among ecological, socioeconomic, and institutional drivers. Ecologically, habitat fragmentation reduces forest connectivity and natural food availability, prompting wildlife to exploit cultivated crops, especially during periods of low forest productivity [18]–[20]. Deforestation and land-use change linked to agricultural expansion, illegal logging, and infrastructure development compress wildlife ranges and create permeable boundaries that facilitate animal movement into human-dominated landscapes [21], [22]. Socioeconomically, buffer zone communities often have limited livelihood diversification and low economic resilience, making them highly vulnerable to conflict impacts and constraining their capacity to adopt effective mitigation measures [23], [24]. Institutionally, weak participatory governance and limited integration of local perspectives in conservation planning create implementation gaps in conflict management interventions [25]–[27].

Mitigating HWC therefore, requires multi-faceted solutions that combine technical interventions with socio-ecological understanding and meaningful community engagement. Globally, a wide range of strategies has been tested, including physical barriers, deterrents, compensation schemes, and community-based management approaches [28]–[30]. Physical barriers—particularly electric fencing—show variable effectiveness depending on design, installation quality, species-specific behavior, and maintenance capacity [31], [32]. In African elephant conflict hotspots, electric fencing has reduced crop-raiding incidents by approximately 60–85% when combined with regular maintenance and community training

[33], [34]. Biological deterrents such as chili-based repellents and beehive fences offer lowercost alternatives but produce inconsistent results, with effectiveness influenced by target species, environmental conditions, and implementation quality [35], [36]. Compensation schemes, while politically attractive, frequently encounter problems such as delayed payments, inadequate verification procedures, and moral hazard, where guaranteed payments may reduce incentives for preventive action [37], [38].

Recent literature increasingly emphasizes the central role of community-based approaches that integrate local ecological knowledge, enhance participation in decision-making, and align conservation objectives with livelihood improvement [39]–[41]. Participatory conservation frameworks recognize that lasting conflict mitigation must address underlying socioeconomic vulnerabilities, strengthen community capacity for adaptive management, and foster shared ownership of conservation outcomes [26], [27], [42], [43]. In Indonesia, communities with stronger collective action capacity, diversified livelihoods, and meaningful involvement in protected area governance tend to show higher tolerance toward wildlife and greater adoption of preventive measures [44]–[46]. Gender-inclusive approaches—such as the involvement of women rangers in BNWNP—have been shown to enhance community trust, improve information flows, and reinforce social cohesion around conservation efforts [42], [47]. Economic incentives, including ecotourism and sustainable resource-use agreements, can provide tangible benefits that offset conflict costs and build local support for wildlife conservation [48], [49].

Despite growing attention to HWC in Southeast Asia, several critical knowledge gaps remain. First, while macro-scale assessments document conflict prevalence across broad regions, sitespecific quantification of conflict frequency, causative factors, and socioeconomic impacts is still limited, particularly in understudied locations such as BNWNP buffer zones [50], [51]. Second, comparative evaluations of mitigation effectiveness under real-world conditions are scarce; most studies focus on controlled experiments that may not reflect the constraints and adoption patterns of resource-limited communities [30], [52], [53]. Third, empirical analyses linking community participation, social capital, and collective action capacity to conflict vulnerability and mitigation outcomes are underdeveloped, despite their recognized importance in conservation theory [1], [54]. Fourth, occupation- and gender-disaggregated assessments of conflict experiences and coping strategies remain limited, constraining the design of interventions targeting differential vulnerabilities within heterogeneous communities [55], [56]. Finally, integrated frameworks connecting local conflict patterns to broader landscapescale processes—such as habitat quality changes and trajectories of agricultural intensification—require further development to guide ecosystem-scale conservation planning [57], [58].

Advances in technology and methodology offer new opportunities to address these gaps. Mobile survey platforms and participatory mapping tools enable fine-scale documentation of conflict incidents, spatial patterns, and community perceptions [59], [60]. Species distribution models that incorporate human activity data allow prediction of conflict hotspots and prioritization of intervention areas [61], [62]. Social network analysis and mental model approaches help reveal stakeholder relationships, information flows, and cognitive frameworks that shape conflict-management outcomes [63], [64]. Participatory action research, which positions local communities as co-researchers rather than passive respondents, can generate contextually grounded insights while building analytical capacity and ownership of results [26], [27]. Combined with mixed-method designs that integrate quantitative surveys and qualitative narratives, these approaches support holistic

characterization of HWC as a coupled socio-ecological phenomenon requiring adaptive, context-sensitive management [7], [65].

This study addresses these knowledge gaps by providing empirical evidence on HWC dynamics, community perceptions, and mitigation effectiveness in Tulabolo Village, a buffer zone community adjacent to BNWNP in North Sulawesi, Indonesia. The specific objectives are: (1) to quantify conflict patterns by identifying key wildlife species, incident frequency, and temporal dynamics; (2) to assess multidimensional impacts of conflict across economic, psychological, and social domains; (3) to evaluate the effectiveness and adoption of existing mitigation strategies; and (4) to examine participation patterns and identify barriers that limit farmer engagement in conflict-management initiatives. The study contributes novel empirical data on HWC in an understudied Indonesian protected area, provides a comparative assessment of mitigation performance under real-world implementation conditions, and offers occupationdisaggregated insights into differential vulnerabilities and participation constraints. Methodologically, it demonstrates participatory assessment approaches that can be applied to similar conservation contexts across the Wallacea bioregion and Southeast Asia. Practically, the findings inform evidence-based policy recommendations for BNWNP management, emphasizing community-centered strategies that integrate habitat restoration, economic support, capacity building, and inclusive governance to foster sustainable coexistence between wildlife conservation and local livelihoods in tropical forest buffer zones.

2 Methodology

2.1 Study Area

This research was conducted in Tulabolo Village, a buffer-zone settlement bordering Bogani Nani Wartabone National Park (BNWNP) in North Sulawesi Province, Indonesia. BNWNP represents one of Indonesia's key biodiversity conservation areas within the Wallacea region, characterized by rugged topography, tropical rainforest, and a mosaic of protected and community-managed lands. The Tulabolo landscape illustrates a typical protected area buffer zone in which smallholder agriculture, settlement expansion, and conservation land uses are tightly interwoven, generating intense human–environment interactions and elevated potential for human–wildlife conflict [4], [10]–[12], [66], [67].

Land-use data for Tulabolo Village (Table 2) demonstrate that a large proportion of the village territory is under conservation or semi-conservation use, with agricultural plots and settlements concentrated along accessible valley floors and lower slopes. This spatial configuration creates a pronounced interface between croplands and forest edges, which functions as a corridor for wildlife movement and a hotspot for conflict incidents [18], [21], [57], [68].

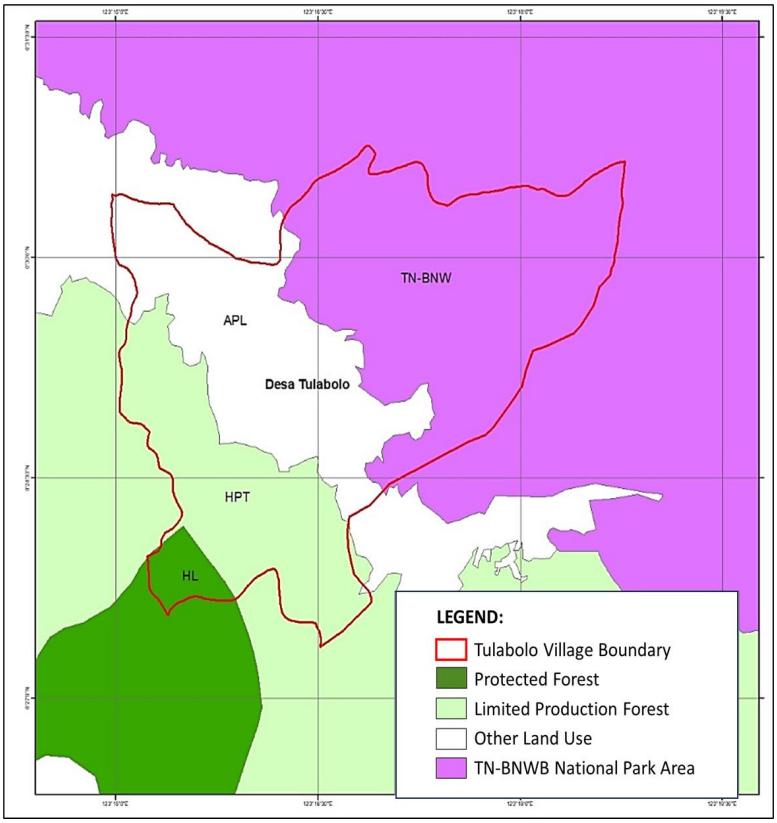

Figure 1. Research Location

2.2 Research Design

The study employed a cross-sectional survey design to characterize patterns of human–wildlife conflict, its socio-economic and psychological impacts, and community participation in mitigation initiatives. A structured questionnaire was used to gather quantitative and qualitative data from household respondents, complemented by secondary information on demographics, land use, and conservation policies.

This design is widely used in human–wildlife conflict research to document incident frequencies, spatial patterns, and associated livelihood outcomes within a defined time frame [52], [61], . The survey approach also facilitates the establishment of a baseline for future longitudinal monitoring and comparative analyses across buffer-zone communities [30], [51], [65].

2.3 Sampling Strategy

Households were selected using purposive and proportional sampling, focusing on farmers and other residents whose primary livelihoods depend on agriculture and who occupy locations adjacent to forest edges or wildlife movement routes. Village administrative records

and spatial information were used to delineate settlement clusters and identify potential respondents.

Sampling aimed to capture variation across key socio-demographic attributes including age, gender, education, occupation, and length of residence, thereby enabling a nuanced analysis of how conflict exposure and responses differ among social groups [23], [24], [54]. The final sample size was determined based on resource constraints and logistical feasibility in the field, while remaining adequate to support descriptive and cross-tabulation analyses commonly applied in similar HWC studies [52], [59], [65], .

2.4 Data Collection Instruments

Primary data were collected using a structured questionnaire developed specifically for this study. The instrument contained sections on: (1) household socio-demographic characteristics; (2) land ownership and cropping patterns; (3) experience of wildlife-related incidents, including conflict species, frequency, timing, and location; (4) economic impacts on crops and livestock; (5) psychological and social consequences of conflict; (6) mitigation strategies used and perceived effectiveness; and (7) levels of participation in formal and informal conflictmanagement initiatives.

Questionnaire items drew upon established instruments in human–wildlife conflict and conservation social science research [26], [39], [54], and were adapted to the Tulabolo context through consultation with park staff and local leaders. Content validity was sought by aligning question items with the study objectives and by cross-checking coverage of key dimensions identified in earlier HWC literature [8], [23], [30], [39], [52], [65], –.

2.5 Data Collection Procedures

Fieldwork was conducted in 2025, following ethical guidelines for research involving human participants in conservation settings [24], [39], [54], . Prior to data collection, the research team coordinated with village authorities and BNWNP management to obtain permission, provide information about the study objectives, and schedule household visits.

Questionnaires were administered through face-to-face interviews in respondents' homes or farm locations. This approach reduced literacy-related barriers, allowed clarification of questions, and facilitated the collection of detailed narratives regarding conflict experiences. Interviews were conducted in the local language, with responses recorded using standardized forms. Informed consent was obtained from all participants, and privacy and confidentiality were maintained throughout the research process. To enhance reliability, enumerators received training on interview techniques, ethical considerations, and procedures for probing sensitive issues such as retaliatory actions against wildlife or conflicts with authorities [23], [39], [52].

2.6 Data Analysis

Survey responses were coded and entered into a spreadsheet for cleaning and verification. Descriptive statistics were used to summarize socio-demographic characteristics, conflict

patterns, and impact categories. Cross-tabulations and percentage distributions were generated to explore relationships between key variables, such as conflict frequency by occupation group, mitigation strategies by conflict type, and participation levels by gender and livelihood category [19], [23], [52], [54], [59].

Where appropriate, results were presented in tables and figures to facilitate interpretation and comparison. Qualitative responses, including open-ended descriptions of conflict experiences and aspirations for improved management, were thematically grouped and integrated into the narrative to provide additional context and explanatory depth [26], [27], [39].

This analytical framework is consistent with established practices in survey-based human– wildlife conflict research, which emphasize both quantitative characterization of incident patterns and qualitative insight into social perceptions and decision-making processes [7], [30], [52], [59], [63].

3. Result and Discussion

3.1 Socio-Demographic Characteristics of Respondents

Secondary data on Tulabolo Village (Table 1) show a growing population and ongoing expansion of settlement and agricultural land, intensifying human–environment interactions in the buffer zone [4], [21]. The survey sample reflects the dominance of agriculture-based livelihoods, with most respondents engaged in farming either as a primary or secondary occupation (Tables 2, 3, and 4).

Table 1. Population and Area Distribution of Tulabolo Village

No	Hamlet (Dusun)	Male (L)	Female (P)	Total Population	Households (KK)	Area (m^2)
1	Dusun 1 (Bula)	100	111	211	69	15,000
2	Dusun 2 (Tanggi)	89	68	157	49	18,750
3	Dusun 3 (Tutuwoto)	167	158	325	91	120,000
Total	Total	356	337	693	209	753,750

Table 2. Age Distribution of Respondents

No	Age Category	Frequency	Percentage (%)
1	<20	1	3.3
2	20-35	7	23.3
3	36-50	9	30.0
4	51-65	8	26.7

5	>65	5	16.7
Total	Total	30	100.0

Table 3. Gender Composition of Respondents

No	Gender	Frequency	Percentage (%)
1	Male	18	60.0
2	Female	12	40.0
Total	Total	30	100.0

Table 4. Occupation Structure of Respondents

No	Occupation	Frequency	Percentage (%)
1	Farmer	23	76.7
2	Trader	2	6.7
3	Laborer/Entrepreneur	3	10.0
4	Civil Servant	2	6.7

Age and education distributions reveal that a substantial share of respondents are in productive age groups, with diverse educational attainment ranging from primary schooling to secondary and, in some cases, higher education. These patterns influence both vulnerability to conflict and the capacity to adopt new mitigation strategies, as education and age shape access to information, risk perceptions, and willingness to participate in collective action [23], [24], [44], [54].

Gender composition indicates that men are more frequently represented as primary respondents, reflecting gendered roles in agricultural decision-making and field-based activities. However, women play critical roles in crop management, household budgeting, and informal surveillance of fields, which has implications for designing inclusive conflictmitigation initiatives [44]–[47], [55].

3.2 Patterns of Human–Wildlife Conflict

Analysis of reported conflict species (Table 5) shows that primates—particularly macaques (*Macaca* spp.)—are the dominant conflict agents in Tulabolo Village, followed by wild pigs and, to a lesser extent, other wildlife such as rodents and birds [11], [15], [16]. The majority of households report experiencing repeated crop-raiding incidents, with some indicating very frequent occurrences during certain seasons.

Table 5. Wildlife Species Reported as Conflict Agents

No	Wildlife Species	Frequency Mentioned	Percentage (%)
1	Macaque (Macaca)	29	96.7
2	Wild Boar	9	30.0
3	Snake	5	16.7

4	Birds	3	10.0

Temporal patterns (Table 6) highlight that conflicts often peak during specific crop stages, such as fruiting or ripening, and may be concentrated in morning and late afternoon hours when animals are most active. Seasonal variation is linked to the availability of natural food sources in the forest and to agricultural cycles, consistent with findings from other tropical forest landscapes [18]–[20].

Table 6. Wildlife Conflict Frequency

Conflict Frequency	Number of Respondents	Percentage (%)
Very Frequent	15	50.0
Frequent	9	30.0
Occasional	4	13.3
Rare	2	6.7
Total	30	100.0

Spatially, incidents are concentrated in fields adjacent to forest edges and along wildlife movement corridors (Table 7). These high-exposure zones are characterized by limited physical barriers and dense vegetation cover at the boundary between cropland and forest, which provides concealment and access routes for wildlife [18], [21].

Table 7. Conflict Frequency vs. Mitigation Effectiveness

Conflict Frequency	Low Effectiveness	Moderate Effectiveness	High Effectiveness	Total
Very Frequent	13	3	0	16
Frequent	5	2	1	8
Occasional	1	2	1	4
Rare	1	0	1	2
Total	**20**	**7**	**3**	**30**

3.3 Economic Impacts on Crops and Livestock

The economic consequences of wildlife conflict in Tulabolo are substantial (Tables 8–10). Respondents report a range of impacts including partial damage to crops, total crop failure in severely affected plots, and loss of livestock and poultry. For many households, these losses represent a significant portion of annual production and income, reducing their capacity to invest in farm improvement and increasing vulnerability to livelihood shocks [6], [7], [23].

Table 8. Perceived Causes of Wildlife Conflict

No	Cause of Conflict	Number of Respondents	Percentage (%)

1	Loss of wildlife food sources	23	76.7
2	Habitat damage/human activities	17	56.7
3	Settlement near forest	14	46.7
4	Wildlife activities close to humans	10	33.3

Table 9. Economic Impacts of Wildlife Conflict

No	Economic Impact	Number of Respondents	Percentage (%)
1	Crop failure	20	66.7
2	Plant damage	18	60.0
3	Livestock losses	12	40.0

Table 10. Psychological Impacts of Wildlife Conflict

No	Psychological Impact	Number of Respondents	Percentage (%)
1	Fear	19	63.3
2	Anxiety/Fatigue	17	56.7
3	Insecurity while working	14	46.7

Crop losses are particularly pronounced for high-value and staple commodities, which undermines both food security and cash income. The concentration of impacts on crops rather than livestock reflects local land-use patterns and the relative accessibility of fields compared with livestock enclosures [28], [29]. This aligns with studies from other regions, where cropraiding by primates and ungulates is often the most severe and visible form of HWC, shaping negative perceptions of wildlife [19], [34].

Some households report that repeated severe losses have forced them to abandon particular crops or fields, modify cropping calendars, or reduce cultivated area. Such adaptive responses can have long-term implications for agricultural productivity, land-use patterns, and conservation attitudes [7], [23], [37].

3.4 Psychological and Social Impacts

Beyond direct economic losses, respondents describe significant psychological impacts associated with human–wildlife conflict (Table 11). Many households express feelings of fear, frustration, and anxiety related to the unpredictability of wildlife incursions and the risk of physical encounters during field activities [6], [7], [55].

Table 11. Social Impacts of Wildlife Conflict

No	**Social Impact**	**Number of Respondents**	**Percentage (%)**

1	Motivation to kill wildlife	7	23.3
2	Inter-community conflict due to losses	1	3.3
3	Community hatred toward wildlife	3	10.0

These emotional responses contribute to stress and can erode mental well-being, particularly when conflicts are recurrent and mitigation options are limited. In some cases, respondents report concern for the safety of children and elderly family members, who may be exposed to wildlife while traveling to fields or performing daily tasks [6], [44], [55].

Socially, conflict contributes to tensions within and between households, especially when crop losses exacerbate economic hardship and competition for productive land. There are also indications of growing dissatisfaction with conservation authorities, as some community members perceive that wildlife is better protected than local livelihoods. If unaddressed, these perceptions can lead to declining support for conservation initiatives and increased willingness to engage in illegal activities such as hunting or forest encroachment [6], [7], [25].

3.5 Mitigation Strategies and Perceived Effectiveness

Households employ a variety of mitigation strategies to reduce wildlife impacts on crops and livestock (Table 12). Common measures include active guarding, noise-making, the use of simple barriers, and the deployment of deterrents such as lights or scare devices. Some households also report using dogs and other traditional methods to detect and repel wildlife.

Table 12. Community Mitigation Strategies Used

No	Mitigation Strategy	Number of Users	Percentage (%)
1	Electric fencing	7	23.3
2	Chasing/Killing	10	33.3
3	Intensive guarding	9	30.0
4	Trapping	2	6.7

Electric fencing, where implemented, is perceived by respondents as one of the most effective measures, with many reporting substantial reductions in crop damage in fenced plots (Table 13) [31]–[35]. However, the adoption of electric fencing remains limited due to high initial costs, the need for technical knowledge, and ongoing maintenance requirements. These constraints are consistent with findings from other contexts where the benefits of electric fencing are unevenly distributed and sustainability depends on stable institutional and financial support [30]–[34].

Other strategies, such as intensified guarding and the use of fire or loud noises, are laborintensive and may offer only temporary relief, particularly when wildlife become habituated to deterrents [29], [33], [36]. Respondents also note that some methods, if misused, can raise safety concerns or cause friction with neighbors, such as when noise-making devices are disruptive during night-time hours [30], [35], [52].

Table 13. Effectiveness of Mitigation Strategies

No	Mitigation Strategy	Effective	Not Effective	Effectiveness (%)
1	Electric fencing	5	2	71.4
2	Chasing/Killing	3	7	30.0
3	Intensive guarding	4	5	44.4

3.6 Community Participation in Conflict Management

Community participation in formal conflict-mitigation programs and conservation initiatives is generally low (Table 14). Only a minority of respondents report active involvement in parkled or village-level initiatives, such as participatory boundary monitoring, community patrols, or structured training programs. Participation appears to be somewhat higher among farmers located closest to the park boundary, who experience the most severe impacts and thus have stronger incentives to engage [25]–[27].

Several barriers to participation are identified, including limited time due to livelihood responsibilities, perceptions that programs do not address immediate livelihood needs, insufficient information, and low trust in institutions. Some respondents indicate that previous experiences with external initiatives have not produced tangible benefits, reducing motivation to participate in new programs [39]–[41].

These patterns are consistent with broader evidence that participation cannot be assumed in buffer-zone communities; rather, it must be actively cultivated through inclusive processes, clear benefit-sharing arrangements, and recognition of local knowledge and priorities [25]–[27].

Table 14. Community Participation by Occupation

No	Occupation	Active	Passive	Not Involved
1	Farmer	3	2	18
2	Trader	0	0	2
3	Laborer/Entrepreneur	0	1	2
4	Civil Servant	0	0	2
Total	**Total**	**3**	**3**	**24**

3.7 Aspirations for Management and Concrete Solutions

Respondent aspirations for improved conflict management (Table 15) emphasize a combination of technical measures and socio-economic support. Many households express interest in expanded access to effective physical barriers such as electric fencing, provided that financial and technical assistance is available. Other priorities include improved crop protection technologies, support for diversified livelihoods, and enhanced coordination between community groups and park authorities [25]–[27], [39]–[41], [47]. **Table 15.** Management Aspirations of Respondents

No	Main Aspiration	Number of Respondents	Percentage (%)

1	Compensation for losses	12	40.0
2	Electric fencing	14	46.7
3	Education and training	8	26.7
4	Relocation of park boundary	4	13.3

Table 16 synthesizes concrete community recommendations, which include: (1) subsidized or cost-shared electric fencing and barrier systems; (2) community-based monitoring teams supported by BNWNP; (3) training in non-lethal deterrent methods and wildlife-safe farming practices; and (4) mechanisms for compensation or risk-sharing in cases of severe losses. These recommendations align with emerging best practices in human–wildlife conflict mitigation that seek to integrate livelihood support, participatory governance, and adaptive management [28]– [30].

Table 16. Concrete Recommendations for Conflict Mitigation

No	Concrete Recommendation	Number of Respondents	Percentage (%)
1	Wildlife habitat restoration	5	16.7
2	Economic assistance program	12	40.0
3	Multi-stakeholder collaboration	4	13.3

3.8 Discussion

The findings from Tulabolo Village provide critical empirical evidence on how human–wildlife conflict unfolds in a tropical forest buffer zone and how it shapes community perceptions and conservation outcomes. The dominance of macaques and other crop-raiding wildlife as conflict agents mirrors patterns reported from other regions where forest fragments border smallholder agriculture [18]–[20]. Recurrent, sometimes chronic, crop losses erode tolerance toward wildlife and can undermine conservation objectives, particularly when communities perceive that costs are borne locally while benefits of conservation accrue elsewhere [1], [2], [6].

The spatial concentration of incidents in fields adjacent to forest edges supports broader evidence that land-use configuration—rather than merely proximity to protected areas— strongly influences conflict risk [4], [18], [21]. In Tulabolo, the juxtaposition of conservation land and intensively cultivated plots creates a permeable interface through which wildlife can access high-energy crops. Without adequate barriers or deterrent systems, these interface zones become chronic conflict hotspots, driving conflict fatigue and negative attitudes toward conservation [6], [7].

Economically, the study reinforces the view that human–wildlife conflict functions as a significant non-market cost of conservation, disproportionately affecting households with limited diversification and low resilience [23], [24]. For such households, even moderate crop losses can trigger cascading livelihood impacts, including reduced ability to invest in inputs, heightened indebtedness, and increased pressure to exploit forest resources illegally [7], [21], [37]. These dynamics underscore the importance of integrating conflict mitigation

into broader rural development and poverty-reduction strategies, rather than treating it as a narrow conservation problem.

Psychological and social impacts documented in Tulabolo—fear, anxiety, and frustration, along with emerging distrust toward institutions—align with findings from other human–wildlife conflict contexts [6], [7], . Such impacts can be subtle yet profound, shaping everyday decisionmaking and long-term attitudes toward wildlife. If left unaddressed, they can lead to retaliatory behavior, decline in community cooperation with park authorities, and resistance to conservation regulations [40], [55]. Recognizing and addressing these non-material dimensions of conflict is therefore essential for sustaining conservation outcomes.
The results also highlight the promise and limitations of technical mitigation measures. Electric fencing emerges as a highly valued intervention among Tulabolo households, consistent with experiences from elephant and primate conflict landscapes in Africa and Asia [31]–[35]. However, as in other sites, adoption is constrained by capital costs, maintenance requirements, and the need for institutional support [68], . Over-reliance on fencing without parallel investments in community capacity, governance mechanisms, and livelihood support may create inequities and sustainability challenges [39], [41], [54].

Low participation levels observed in Tulabolo corroborate critiques of top-down conservation approaches that insufficiently accommodate local realities [41], [55]. Participatory models that meaningfully engage community members in decision-making, monitoring, and benefitsharing have been shown to improve both conservation outcomes and social legitimacy [63], [64]. Gender-inclusive initiatives, such as women ranger programs and targeted support for women's roles in agriculture and natural resource management, can further strengthen social cohesion and conflict-management capacity [42], [55].

Finally, the aspirations and recommendations articulated by Tulabolo residents demonstrate that communities are not merely victims of conflict but active agents with ideas for solutions. Their priorities—electric fencing support, community monitoring, training, and risk-sharing mechanisms—are consistent with emerging frameworks that conceptualize human–wildlife conflict as a coupled socio-ecological challenge requiring integrated, multi-scalar responses [7], [8], [39]. By grounding interventions in local experience and knowledge, conservation authorities can enhance the feasibility, equity, and durability of conflict-mitigation efforts.

4. Conclusion

This study provides an empirically grounded assessment of human–wildlife conflict (HWC) in Tulabolo Village, a buffer-zone community adjacent to Bogani Nani Wartabone National Park (BNWNP) in North Sulawesi, Indonesia. By combining household surveys with secondary demographic and land-use data, we quantified conflict patterns, examined multidimensional impacts, evaluated mitigation strategies, and explored community participation in conflictmanagement initiatives. The findings show that HWC in Tulabolo is frequent, spatially concentrated, and strongly intertwined with local livelihood security and perceptions of conservation governance, consistent with broader evidence from tropical forest landscapes.

Conflict incidents are dominated by macaques and other crop-raiding wildlife, with events concentrated in fields bordering forest edges and wildlife movement corridors. For

many households, repeated crop damage and occasional livestock loss constitute substantial economic shocks that erode resilience and constrain investment in farm improvement. These material impacts are compounded by psychological and social consequences, including fear, anxiety, frustration, and emerging distrust toward conservation institutions, which together threaten long-term community support for protected area management.

Mitigation efforts in Tulabolo remain fragmented and unevenly distributed. Electric fencing is widely perceived as one of the most effective interventions, yet its adoption is limited by high capital and maintenance costs, technical requirements, and the absence of robust institutional support mechanisms. More traditional measures—such as manual guarding, noise-making, and simple barriers—are labor-intensive and often provide only short-term relief, particularly as wildlife adapt to deterrents. Meanwhile, overall community participation in formal mitigation programs and conservation initiatives is low, constrained by time, information gaps, limited trust, and the perception that existing programs do not adequately address immediate livelihood needs.

These findings underscore that HWC in Tulabolo is not merely an ecological problem but a coupled socio-ecological challenge that bridges conservation, rural development, and local governance. Effective responses must therefore move beyond isolated technical fixes to embrace integrated, community-centered strategies. Key priorities include: (1) expanding access to effective physical barriers such as electric fencing through cost-sharing, technical assistance, and maintenance support; (2) strengthening community-based monitoring and early-warning systems, including gender-inclusive participation that recognizes the roles of both men and women in agriculture and resource management; (3) promoting livelihood diversification and risk-sharing mechanisms that buffer households against conflict-related losses; and (4) institutionalizing participatory governance arrangements that embed local knowledge, ensure transparent benefit-sharing, and foster mutual accountability between communities and BNWNP authorities.

Ultimately, the Tulabolo case contributes to a growing body of evidence that durable solutions to HWC must simultaneously reduce wildlife-induced damage, enhance livelihood security, and rebuild social trust in conservation institutions. By aligning technical interventions with participatory, equity-oriented governance, BNWNP and local stakeholders can move toward more functional coexistence between human communities and wildlife in Tulabolo and similar buffer-zone landscapes across the Wallacea region and Southeast Asia.

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