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Transforming Human–Manatee Relations: Socio-Ecological Drivers of Conflict and Coexistence in Lake Ossa, Cameroon

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ABSTRACT

Aquatic ecosystems worldwide face increasing human–wildlife conflicts as fishing activities overlap with critical habitats for vulnerable species. Human–wildlife interactions in artisanal fisheries exemplify socio-ecological systems that necessitate adaptive management approaches, integrating ecological and social dimensions. This study integrates socio-ecological systems theory and quantitative modelling to identify gear-based and attitudinal pathways for coexistence between fishermen and the African manatee (*Trichechus senegalensis*) in Lake Ossa Wildlife Reserve, Cameroon. We conducted structured interviews with 143 fishermen (1–50 years' experience) across five sites in Lake Ossa Wildlife Reserve, Cameroon, to assess entanglement patterns, net deployment configurations and attitudes toward manatees. Statistical tools included random forest imputation for missing values, Spearman correlation, chi-squared tests, multinomial logistic regression (MnLR) and Non-Metric Multidimensional Scaling (NMDS) ordination. Manatee entanglement was reported by 70.6% of respondents, with 82.5% of which experiencing net damage. MnLR revealed that fishermen with ≥ 3 entanglement incidences/month were more likely to support hunting/keeping away manatees ($OR = 3.05$, $p = 0.03$) or seek compensation ($OR = 5.00$, $p = 0.01$). Conversely, frequent manatee sightings (≥ 4 times/month) significantly reduced negative attitudes. Nets deployed parallel to vegetation (57.3%) and circular in open water (34.3%) were most associated with fish damage. Our findings reveal that adaptive gear deployment and positive encounter frequency can shift attitudes toward coexistence, offering an empirically grounded model for transformative aquatic biodiversity conservation management in Africa.

1 | Introduction

The field of human–wildlife conflict research faces critical challenges in developing effective conservation strategies that balance species protection with community livelihoods, particularly in developing countries where local communities depend heavily on natural resources (Dickman 2010; Nyhus 2016). These challenges are especially acute in aquatic ecosystems where fishing activities overlap with critical habitats for endangered mammals, creating complex socio-ecological system (SES) conflicts that require interdisciplinary approaches to resolve (Moore et al. 2009; Pooley et al. 2017; Brownell et al. 2019). Across the Global South, the problem is further compounded by limited financial resources for conservation, weak institutional frameworks, and the urgent need to address immediate livelihood concerns while ensuring long-term wildlife species survival (Read et al. 2006; Turvey et al. 2013; Mintzer et al. 2013).

Aquatic human–wildlife interactions present unique challenges compared to terrestrial systems due to the invisibility of underwater interactions that prevent direct behavioural observation. The permeable nature of aquatic habitat boundaries complicates territory mapping, especially where people engage in highly mobile fishing-based livelihoods, whereas monitoring submerged wildlife behaviour without technological intervention is extremely challenging (Moore et al. 2009; Brownell et al. 2019). In the freshwater context, there is a dearth of available research from which to draw to understand human–wildlife interactions, with more than 85% of published aquatic human–wildlife conflict studies focusing on marine systems (Read et al. 2006). Most research focuses on marine mammal–fisheries interactions where documented trends show gear entanglement leading to wildlife mortality, economic losses from damaged fishing equipment and polarized community attitudes toward protected species conservation (Castelblanco-Martínez et al. 2013; Lewison et al. 2014). Unlike marine systems with large spatial scales and terrestrial systems with clear boundaries, freshwater ecosystems are characterized by hydrological connectivity, seasonal variability and multi-scale governance structures that create complex transformation dynamics (Berkes 2017; Pahl-Wostl 2019). Further, the enclosed nature of many tropical freshwater systems, in particular in the Global South, likely intensifies human–wildlife interactions by concentrating both human activities and wildlife habitat use within limited spatial boundaries, creating a pressure effect where conflicts become inevitable without adaptive governance approaches.

SES transformation theory emphasizes the need for adaptive governance that enables learning, innovation and coexistence across ecological and social boundaries (Chaffin et al. 2016; Berkes 2017). However, theoretical and empirical understanding of how such transformations occur in freshwater contexts remains limited. As a result, the mechanisms through which fisheries communities transition from conflict to coexistence with aquatic wildlife remain poorly understood, particularly concerning the role of experiential learning and adaptive capacity in driving attitudinal and behavioural change (Armitage et al. 2020; Bennett et al. 2021). A growing body of work in human–wildlife conflict research uses a socio-ecological lens, incorporating both environmental and human components through systems thinking. This approach enables a functional relation between parts and an effective conflict resolution as it uncovers underlying soci-ecological dynamics rather than focusing solely on technological solutions (Ostrom 2009; Berkes 2017). Research on terrestrial mammals demonstrates that spatial patterns of habitat overlap, resource competition, and human activity density are critical determinants of conflict intensity and frequency (Read et al. 2010; Buchholtz et al. 2019). For example, human–elephant conflicts peak in areas where agricultural expansion intersects with traditional migration corridors, whereas carnivore conflicts are highest in livestock grazing areas adjacent to protected areas (Woodroffe et al. 2005; Graham et al. 2009). However, limited work has examined how these spatial dynamics operate in freshwater systems, where three-dimensional habitat use by marine mammals intersects with fishing activities across varying depths and vegetation zones.

Globally, aquatic human–wildlife conflicts affect diverse taxa including marine and freshwater mammals, sea turtles and large fish species, with gillnet fisheries identified as a primary threat (Read et al. 2006; Lewison et al. 2014). In the tropical freshwater systems of West and Central Africa, coastal and riverine human communities depend heavily on gillnet fisheries resources, where they come into contact with vulnerable marine mammal populations (Van Waerebeek et al. 2004; Dodman et al. 2008). Freshwater aquatic mammals in tropical Africa include the hippopotamus (*Hippopotamus amphibius*), African softshell turtle (*Trionyx triunguis*) and other marine and terrestrial threatened biodiversity such as the West African manatee (*T. senegalensis*), the African dwarf crocodile (*Osteolaemus tetetraspis*), as well as many fish species and migratory birds and otter species (*Aonyx capensis*, *Lutra maculicollis*), all of which face increasing pressure from expanding human activities in aquatic ecosystems (Laurance et al. 2012; Kingdon 2015). These species are particularly vulnerable because of their dependence on specific habitat requirements and their slow reproductive rates, making population recovery following declines difficult, and which overlap spatially with artisanal fishing activities (Lévêque et al. 2008; Reynolds et al. 2018).

The West African manatee is classified as Vulnerable by the IUCN Red List, with declining population trends across its range from Senegal to Angola (Powell 1996; Keith et al. 2008; Marsh et al. 2012). Historically, West African manatee populations have experienced significant reductions due to hunting, habitat loss and incidental capture in fishing gear, with current estimates suggesting fewer than 10,000 individuals remain range-wide (Reeves et al. 1988; Grigione et al. 2005; Marsh et al. 2012). West African manatees inhabit coastal waters, estuaries and freshwater rivers throughout West and Central Africa, with critical populations in countries including Senegal, Guinea-Bissau, Ivory Coast, Ghana and Cameroon (Reynolds and Powell 2002; Dodman et al. 2008; Akomo-Okoue et al. 2015). Conservation efforts have been limited by inadequate funding, weak law enforcement and limited scientific knowledge of population status and ecology of the West African manatee (Treves et al. 2006; Dodman et al. 2008; Lopes et al. 2016). The range of the West African manatee has shrunk significantly because of dam construction, coastal development and increased fishing pressure, with many historical habitats now supporting only remnant populations or becoming locally extinct (Dodman et al. 2008). Primary threats include incidental capture in fishing nets, hunting for meat and traditional medicine, habitat degradation and boat strikes in areas of high human activity (Laist and Shaw 2006; Akomo-Okoue et al. 2015).

Recent work on socio-ecological transformations highlights the need for integrative governance approaches that enable coexistence, learning and innovation across ecological and social boundaries (Moore et al. 2014; Chaffin et al. 2016). However, collective management systems can also generate human–wildlife conflicts when community-based resource rules conflict with wildlife protection needs, when resource scarcity intensifies competition between human and wildlife users or when collective institutions lack capacity to address novel conservation challenges (Read et al. 2006). Despite the growing recognition of the importance of SES approaches in conservation, significant empirical gaps remain in understanding how freshwater human–wildlife conflicts emerge, persist and can be transformed, particularly in data-scarce regions of sub-Saharan Africa. Furthermore, although theoretical frameworks for SES transformation exist, few studies have empirically examined how local communities, conservation organizations and government institutions interact to shape conservation outcomes in freshwater contexts (Turvey et al. 2013). This knowledge gap is particularly pronounced for large aquatic mammals, where conflicts often involve multiple stakeholder groups with different relationships to both the species and the ecosystem services it represents (Marshall et al. 2007). Understanding these dynamics requires moving beyond single-species or single-sector approaches to examine the full constellation of socio–ecological interactions that influence conservation success (Kansky et al. 2016).

These knowledge gaps are particularly problematic for freshwater megafauna conservation, where transformation toward coexistence is essential for species persistence but the pathways for achieving such transformation remain theoretically and empirically underdeveloped (Moore et al. 2014). Therefore, understanding how fisheries communities adapt practices, attitudes and governance systems in response to wildlife conservation needs represents a critical frontier for both SES theory and applied conservation science (Bennett et al. 2021). Without this understanding, conservation interventions risk failing to achieve the systemic changes necessary for long-term sustainability in human-dominated freshwater landscapes (Olsson et al. 2014). This study addresses these knowledge gaps by examining socio-ecological transformation pathways in freshwater human–wildlife interactions using Lake Ossa Wildlife Reserve (LOWR), Cameroon, as a case study. LOWR represents an ideal model system where West African manatee conservation intersects with artisanal fishing livelihoods in an enclosed freshwater environment. Using fishermen–manatee interactions as a model system, we investigate three research questions that advance understanding of SES transformations in freshwater contexts: (1) What is the frequency of manatee entanglements in fishing nets in Lake Ossa?, (2) Which net configurations are most associated with higher fish yield and greater risk of fish damage by manatees and other species? and (3) What factors influence fishermen's attitudes toward manatee conservation and conflict?

2 | Materials and Methods

2.1 | Study Area

LOWR (3°46′N, 10°02′E) is located in Cameroon's Littoral Region, 40 km northeast of Douala. Established in 1968, the reserve encompasses 4000 ha and includes Lake Ossa proper along with several interconnected water bodies (Mevia, Mwembe and Koungue Lakes) (Mayaka et al. 2013). The area experiences a tropical humid climate with distinct dry (November–March) and wet (April–October) seasons, with annual rainfall ranging from 2500 to 4000 mm (Ngouessono et al. 2016), (Figure 1).

The reserve is ranked seventh out of 1256 catchment areas in the Congo Basin, for intense protection, community-based management and for the protection of the West African manatee—qualifying the lake as a Key Biodiversity Area within the Congo Basin Forest Hotspot. The LOWR aquatic ecosystem is characterized by high primary productivity, supporting fish assemblages dominated by cichlids (*Tilapia* spp., *Oreochromis* spp.), catfish (*Clarias* spp., *Heterobranchus* spp.), and characins (*Hydrocynus* spp.) (Tchouto et al. 2006; Pouomogne 2008; Njifonjou et al. 2019). Lake margins (1–3 m depth) are dominated by emergent and submerged vegetation including *Eichhornia crassipes*, *Pistia stratiotes* and *Nymphaea species*, providing critical manatee habitat.

The reserve encompasses Lake Ossa and several interconnected water bodies—one of which is the Sanaga River—that support one of Central Africa's most important West African manatee populations (Mayaka et al. 2013; Akomo-Okoue et al. 2015; Kouadio et al. 2015). The LOWR aquatic ecosystem also sustains five traditional fishing communities—Beach, Mevia, Lindema, 3Km and Pongo-Petti—whose livelihoods depend heavily on artisanal gillnet fishing practices that have been practised over generations (Infield 1988; Mayaka et al. 2013). These fishing communities face complex socio–ecological challenges, in part due to nearby urban populations with growing demand for fish and other rurally-sourced foods, as well as expanding agro-industrial plantations of rubber and palm oil. The reserve's aquatic ecosystem supports diverse fish communities that form the basis of local artisanal fisheries. LOWR villages have high poverty levels, with over 70% of households living below the national poverty line, and fishing providing the primary source of income and protein for approximately 80% of households (Folifac et al. 2009).

These five fishing communities vary significantly in size, fishing intensity and socioeconomic characteristics. Beach (population ~450, with 120 active fishermen) represents the largest community with the most diverse fishing techniques and highest market access. Mevia (population ~380, with 110 fishermen) specializes in gillnet fishing and has the longest fishing tradition in the reserve. 3KM (population ~150, with 35 fishermen) is the smallest community, practicing intensive fishing with high gear investment per fisher. Pongo-Petti (population ~200, with 30 fishermen) combines fishing with agriculture, making fishing a secondary livelihood activity for many households. Lindema (population ~80, with 15 fishermen) represents a remote community with limited market access and highest dependence on subsistence fishing. Resource use patterns differ among communities: Beach and Mevia practice commercial fishing with daily market sales, 3KM and Pongo-Petti combine commercial and subsistence fishing, whereas Lindema focuses primarily on subsistence with occasional surplus sales. As pressure on the LOWR fisheries mounts due to growing urban demand, so does the impact on manatees given that traditional fishing grounds extensively overlap with prime manatee habitat (Mayaka et al. 2013; Akomo-Okoue et al. 2015).

All communities practice individual fishing rights with informal territorial agreements, though collective gear sharing occurs during peak fishing seasons (Njifonjou et al. 2019; Eyina Ayina et al. 2020). Traditional methods include gillnets

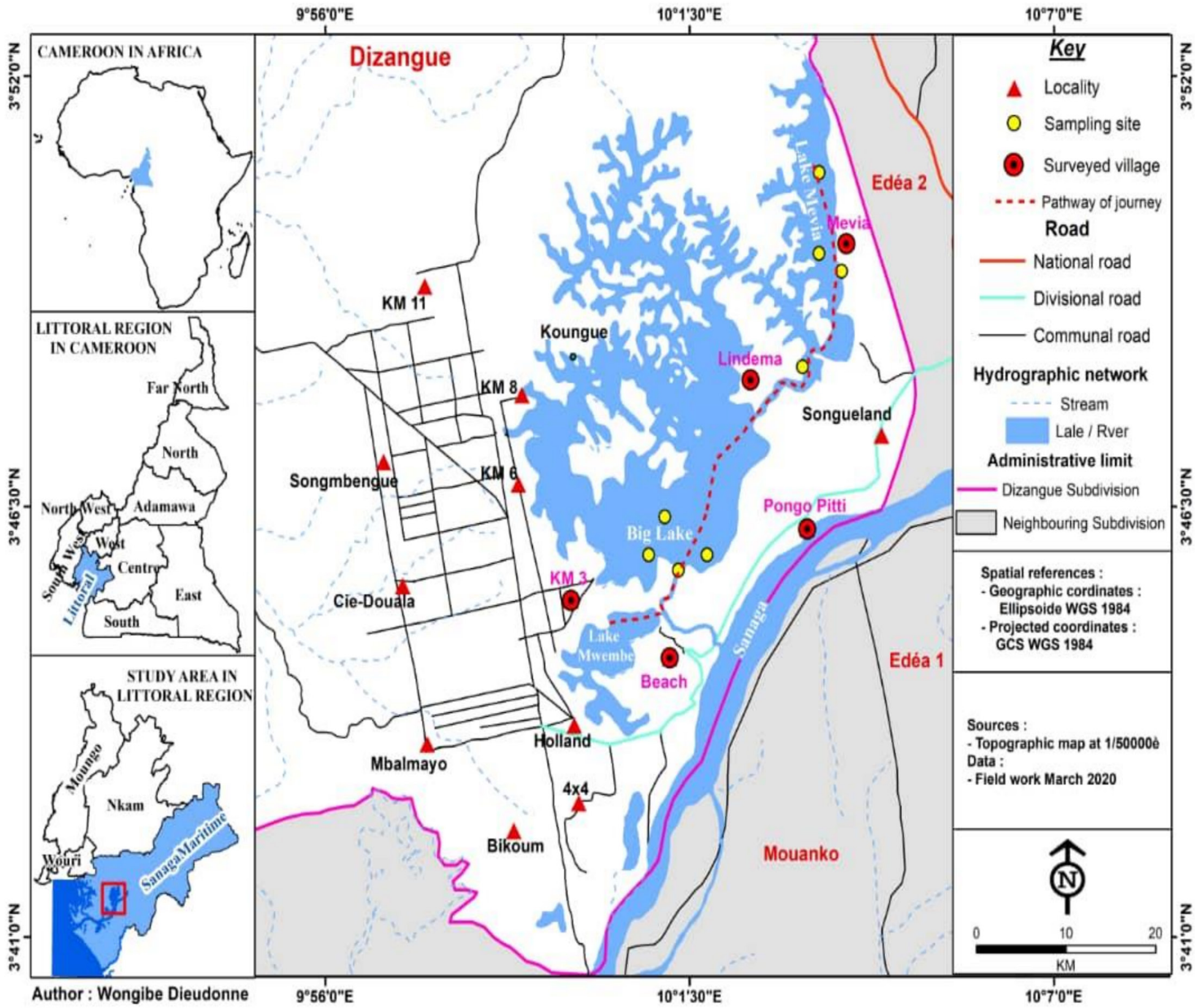


FIGURE 1 | Map of Lake Ossa Wildlife Reserve (LOWR) showing spatial distribution of fishing communities and sampling locations. Red points with black centers indicate primary sampling stations where structured interviews were conducted with fishermen ($n = 143$).

(locally "filets maillants"), cast nets ("éperviers"), fish traps ("nasses") and hook-and-line fishing, with gillnets dominant due to efficiency in capturing diverse species (Pouomogne 2008; Ngouessono et al. 2016). The "Bither" technique is a common fishing practice within the reserve that requires a gillnet, coupled with plumbs at the base and floaters at the top, all attached on the gillnet using twines, separated 2 m apart for each floater or plumbs. It is a drifting method where nets are deployed for 12–24 h in open water, along/across corridors and along/around manatee grazing areas before harvest. The nets could be placed for up to 2 or 3 days at a site depending on the fish yield in this area. It is done in all seasons and usually by one or two people depending on the number of nets to be deployed. The catch per unit effort depends on the mesh size, with mesh size varying with season as fishers target different fish species.

Despite the regional conservation importance of LOWR, critical knowledge gaps limit effective management. No comprehensive assessment has quantified manatee entanglement frequency and patterns in fishing gear, hindering understanding of population-level impacts. The relationship between specific net deployment techniques and entanglement risk remains poorly understood, preventing development of evidence-based mitigation strategies. Additionally, factors influencing local attitudes toward manatee conservation have not been systematically analysed, limiting community engagement effectiveness.

2.2 | Data Collection

We conducted structured interviews with 143 local fishermen between March and August 2019 using a standardized questionnaire developed in consultation with community leaders and conservation organizations. A semi-structured questionnaire was developed and pre-tested (see Supporting Information S1). The questionnaire was pre-tested with 10 fishermen from the Beach community, revealing issues with technical terminology comprehension and question sequencing that were subsequently refined for cultural relevance and validity. Refinement included: (1) simplifying technical fishing terminology to local equivalents ("filet maillant" for gillnet, "nasse" for trap); (2) adding French language translations for gear type names with visual aids; (3) restructuring a 5-point Likert scale attitude questions to use locally-appropriate with three-category responses (agree, neutral and disagree); and (4) reordering questions beginning with non-sensitive topics before conflict and attitude questions to reduce respondent fatigue and promote talk flow. The interview survey was conducted by two trained enumerators: the principal investigator and a field assistant who was a native French speaker recruited from the broader study region (though not from study villages to maintain objectivity). Both received 2 days of training covering standardized techniques, research ethics protocols and data recording procedures. Training included role-playing exercises with practice interviews, cultural sensitivity protocols for discussing wildlife conflicts and calibration exercises to ensure consistent question delivery and response recording. Interviews lasted approximately 45–60 min and were conducted in participants' preferred language (French) at locations chosen by respondents to ensure comfort and privacy. A systematic sampling approach targeting every third household in each of the survey villages was employed. We achieved a response rate of 89.4% (143 of 160 approached fishermen). The random effects testing the differences in responses across the principal investigator and a field assistant, particularly for sensitive variables including entanglement frequency, hunting attitudes and compensation demands. We found no significant interviewer effects (likelihood ratio test, $\chi^2 = 0.91$, $\mathrm{df} = 1$, $p = 0.34$), indicating consistent data collection across interviewers and reducing concerns about systematic bias in responses to sensitive topics (Infield 1988; Mehta and Kellert 1998).

Because fishermen represent a hard-to-reach population without formal registries, sampling employed purposive and snowball techniques to ensure representation across sampling stations, experience levels and age groups (Table 1). We established initial contact through community leaders at each sampling station, then used systematic referral chains asking each participant to identify additional fishermen with different experience levels and fishing practices. Snowball sampling limitations include potential bias toward well-connected individuals and possible exclusion of marginalized fisheries members. However, this approach was necessary given the absence of complete fisher registries. We mitigated bias by using multiple seed points per sampling station (3–4 initial contacts per site) and achieved saturation when no new fishermen were identified after three consecutive referral rounds (Burnham and Anderson 2002). Our sample represents 35%–49% of active fishermen per sampling station based on village leader estimates. Fishermen were approached at designated sampling stations including landing sites, fishing camps and community gathering places along established survey pathways. Participation was voluntary and informed consent was obtained verbally from all respondents following ethical guidelines for research with local communities (Dawson and Suich 2025)).

The questionnaire covered five areas: (1) Demographic factors included age (years), fishing experience (years), community residence duration (years), household size (number of dependents), education level (none/primary/secondary), and livelihood dependence (fishing as primary versus supplementary income source). These variables were selected based on literature indicating their influence on resource use patterns and conservation attitudes (Infield 1988; Mehta and Kellert 1998); (2) fishing practices including net deployment configurations, timing, and effort; (3) experiences with manatee and wildlife entanglement; (4) fish yield and damage patterns; and (5) attitudes toward manatees and conservation. Attitude questions used structured response options (neutral behaviour, compensation for damage, hunt/keep away manatees) that were pre-coded during questionnaire development (Naughton-Treves et al. 2003). Regarding net configuration questions, we used categorical responses (parallel to vegetation, perpendicular to vegetation, circular in open water, corridors) based on local fishing terminology and techniques. Entanglement frequency and damage timing was used on an ordinal scale, whereas sighting frequency used categorical groupings developed through pilot testing.

2.3 | Statistical Analysis

Data exploration revealed missing values in 18 of 32 variables (1–13 missing values per variable, representing 2.1%–8.7% of responses per variable). The raw survey data supporting the conclusions of this article are available in Supporting Information S2. Missing data occurred due to: (1) some respondents declining to answer sensitive questions about hunting attitudes ($n = 8$ cases); (2) interviewer error in recording net configuration details ($n = 12$ cases); and (3) respondents uncertain about exact frequencies of rare events like python encounters ($n = 14$ cases). Given the mixed numeric and categorical nature of variables, random forest imputation was employed using the *missForest* package (Stekhoven and Bühlmann 2012). This method was selected because it handles mixed-type data effectively and

TABLE 1 | Demographic characteristics and sampling distribution across five fishing communities in Lake Ossa Wildlife Reserve, Cameroon. Sample sizes represent 35%–49% of estimated active fishermen per community based on village leader estimates.

Sites	Sample size (*n*)	Estimated fishermen population*	Age range (years)	Experience range (years)
Beach	54	~120	19–73	2–45
Mevia	52	~110	18–68	1–50
3KM	18	~35	22–65	5–35
Pongo-Petti	15	~30	20–58	3–28
Lindema	4	~15	35–62	15–40

*The estimated active fishers' population by village leaders.

does not assume linear relationships between variables (Bartoń 2020). As with most interview studies, the possibility of missingness not at random cannot be entirely excluded. However, sensitivity analyses comparing complete-case and imputed datasets yielded consistent results (Figure 2), indicating robustness to the handling of missing data. Imputation accuracy was evaluated through out-of-bag (OOB) error estimates, yielding excellent performance for numeric variables (Normalized Root Mean Square Error, NRMSE = 0.038) and moderate accuracy for categorical variables (Proportion of Falsely Classified entries, PFC = 0.213).

The multinomial logistic regression (MnLR) was fitted, using the *glmmTMB* package, to analyse fishers' attitudes toward conflict resolution from net damage. We used this statistical method because the dependent variable (fishermen attitudes) comprised three unordered categories: neutral behaviour, compensation seeking and hunting/keeping away of manatees. Eight independent variables were initially considered in the full model, based on theoretical relevance: fishing experience (years), age (years), entanglement frequency, sighting frequency, net damage frequency, fishing site, nets deployed per trip and total net length.

To ensure there was no multicollinearity among the eight independent variables, we calculated the variance inflation factor (VIF) for these variables and retained variables that were sufficiently not correlated (VIF ≤ 5). Spatial autocorrelation was assessed using Moran's I test on model residuals, revealing no significant spatial clustering ($I = 0.12$, $p = 0.34$).

Backward stepwise elimination was performed using the *step()* function of base R, removing predictors that did not improve model fit ($\Delta AIC < 2$). The final model retained entanglement incidents (≤ 2 times versus > 2 times) and manatee sighting frequency (< 4 times, ≥ 4 times).

The "never seen" class of the latter predictor was excluded in the model due to its small sample size ($n = 6$) which could inflate the standard error (Agresti 2013). The model quality was assessed using Cox & Snell pseudo-R^2 and classification accuracy, and this yielded, 21% and 56%, respectively.

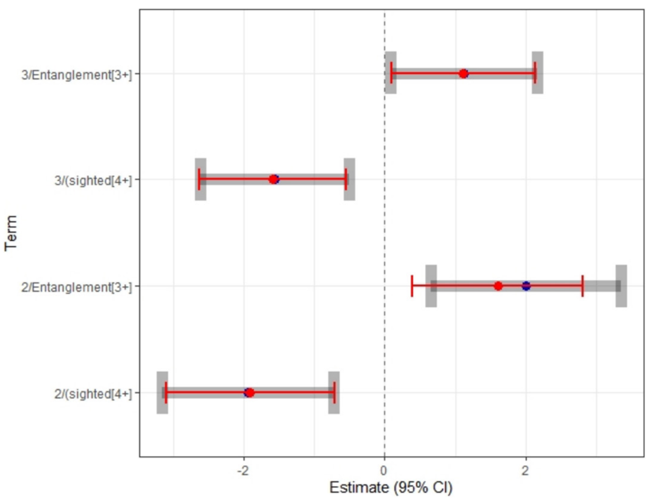


FIGURE 2 | Revealing missing values, plot displays choice of imputation missing data.

Descriptive statistics were calculated for demographic and fishing practice variables. The Spearman correlation analysis examined relationships between net length and number deployed. Chi-squared tests compared response proportions regarding species entanglement, attitudes and net configurations. When expected cell counts were below five, Fisher's exact tests were employed.

Non-Metric Multidimensional Scaling (NMDS) ordination with Jaccard dissimilarity distance was used to explore patterns in fishermen's responses across fishing sites regarding net deployment practices and species causing fish damage (Oksanen et al. 2020). The significance of correlations between response variables and NMDS axes was evaluated using Monte Carlo permutation tests ($n = 999$ permutations). NMDS was chosen over other multivariate analyses because our data contained mixed categorical and ordinal variables with nonlinear relationships. This method makes no assumptions about data distribution and is robust to the type of ecological data collected in this study. Jaccard dissimilarity was selected as the distance measure because it is appropriate for presence/absence and categorical data, giving equal weight to shared presences and absences.

This integrated approach allowed us to examine feedback loops between fishing practices, manatee encounters and conservation outcomes within the socio-ecological systems (SES) framework. This identified fishing practices, represent net configurations, and fishing strategies constitute potential intervention points for reducing human–manatee conflicts while maintaining fishing livelihoods. However, optimization of trade-offs between conservation and economic outcomes would require additional economic modelling and spatial optimization techniques (Phalan et al. 2011) beyond the scope of this study. All statistical analyses were carried out in R 4.0.2 (R Core Team 2021), and significance level (alpha) was set at the 5% probability level.

3 | Results

3.1 | Respondent Characteristics and Fishing Practices

Respondent ages ranged from 18–73 years (mean = 40.4 ± 1.05), with fishing experience of 1–50 years (mean = 15.7 ± 0.84). Participants had resided in their communities for 2–65 years (mean = 28.9 ± 1.11). Fishing experience varied significantly among sites (Table 2). Lindema fishermen showed the highest experience (22.8 ± 6.8 years) and oldest age (44.2 ± 11.3 years), whereas Pongo-Petti had the least experience (12.9 ± 2.3 years) and youngest age (37.5 ± 3.1 years). Residence duration was relatively consistent across sites, ranging from 27.1 to 29.6 years. These demographics align with regional patterns where mean fisher age ranges between 35 and 45 years (Read et al. 2006). Village-specific census data were unavailable for direct comparison, representing a limitation for contextualizing our sample representativeness.

Fishing intensity was high across all sites, with 80.5% of respondents fishing 6 days per week. The number of fishing days ranged from one (1.4% of respondents) to seven (4.2% of respondents), with mean values consistent across sites (approximately 6 days/week). All 18 respondents from 3KM reported fishing exactly 6 days per week.

Net deployment patterns showed considerable variation among sites (Table 2). The number of nets per trip ranged from 1 to 10 (mean = 4.69 ± 0.19), whereas total net lengths extended from 80 to 400 m (mean = 219.51 ± 8.75 m). 3KM and Beach fishermen deployed the most nets per trip (5.2 nets/fisher/trip), followed by Mevia (4.3 nets/fisher/trip), whereas Lindema and Pongo-Petti used fewer nets (3.8 nets/fisher/trip each).

Despite deploying fewer nets, Lindema fishermen used significantly longer nets (275 ± 72.6 m), suggesting a strategy of fewer but more extensive deployments. Beach and 3KM fishermen used similar total net lengths (228.7 ± 15.1 and 227.8 ± 26 m, respectively), whereas Mevia and Pongo-Petti employed shorter nets (210.4 ± 13.3 and 193.3 ± 29.4 m, respectively) (Table 3). A significant negative correlation was found between the number of nets deployed and total net length ($\rho = -0.22$, $p = 0.008$), indicating that fishermen using more nets tended to use shorter individual net lengths.

Most fishermen (62.2%) deployed nets in the morning, with fewer deploying in the evening (23.1%) or throughout the day (14.7%). The "bither" fishing technique was universally practiced and was reported as season-independent by 70.6% of respondents.

3.2 | Manatee Entanglement and Net Damage

Manatee entanglement was reported by 70.6% ($n = 101$) of respondents. Among those reporting entanglement, 56% ($n = 70$) experienced 3–5 events, 20% ($n = 25$) more than five events and 24% ($n = 30$) single occurrences. Other bycatch species included turtles (72.7%, $n = 104$) and pythons (62.2%, $n = 89$). Entanglement likelihood did not differ significantly among species groups ($\chi^2 = 4.09$, df = 2, $p = 0.13$) (Figure 3). Net damage was reported by 82.5% ($n = 118$) of respondents. Damage timing varied: 40% ($n = 52$) reported evening damage as most common, 31.5% ($n = 41$) indicated damage at any time, and 2.3% ($n = 3$) identified morning as primary period.

3.3 | Fishermen's Attitudes Toward Manatees

Manatee entanglement rates were consistently high across all sites (66.7–75.0%), with an overall prevalence of 70.6% among respondents, indicating that human–manatee interaction represents a widespread challenge throughout the LOWR rather than being localized to specific areas. Similarly, net damage rates exceeded 75% in all villages, reaching 85.2% in Beach, demonstrating the substantial economic impact of wildlife interactions on fishing operations across the study area.

Notably, conservation attitudes varied significantly among villages despite similar conflict experiences. Beach and Mevia showed strong preferences for hunting/keeping away manatees (HKAM, 57.1% and 77.0% respectively among non-neutral respondents), whereas 3KM and Pongo-Petti favoured compensation-based approaches (100% and 57.1%, respectively). Lindema showed equal preference between approaches, and overall, neutral attitudes predominated (55.9%), suggesting that many fishermen remained open to various conservation interventions. These spatial variations in attitudes, despite comparable conflict rates, highlight the importance of site-specific factors in shaping community responses to human–wildlife

TABLE 2 | Profile of fishing experience across the five surveyed sites/villages, including mean duration of fishing experience, mean age, and longevity.

Site	Mean duration of fishing (years)	Mean respondent's age	Longevity in the site (years)
Beach	17.6 ± 1.6	41.7 ± 1.8	29.5 ± 1.8
Mevia	13.4 ± 1.2	38.9 ± 1.8	28.5 ± 1.9
3Km	17.3 ± 2.2	42.6 ± 2.6	29.6 ± 2.9
Pongo-Petti	12.9 ± 2.3	37.5 ± 3.1	27.1 ± 4.1
Lindema	22.8 ± 6.8	44.2 ± 11.3	29 ± 8.2

TABLE 3 | Village-level comparison of fishing pressure indicators in Lake Ossa Wildlife Reserve: weekly fishing frequency, net deployment rates, and cumulative net length (metres) across five surveyed communities ($n = 125$ fishermen). Mean values ± standard error demonstrate spatial variation in fishing intensity potentially affecting human–manatee conflict patterns.

Site	Mean fishing days per week	Mean number of nets deployed	Mean total net length (m)
Beach	5.8 ± 0.1	5.2 ± 0.3	228.7 ± 15.1
Mevia	5.7 ± 0.1	4.3 ± 0.3	210.4 ± 13.3
3Km	6 ± 0	5.2 ± 0.7	227.8 ± 26
Pongo-Petti	5.9 ± 0.1	3.8 ± 0.6	193.3 ± 29.4
Lindema	5.8 ± 0.3	3.8 ± 0.9	275 ± 72.6

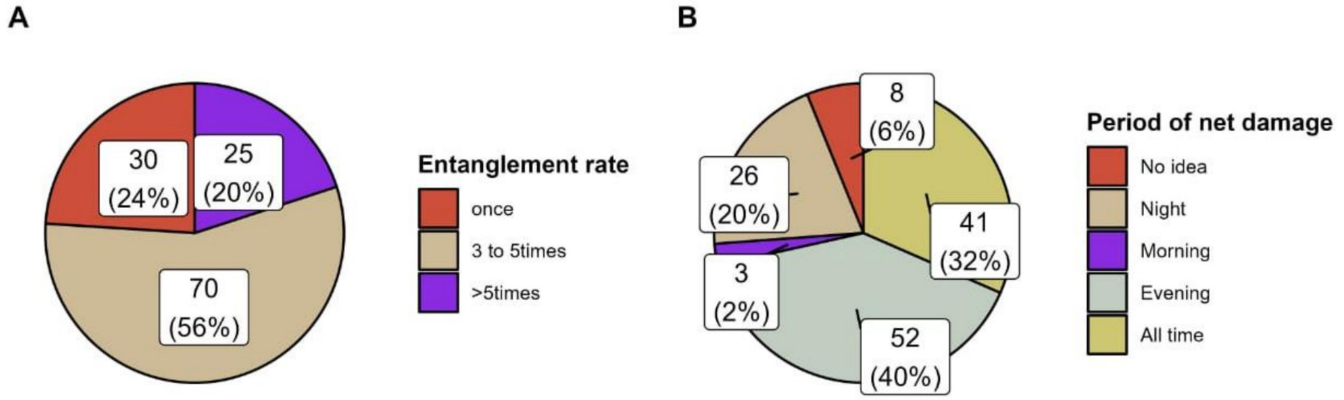


FIGURE 3 | Manatee–fishermen interaction patterns in Lake Ossa. (A) Frequency distribution of manatee entanglement events experienced by individual fishermen ($n=125$), with 70.6% reporting at least one entanglement. (B) Temporal patterns of net damage incidents ($n=130$), showing evening predominance (40%) of wildlife-related fishing nets damage.

TABLE 4 | Village-level comparison of manatee entanglement rates, net damage frequency, and dominant conservation attitudes among Lake Ossa fishing communities ($n=143$ fishermen across five sites). Data demonstrate uniform conflict prevalence but spatially variable community responses to human–manatee interactions.

Sites	Manatee entanglement (%)	Net damage (%)	Dominant attitude*
Beach	38 (70.4%)	46 (85.2%)	HKAM (57.1%)
Mevia	37 (71.2%)	42 (80.8%)	HKAM (77.0%)
3KM	13 (72.2%)	15 (83.3%)	Compensation (100%)
Pongo-Petti	10 (66.7%)	12 (80.0%)	Compensation (57.1%)
Lindema	3 (75.0%)	3 (75.0%)	Equal preference
Total	101 (70.6%)	118 (82.5%)	Neutral (55.9%)

Abbreviation: HKAM = Hunt/Keep Away Manatees.
*Among non-neutral respondents only.

conflicts and underscore the need for locally adapted conservation strategies (Table 4).

Fishermen exhibited four distinct attitudes toward manatees in response to conflicts: hunting to reduce population size (14.7%), keeping manatees away from fishing sites (10.5%), requesting government compensation for net damage (18.9%), and neutral behaviour (55.9%).

While ignoring neutral attitudes to focus on active management, there was variation among sites in the preference for compensation versus HKAM (Figure 4). Fishermen from 3KM (46.2%) and Pongo-Petti (28.6%) showed stronger support for compensation compared to HKAM strategies. Conversely, respondents from Mevia (37.8%) and Beach (20.4%) demonstrated higher support for HKAM approaches compared to compensation, with the difference in this attitude significant in Mevia ($\chi^2=11.57$, df $=1$, $p=0.001$). Lindema fishermen showed equal support for both compensation and HKAM strategies.

The MnLR model (Cox & Snell pseudo-$R^2=0.21$, classification accuracy $=56\%$, Figure 5) revealed significant relationships between conflict experiences and attitudes. Fishermen who had experienced three or more manatee entanglements were significantly more likely to support HKAM (OR $=3.05$, 95% CI $=1.10$–8.45, $p=0.03$) and to advocate for compensation (OR $=5.00$, 95% CI $=1.47$–16.94, $p=0.01$) compared to those with fewer (once or never) entanglement experiences. The multi-species nature of bycatch suggests interventions targeting manatees could yield broader biodiversity benefits. Site-specific variations emphasize the need for locally-tailored approaches rather than uniform management prescriptions.

Surprisingly, frequent manatee sightings (≥ 4 times/month) significantly reduced by 80% and 85% respectively the likelihood of both HKAM attitudes (OR $=0.20$, 95% CI $=0.07$–0.58, $p=0.003$) and support for compensation (OR $=0.15$, 95% CI $=0.04$–0.50, $p=0.002$) compared to neutral attitudes.

3.4 | Fish Yield and Damage Patterns

A significant proportion of fishermen (78.3%, $n=112$) reported fish predation or damage from gillnets ($\chi^2=45.88$, df $=1$, $p<0.001$), indicating widespread losses in the study area. Manatees were frequently cited as causing damage (71.3%); other damage-causing species included large catfish (*Clarias* spp.), *Turtle* spp., otters (*Lutra lutra*), and African giant shrew (*Crocidura olivieri*), which were equally implicated (72.7%), suggesting multiple sources of fish loss. No clear taxonomic pattern emerged, though most were nontarget species of limited

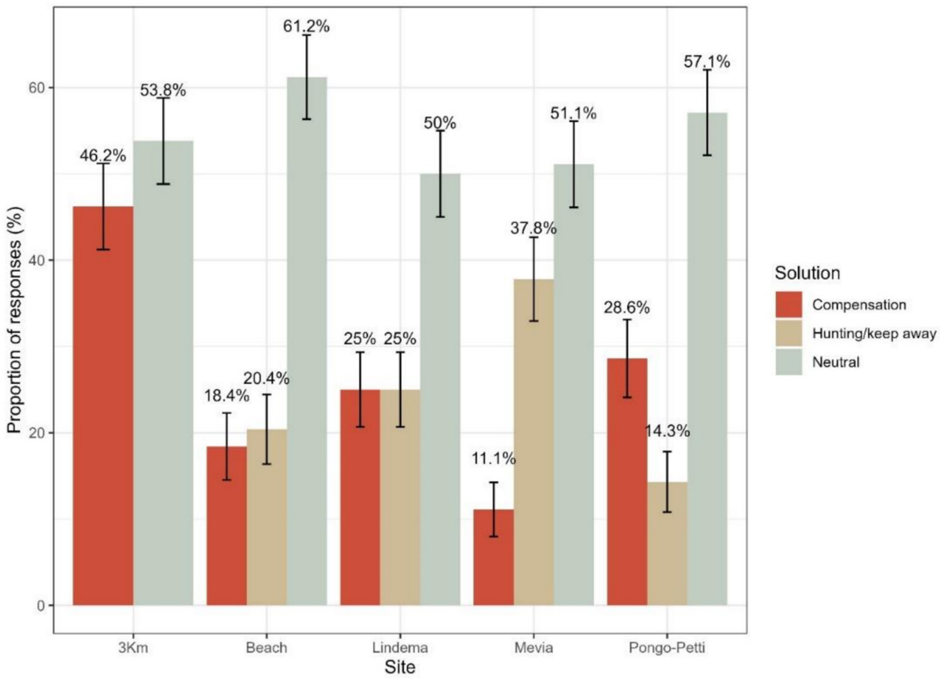


FIGURE 4 | Distribution of fishermen's attitudes toward manatees across five fishing communities in LOWR. The graph shows the proportion of respondents in each village who prefer either compensation from government for net damage, hunting/keeping away manatees (*HKAM*) or neutral attitude as conflict resolution strategies. The error bars are derived from standard error.

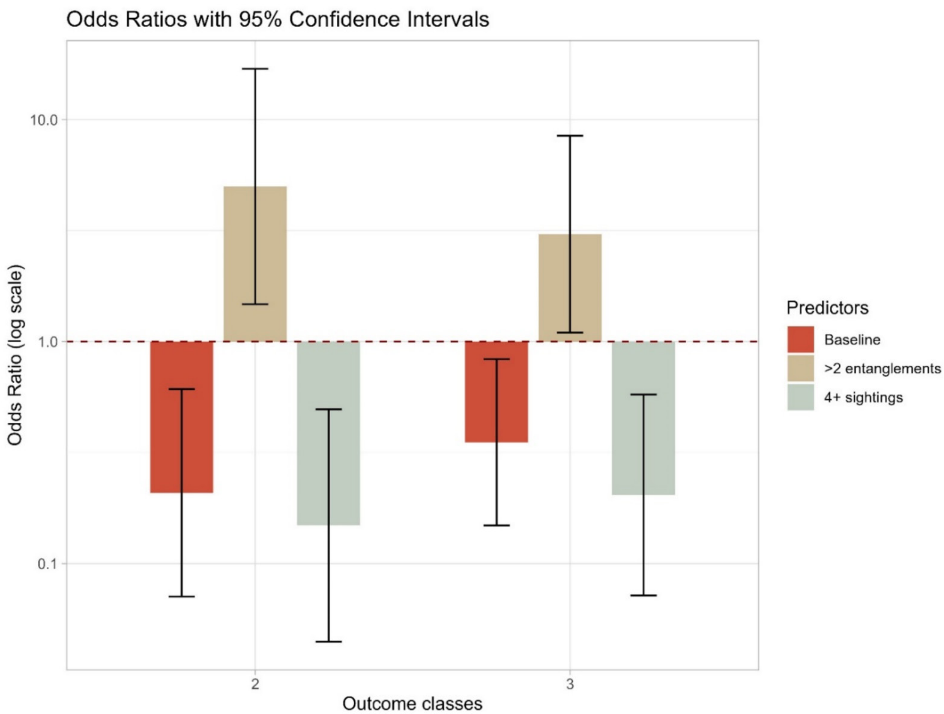


FIGURE 5 | Predicted attitudes of fishermen (outcome variables) in relation to experienced entanglement of manatees and reporting sighting of manatees. The attitudes included: 1 = neutral (the reference, not shown on the graph); 2 = compensation; and 3 = hunting/keep away. The baseline classes of the two predictors were: ≤ 2 times (for number of experienced entanglement) and < 4 sightings (for reported sighting). The error bars represent the 95% confidence intervals.

commercial value, suggesting fishermen may be more tolerant of damage from economically valuable species.

Net configuration significantly influenced both fish yield ($\chi^2 = 70.0$, df = 3, $p < 0.001$, (Figure 6) and damage patterns ($\chi^2 = 36.98$, df = 2, $p < 0.001$). Circular deployment in open water (61.5%) and perpendicular placement to vegetation (54.9%) were most frequently associated with high fish yields, whereas corridor placement was least favoured (16.1%). Three net configurations were associated with fish damage, occurred with nets set

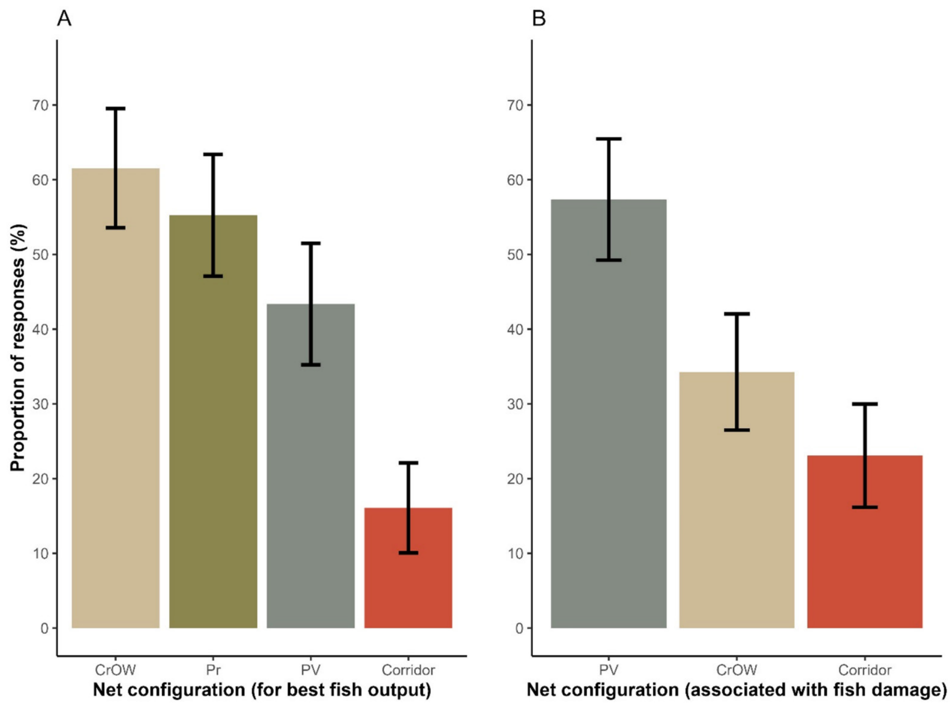
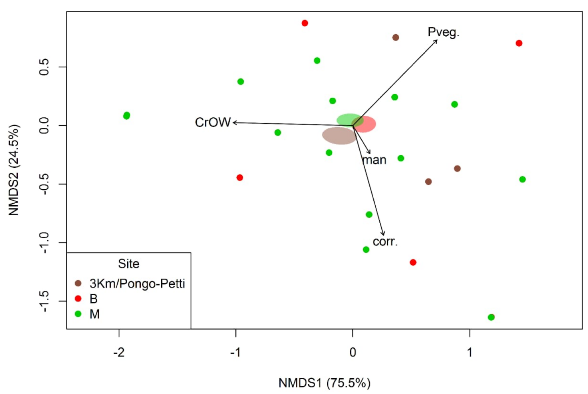


FIGURE 6 | Fishermen's responses (with 95% confidence intervals) on (A) net configurations associated with higher fish yields and (B) configurations associated with greater fish damage by manatees and other aquatic species. (Corridor; CrOW = circular in open water; PV = parallel to vegetation).

parallel to vegetation (57.3%) or circular in open water (34.3%). Although corridor placement was least reported overall for fish damage (23.1%), NMDS analysis (Figure 7) revealed that manatee-specific damage was most strongly associated with corridor deployment ($R^2 = 0.64$, $p < 0.001$).

Site-specific patterns emerged from the NMDS analysis (Figure 7). Pongo-Petti and Beach fishermen most frequently reported parallel net setting as causing fish damage ($R^2 = 0.72$, $p < 0.001$). 3KM respondents were distinct from other sites, predominantly associating circular open-water deployment with fish damage ($R^2 = 0.71$, $p < 0.001$). Turtle-related damage showed no significant association with fishing sites ($R^2 = 0.05$, $p = 0.15$).

These integrated findings demonstrate that human–manatee interactions in LOWR are embedded within broader socio-ecological transformations driven by adaptive fishing technologies, spatial habitat use patterns and evolving conservation awareness, providing multiple pathways for sustainable coexistence.



*(**B**=Beach; **M**=Mevia; **man**=Manatee; **Pveg**=parallel to vegetation; **CrOW** = circular in open water; **corr.**= Corridor).*

FIGURE 7 | Non-Metric Multidimensional Scaling (NMDS) of Site-Based reported causes of fish damage, and net deployment Practices. Lindema's smaller sample ($n = 4$ of 15 total fishermen, 27% participation) reflected the community's limited fishing activity and scheduling conflicts during the agricultural season when fishing is secondary to farming activities. The percentage values on the axes represent the proportion of variation in fitted distances, provided for comparison purposes only; they are not eigenvalues. (B = Beach; corr. = Corridor; CrOW = circular in open water; M = Mevia; man = Manatee; Pveg = parallel to vegetation).

4 | Discussion

4.1 | Implications for LOWR Conservation and Livelihoods

4.1.1 | Specific Findings for Manatee Conservation in LOWR

Our findings reveal that human–manatee interactions in LOWR are characterized by exceptionally high conflict rates, with 70.6% of fishermen reporting manatee entanglement experiences significantly exceeding global averages for Florida (25%–30%, Flamm et al. 2000) and Brazilian systems (40%–50%, Lima et al. 2012). This elevated conflict intensity reflects the unique ecological constraints of LOWR as an enclosed lacustrine system where spatial compression creates an ecological pressure effect. Unlike coastal environments where both manatees and fishing activities can disperse across vast areas, LOWR's limited spatial extent (4000 ha) with only one inlet connecting to the Sanaga River concentrates human and wildlife activities into overlapping zones, exacerbated by the shallow mean depth (2.5 m) that forces both manatee foraging and fishing activities into the same vertical water column.

The predominance of evening net damage (40% of reports) reveals a critical temporal dimension to these conflicts, aligning with known manatee crepuscular and nocturnal feeding patterns (Reynolds and Odell 1991; Marsh et al. 2011). This temporal pattern represents an evolutionary mismatch between manatee feeding rhythms optimised for avoiding historical predators and human fishing schedules driven by market demands and social conventions. The NMDS analysis further revealed that corridor deployments are disproportionately associated with manatee damage ($R^2 = 0.64$, $p < 0.001$), indicating that these areas represent critical manatee movement pathways, with ecological highways connecting feeding, resting and breeding areas where even limited human activities can have outsized conservation impacts (Deutsch et al. 2003).

4.1.2 | Economic Impacts on Local Fishing Communities

The economic dimensions of human–manatee conflict extend beyond simple gear damage to represent systematic disruptions to community livelihoods. Nets set parallel to vegetation and circular in open water—strategies associated with both high fish yields and increased damage risk—exemplify what we term the optimization paradox in SES's. Fishermen have evolved these deployment strategies through generations of trial-and-error learning, optimizing for immediate economic returns within their current technological constraints, yet these locally optimal strategies create system-level inefficiencies when wildlife conservation is considered.

The negative correlation between net number and total length ($\rho = -0.22$, $p = 0.008$) reveals sophisticated adaptive strategies employed by fishermen to optimize effort under varying constraints. Some prefer many shorter nets for greater spatial coverage and risk distribution, whereas others use fewer but longer deployments to reduce labour costs and equipment complexity. This strategic diversity represents valuable local ecological knowledge that demonstrates the economic sophistication of fishing communities and their capacity for adaptive management when properly supported.

Site-specific variations in economic impacts reflect differences in market access, ethnic composition and livelihood diversification. Villages with daily transport access (Beach and Mevia) versus weekly access (others) and communities with greater economic diversification (agro-fishing in Mevia and Lindema) versus fishing-dependent economies (Beach and Mouanko) show different vulnerability patterns to manatee-related economic losses, emphasizing the need for differentiated support strategies (Read et al. 2010).

4.1.3 | Management Recommendations for the Reserve

Our results support integrated management strategies that address the entire SES rather than focusing individually on biological or social components. Specific recommendations include: (1) promoting morning rather than evening net deployment to reduce overlap with peak manatee activity periods; (2) designating corridor areas as priority conservation zones with modified fishing practices rather than complete exclusion; (3) encouraging fewer, longer nets rather than multiple shorter deployments to reduce overall interaction frequency while maintaining fishing efficiency; (4) that increase positive manatee encounters, leveraging our finding that frequent sightings (≥ 4 times/month) significantly reduce negative attitudes (OR = 0.20 for hunting support, OR = 0.15 for compensation demands); and (5) addressing economic losses while incentivizing conservation-compatible practices.

The multi-species nature of bycatch affecting manatees, turtles, and pythons ($\chi^2 = 4.09$, df = 2, $p = 0.13$) indicates that interventions targeting manatees could yield broader biodiversity benefits, supporting ecosystem-based management approaches. The predominance of neutral attitudes (55.9%) among fishermen suggests significant potential for building community support through appropriate interventions, representing a receptive audience for conservation engagement rather than the strongly polarized attitudes found in some human–wildlife conflict contexts.

4.2 | Freshwater SES Transformation Dynamics

4.2.1 | How Findings Demonstrate SES Transformation Principles

Our findings provide important empirical evidence for SES transformation theory by demonstrating how feedback loops between social and ecological components shape conservation outcomes in complex, bidirectional ways. The relationship between manatee sightings and positive conservation attitudes illustrates how ecological components (manatee behaviour and distribution) directly influence social components (community attitudes), creating positive feedback loops that could support conservation goals (Ostrom 2009; Folke et al. 2010). This finding supports the SES principle that transformation occurs through the dynamic interaction of social and ecological subsystems rather than through isolated interventions in either domain.

Conversely, the relationship between entanglement frequency and negative attitudes demonstrates negative feedback loops where ecological interactions (manatee-net encounters) generate social responses (hunting attitudes, OR = 3.05 for ≥ 3 entanglements) that could further threaten the ecological component. This bidirectional causality exemplifies SES theory's emphasis on understanding system-level dynamics rather than assuming unidirectional impacts (Young et al. 2006; Liu et al. 2007). The spatial compression effects in LOWR demonstrate how ecological constraints can intensify socio-ecological interactions, creating conditions where small changes in either social practices or ecological conditions can trigger system-wide transformations.

4.2.2 | Role of Experiential Learning in Attitude Change

The contrasting effects of different types of manatee encounters offer insights into how experiential learning drives attitude transformation in freshwater SES. Our finding that frequent manatee sightings reduce negative attitudes while frequent entanglements increase them demonstrates that the quality and context of human–wildlife encounters fundamentally shape conservation outcomes. This supports the contact hypothesis from social psychology (Allport 1954; Pettigrew and Tropp 2006), suggesting that positive, nonconflict encounters with wildlife can catalyse transformative changes in community perspectives.

This experiential learning dynamic represents a critical leverage point for SES transformation, as it provides a mechanism through which conservation interventions can shift system trajectories. The fact that 55.9% of fishermen maintained neutral attitudes indicates that many community members have not yet formed strong positions, representing a transformative opportunity where positive encounters could tip attitudes toward conservation support. This finding suggests that carefully designed wildlife viewing or community monitoring programs could serve as transformation catalysts by increasing the frequency of positive manatee encounters while reducing conflict interactions.

4.2.3 | Adaptive Capacity of Fishing Communities

The sophisticated fishing strategies revealed in our analysis demonstrate adaptive capacity within LOWR fishing communities that could be leveraged for conservation transformation. The strategic diversity in net deployment approaches—from spatial coverage optimization to risk distribution strategies—represents valuable local ecological knowledge developed through generations of environmental learning. This adaptive capacity constitutes a foundation for SES transformation, as it indicates that communities possess the knowledge systems and behavioural flexibility necessary to modify practices in response to changing conditions (Tengö et al. 2021).

The site-specific variations in conservation attitudes and fishing practices further demonstrate adaptive capacity, with different communities developing distinct approaches based on their particular ecological, economic, and social contexts (Bennett et al. 2017). Villages with different ethnic compositions, market access patterns, and historical conservation exposure have evolved different strategies for managing human–manatee interactions, indicating that transformation pathways must be locally adapted rather than uniformly applied. This local adaptation capacity represents a key asset for conservation transformation, as it suggests that communities can develop context-appropriate solutions when provided with appropriate support and incentives.

4.2.4 | Feedback Loops Between Social and Ecological Components

The temporal patterns of human–manatee conflict reveal complex feedback loops that operate across multiple timescales in the LOWR. Daily feedback loops operate through the timing of fishing activities and manatee behaviour, where evening net deployment increases conflict probability, potentially leading to immediate behavioural responses from both fishermen (gear modification) and manatees (habitat avoidance). Seasonal feedback loops may operate through changes in manatee distribution patterns in response to fishing pressure, which in turn influences where and when fishermen deploy gear.

Longer-term feedback loops operate through attitude formation and community norm development; where repeated conflict experiences shape individual and collective responses to manatee conservation. The finding that entanglement experiences increase support for hunting ($OR = 3.05$) while sightings reduce it ($OR = 0.20$) demonstrates how this feedback loop can either reinforce conflict trajectories or support transformation toward coexistence. Understanding these multi-scale feedback dynamics is crucial for designing interventions that can shift system trajectories toward more sustainable outcomes.

4.3 | Generalizable Insights for Aquatic Conservation

4.3.1 | Broader Applications to Other Freshwater Systems

The methodological framework developed by integrating surveys, gear typology analysis and conservation attitude assessment provides a replicable approach for understanding human–wildlife conflicts in aquatic systems globally. The emphasis on local ecological knowledge and community-based solutions aligns with emerging best practices in conservation that prioritize socio-ecological fit and local ownership of conservation outcomes (Ostrom 2009; Berkes 2017). The spatial compression effects documented in LOWR likely apply to other enclosed freshwater systems where human activities and wildlife populations are concentrated in limited areas, suggesting that management strategies developed for LOWR could be adapted for similar contexts.

Beyond Lake Ossa, these findings have direct relevance for other West African manatee habitats facing similar pressures from artisanal fishing communities. The documented relationship between encounter frequency and conservation attitudes suggests that carefully managed wildlife viewing or monitoring programs could enhance conservation engagement across the species' range. The multi-species bycatch patterns indicate that interventions targeting manatees could yield broader biodiversity benefits in other freshwater systems where fishing activities affect multiple taxa, supporting ecosystem-based management approaches that address community needs while achieving conservation objectives.

4.3.2 | Theoretical Contributions to SES Transformation Theory

This study contributes to SES transformation theory by providing empirical evidence for how experiential learning drives attitude change in human–wildlife systems, extending theoretical understanding beyond terrestrial contexts to freshwater environments. The finding that positive wildlife encounters can catalyse attitude transformation while negative encounters reinforce conflict provides a mechanistic understanding of how SES transformation occurs at the individual and community level. This contributes to transformation theory by demonstrating that intervention, timing and context are crucial when communities have not yet formed strong negative attitudes, as indicated by the predominance of neutral positions in our study.

The spatial and temporal dimensions of conflict revealed by our analysis contribute to understanding how ecological constraints shape transformation possibilities in SES. The pressure effect of spatial compression in enclosed systems represents a general principle that could apply to other constrained environments, whereas the temporal misalignment between human activities and wildlife behaviour patterns provides insights into how evolutionary and cultural timescales interact in contemporary conservation contexts. These findings advance SES theory by demonstrating how biophysical constraints create both challenges and opportunities for transformation.

4.3.3 | Scalable Approaches for Human–wildlife Coexistence

The integration of traditional ecological knowledge with modern conservation science demonstrated in this study provides a model for addressing human–wildlife conflicts that respects cultural practices while achieving conservation objectives. The adaptive strategies employed by LOWR fishermen represent valuable knowledge systems that exist in fishing communities globally, suggesting that similar approaches could be developed in other contexts by building on existing local knowledge rather than imposing external solutions.

The community-centered approach developed here offers scalable solutions for sustainable coexistence between humans and wildlife as aquatic biodiversity faces increasing pressures worldwide. The emphasis on understanding and working with existing socio–ecological dynamics rather than attempting to override them provides a framework that could be adapted across different cultural, ecological and economic contexts (Redmore et al. 2025). The finding that neutral attitudes predominate in many human–wildlife conflict situations suggests that transformation opportunities may be more widespread than commonly assumed, indicating that proactive engagement strategies could prevent conflicts from escalating to intractable levels.

This knowledge constitutes a critical component of socio-ecological transformation processes, as it provides the foundation for community-based conservation innovations that bridge traditional practices with contemporary conservation needs (Berkes 2017; Tengö et al. 2014). The positive relationship between sighting frequency and conservation attitudes indicates that direct wildlife experiences can transform community perspectives, supporting the development of coexistence-based management approaches that could be scaled across diverse aquatic conservation contexts globally.

5 | Conclusions

- The complex relationships between net deployment configurations, fishing success and conflict risk highlight the need for nuanced management approaches that consider local variations in fishing practices and manatee behaviour. Our findings demonstrate that 70.6% of fishermen have experienced manatee entanglement, with 82.5% reporting associated net damage, indicating widespread and economically significant conflicts.
- This research demonstrates how SES theory can guide transformation toward coexistence in freshwater human–wildlife conflicts. The integration of community knowledge, behavioural ecology and conservation attitudes reveals that experiential learning and adaptive fishing practices may catalyse positive transformation in resource-dependent communities. Frequent positive wildlife encounters reduce negative attitudes while direct conflicts intensify them, suggesting that conservation strategies should emphasize positive interactions while addressing economic impacts through adaptive governance approaches.
- The findings support integrated conservation frameworks that combine temporal and spatial management, gear modifications and community engagement strategies. The predominance of neutral attitudes (55.9%) in fishing communities indicates significant potential for building conservation support through appropriate interventions that respect traditional practices while achieving conservation objectives
- These results contribute to broader understanding of how local communities can become agents of conservation in aquatic systems. The methodological framework provides a replicable approach for understanding human–wildlife conflicts that prioritizes socio-ecological fit and community ownership of conservation outcomes, essential for sustainable coexistence between humans and wildlife in freshwater environments worldwide.

Author Contributions

Wongibe P. Dieudonne: conceptualization, data curation, formal analysis, funding acquisition, investigation, project administration, resources, writing – original draft, writing – review and editing. **Taku Awa II:** conceptualization, supervision. **Lauren Redmore:** writing – original draft, writing – review and editing. **Jean Pascal Koh-Dimbot:** data curation, formal analysis, resources, writing – original draft, writing – review and editing. **Kevin Y. Njabo:** writing – review and editing. **Eddy Nnanga:** project administration. **Nguilissi Lauren:** investigation, resources. **Aristide Kamla Takoukam:** conceptualization, funding acquisition, project administration, resources, supervision. All authors have read and agreed to the published version of the manuscript.

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Ethics Statement

This research was conducted under research permit No. 000039/MINRESI/B00/C00/C10/C12 issued by the Ministry of Scientific Research and Innovation, Cameroon. Ethical approval was obtained from the University of Dschang Ethics Committee (Protocol #2019-UDs-0690). All participants provided verbal informed consent following protocols approved for research with local communities.

Consent

Verbal informed consent was obtained from the participants. All participants were thoroughly informed about the scope of the study and the relevant governmental permits were presented to them prior to the administration of the questionnaires.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Survey data supporting the conclusions of this article are available in Supporting Information S2.

Use of Artificial Intelligence

No artificial intelligence tools were used in the preparation of this manuscript. All data analysis, writing and interpretation were conducted by the authors without AI assistance.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Supplementary Information. **Data S2:** Supplementary Information.