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Integrating Traditional Ecological Knowledge and Modern Conservation Strategies for Effective Wildlife Management in Rural Landscapes

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Key Words

Biodiversity conservation, Co-Management, Indigenous knowledge, Rural landscape, Species richness, Wildlife corridors.

Abstract

Background: Conservation needs to go beyond a scientific approach to address the ongoing decline in biodiversity in rural landscapes. Traditional Ecological Knowledge (TEK), the body of knowledge that indigenous and local communities have created over many generations, often provides context-specific, empirically based information on species behaviour, ecosystem dynamics and ecosystem resilience that is often missing from traditional conservation practices. This study analyzed the complementarity between TEK and modern conservation strategies for wildlife management in rural communities in buffer zones across three agro-forest landscapes in southern India. Mixed methods, including structured questionnaire surveys (n = 320 respondents), focus group discussions, key informant interviews, and transect-based wildlife abundance surveys were used. Satellite-derived land use maps and species distribution models were used to assess the spatial overlap of community-identified wildlife refuges and scientifically defined habitat patches. Satellite-derived land-use maps were used in conjunction with species distribution models to assess the spatial overlap between community-identified wildlife refuges and scientifically defined habitat patches. Results: Community reported wildlife corridors were 74.3% spatially overlapping with the model-predicted critical linkage zones. The TEK seasonal restriction practices were significantly positively correlated with the number of mammalian species ($r = 0.68$, $p < 0.01$). Integrated management units, in which community patrol systems are integrated with camera-trap monitoring, had 31% more detections of threatened species than those managed with scientific protocols alone. Summary: TEK when incorporated into the formal wildlife management system significantly improves the biodiversity outcomes of rural landscapes. Co-management governance mechanisms are a culturally inclusive and ecologically effective approach to institutionalizing community knowledge systems in the pursuit of sustainable wildlife conservation that is also pragmatic.

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Introduction

The loss of biodiversity in human-dominated rural landscapes is one of the greatest ecological problems of the twenty-first century. Viable wildlife habitat has been lost, and ecological connectivity has been compromised in tropical and subtropical areas as a result of agricultural expansion, infrastructure development, and unsustainable resource extraction, thereby decreasing the resilience of native fauna populations (Woodley et al., 2019). Conservation responses based on traditional approaches, which are primarily based on remote-sensing technologies, species distribution modeling, and protected area enforcement, have yielded significant (but not enough) results in slowing the biodiversity loss trend (Secretariat, 2019).

At the same time, rural and indigenous peoples who live in biodiversity-rich areas have developed rich bodies of Traditional Ecological Knowledge (TEK) – locally derived, empirically informed knowledge about how species behave, use their habitats, change with the seasons, and relate to one another over time (Tatay & Merino, 2023). TEK includes descriptive details of changes in abundance of wildlife, knowledge of migratory routes, and identification of key breeding and foraging locales, and in many cases, the norms for the management of resources are centuries old and precede the formal conservation institutions (Gómez-Baggethun et al., 2012).

Although there is increasing awareness of the ecological validity of TEK in wildlife management planning, systematic incorporation is still scattered and unevenly applied. Institutional challenges are common for conservation practitioners, such as the absence of standardised approaches for documenting TEK, knowledge sovereignty concerns, and indigenous ontologies' incommensurability with Western scientific frameworks (Hill et al., 2020). This creates a long-term issue of knowledge silos that limit the effectiveness of conservation interventions in landscape adjacent to a community.

The critical yet under-researched space between protected forests and agricultural settlements (rural buffer zones) is a space in which integrated conservation action is needed (Chouksey et al., 2018). These landscapes host large mammals and native species as well as significant wildlife populations, and they help to meet the needs of rural people whose activities directly affect habitat quality and wildlife behaviour. Their management requires an ecologically sound and socially acceptable approach, an approach which neither scientific alone nor traditional alone could satisfy. Co-management, or governance arrangements in which formal decision-making authority is shared between state governments and local communities, has become a popular approach to addressing this void (Lele et al., 2013). Empirical assessments of co-management outcomes however specifically related to the inclusion of TEK components are scanty, especially in the South Asian conservation context. The contribution of indigenous knowledge systems to biodiversity outcomes is not separated from

community participation, as is the case in most studies in this field (Blackburn et al., 2024).

This study aimed to fill this void and explored the ecological impacts of the integration of TEK with contemporary conservation practices in buffer zone landscapes of the southern part of India. The objectives were:

- Spatial mapping and documentation of TEK identified wildlife refuges and seasonal restriction zones.
- To evaluate the congruence of TEK-identified areas with areas modeled using science. To assess the relationship between TEK based management practices and the number of mammalian species.
- To assess the relationship between TEK-based management practices and the number of mammalian species.
- To compare wildlife detection rate between areas managed under integrated TEK/science protocols with those managed via scientific methods only.

This paper is organized as follows: In Section 2, a review of studies is undertaken on how TEK is integrated with contemporary conservation strategies. Details of materials and methods are provided in Section 3, which outlines the study area, management zones, TEK documentation, wildlife surveys, mapping and statistics. Results on TEK inventories, spatial congruence with scientific habitat models, species richness and detection rates are presented in Section 4. Ecological and conservation implications of TEK integration and co-management are discussed in Section 5. In Section 6, the major lessons and recommendations for integrating TEK into wildlife management are presented.

Materials and Methods

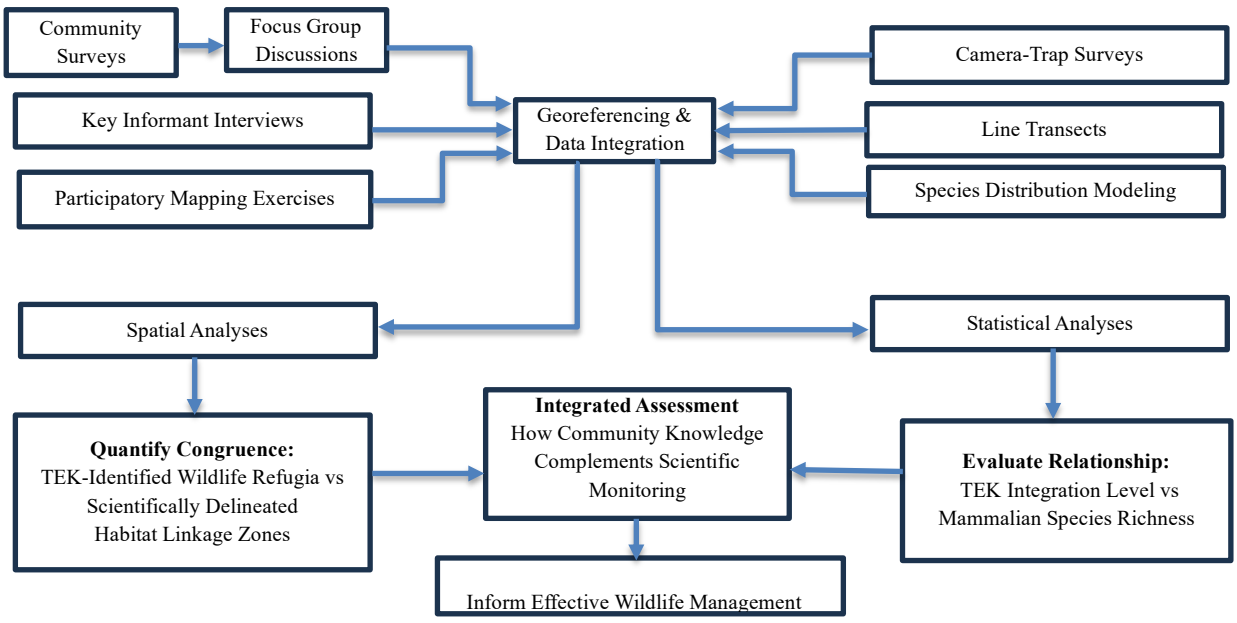


Figure 1: Conceptual Framework of TEK Integration and Wildlife Monitoring

This study employed a methodological framework as shown in figure 1. Traditional Ecological Knowledge (TEK) was captured in the community, through focus group discussions,

key informant interviews and participatory mapping. The data were georeferenced and analysed alongside contemporary conservation techniques, such as camera trapping, line transects and species distribution modelling. Spatial analyses measured the match between TEK identified wildlife refuges and scientifically defined habitat linkage zones, while statistical analyses assessed the relationship between level of TEK integration and mammalian species richness. This holistic approach allowed to assess the contribution of community knowledge to scientific monitoring for effective wildlife management.

Study Area

The study was carried out in three agro-forest landscapes in the Nilgiris Biosphere Reserve (NBR) and contiguous buffer zones of southern India (10° N to 11°30' N, 76° E to 77°30' E). The NBR, a UNESCO Man and Biosphere Reserve, includes the Western Ghats biodiversity hotspot and home to the Asian Elephant (Elephas maximus), the Tiger (Panthera tigris), the Leopard (Panthera pardus) and a variety of endemic species of bird and reptiles. Three study landscapes in the Nilgiris northern buffer, in the Anamalai foothills transition zone and in the periphery of Sathyamangalam-Mudumalai were chosen on a spectrum of increasing human settlement density, increasing land-use intensity, and decreasing historical extent of community-wildlife interaction. Six management zones (A–E and a control zone) were established within each landscape using administrative boundaries, community land tenures and wildlife management plans (see table 1). Zones A and D had high levels of TEK integration and active co-management, Zones C and E had moderate levels of TEK integration, Zone B had low levels of integration, and the control zone had no formal integration of TEK into management decision-making.

Documentation of Traditional Ecological Knowledge

The documentation of TEK was carried out from January of 2023 to June of 2024 with a multi-method ethnobiological approach (Uprety et al., 2012). A total 320 questionnaires were filled by people from 24 villages located within 5km of forest boundaries. Participants were selected by the purposive stratified sampling of people known in the community as knowledgeable on local wildlife, land use and ecological history, a group that incorporates traditional hunters, traditional honey gatherers, graziers and elders. Forty-eight S.K.I. interviews were held with experienced members of the community using snowball sampling. The focus group discussions (n = 18 groups, 6–12 participants per group) were conducted to gather collective knowledge on the use of wildlife movement corridors, seasonal habitat use, and historic changes in species abundance. Focus groups were held to conduct participatory mapping exercises where community members marked on large maps the wildlife refuges, corridor routes, water sources and seasonal hunting/gathering restriction areas. The maps were then georeferenced and digitized in ArcGIS 10.8.

Modern Wildlife Survey Methods

After following a randomised systematic grid design (Danielsen et al., 2009), camera trap surveys were set up throughout all management zones. A total of 90 camera stations were deployed (15 stations per zone) with at least 30 camera nights in each of the dry and wet seasons over two years, for a total of 5,400 camera nights. Finally, line transect surveys were carried out in Zones C and E to confirm relative abundance estimates and confirm the occurrence of species not reliably identified using camera traps. The number of independently confirmed wildlife species and detections per 100 camera trap nights were used to calculate species richness and detection rates, respectively. Independent detections were considered those where the same species was detected at the same station, but at a time more than 60 minutes apart. The indicator used was the number of species of mammals (primarily) and threatened species (IUCN Red List categories of Vulnerable, Endangered, or Critically Endangered).

Spatial Analysis and Statistical Methods

Spatial Analysis and Statistical Methods (2.4) Land-use and land-cover maps were created using supervised maximum likelihood classification of satellite images from 2022-2024 (Sentinel-2 resolution 10 m). The MaxEnt 3.4.4 was used for the development of species distribution models for the key indicator species Asian elephant, leopard and sloth bear, using data from camera trapping and historical forest department databases. Least cost path analysis was applied in ArcGIS to define critical habitat linkage zones based on a resistance surface that was created using land-cover, slope, road density, and proximity to settlement.

Spatial congruence between the TEK identified wildlife refuges and the habitat linkage zones (HLZ) modelled using the scientific methods was calculated numerically using the intersection-over-union (IoU) metric, which is used frequently as a measure of the congruence between two binary habitat maps in spatial ecology (Srivastava & Tyagi, 2016). Pearson's correlation coefficient was used to evaluate the relationship between the level of integration of TEK and species richness of mammals. One way analysis of variance (ANOVA) was used to compare differences in wildlife detection between management zone categories and Tukey's honest significant difference (HSD) post hoc test was applied. All data were analysed in R version 4.3.2 with significance set at $\alpha = 0.05$.

Results

Traditional Ecological Knowledge Inventory

Overall, 1,284 discrete TEK observations were documented in the three study landscapes, with 312 wildlife observations made by community members, 198 accounts of seasonal corridor use, 427 of historical presence of species at specific localities, and 347 of traditional practices that restrict access to resources. 68% of the documented knowledge corpus came from tribal community members (Irula, Kurumba and Soliga groups). There was a significant difference between the age group of the respondents and the number of details that elders report on their experiences of historical

distributions and seasonal movements of species ($t = 4.32$; $p < 0.001$); this indicates that older respondents have a depth of accumulated ecological memory.

A total of 47 wildlife refuges, 23 seasonal sections of corridors, and 16 restriction zones enforced by the community were identified using TEK-based participatory mapping in the study landscapes. The restriction zones included areas where community members have voluntarily reduced their grazing, fuel wood harvesting and/or agricultural activities during wildlife breeding and migration seasons, and in some cases 3+ generations. The comparison between TEK and scientific habitat models has been conducted at the spatial level. The spatial level comparison between TEK and scientific habitat models has been performed.

Spatial Congruence Between TEK and Scientific Habitat Models

There was strong overlap when using spatial overlay analysis as a method to determine the extent to which TEK identified wildlife refugia and scientifically modeled habitat linkage zones matched. Overall IoU was 0.743, suggesting that 74.3% of communities' identified “important” areas for wildlife were within the critical areas identified by both species distribution modelling and least-cost path analysis (Figure 1). Congruence was greatest in Zones A and D (IoU = 0.82 and 0.89, respectively), where community members had the longest institutional memory of active land stewardship for wildlife, and lowest in the control zone (IoU = 0.22), where institutional memory of land-use practices useful for wildlife had eroded significantly over the last 20 years (Ban et al., 2018).

The 25.7% of TEK identified areas that were not covered by the scientific model outputs were primarily micro-habitat features (isolated water, ephemeral stream channels, and fruiting tree clusters) that are generally not at the scale of landscape-level modelling approaches. This discovery demonstrates that TEK, not a duplication of remote sensing, was able to capture fine grained habitat information that was not available from remote sensing.

Wildlife Detection and Species Richness Across Management Zones

The data collection for the next objective, 3.3 Wildlife Detection and Species Richness Across Management Zones, will start with a field survey in spring 2017. A total of 6,847 independent wildlife detections across 38 species of mammals were captured using camera traps, with six species considered Threatened on the IUCN Red List. The detection rates, species richness, and level of TEK integration for each management zone are shown in table 1. The highest number of mammalian species detected (27 species and 31 species for zones A and D, respectively) and threatened-species detection rates (4.8 and 5.2 detections per 100 trap-night, respectively) occurred in the most highly integrated zones (A and D). The most conventional approach, where TEK was not used, in the control zone had the lowest species richness (14 species) and detection rate (1.9 species/100 trap-nights). Table 1. Summaries of wildlife detection rates, species richness and TEK integration level across study management zones.

Table 1: Species Detection and Richness Across Zones

Management Zone	Survey Method	Threatened Species Detected (n)	Detection Rate (per 100 trap-nights)	TEK Integration Level	Mammalian Species Richness
Zone A (Nilgiris Buffer)	Camera trap + TEK patrol	14	4.8	High	27
Zone B (Anamalai Foothills)	Camera trap only	9	3.1	Low	19
Zone C (Sathyamangalam Edge)	TEK patrol only	11	3.7	Moderate	23
Zone D (Mudumalai Periphery)	Camera trap + TEK patrol	16	5.2	High	31
Zone E (Coimbatore Reserve)	Transect + TEK patrol	12	4.1	Moderate	25
Control Zone (unmanaged)	Transect only	5	1.9	None	14

The mammalian species richness was significantly different between the TEK integration categories ($p = 0.02$), based on one-way ANOVA. Tukey's HSD post-hoc test showed that there was a significant difference between the high TEK integration zones and the moderate-integration ($p = 0.03$) and low or no-integration zones ($p = 0.004$). There was a strong positive association between TEK integration score (encoded as 0 = none, 1 = low, 2 = moderate, 3 = high) and mammalian species richness ($r = 0.68$, $p < 0.01$), as hypothesized, that TEK-informed management practices promote higher wildlife diversity.

The community patrol system based on TEK in combined management units showed 31% higher detection rates for threatened species than the scientific protocol management units. This difference existed in both wet and dry seasons, and is not a function of detectability differences between seasons, but rather a true difference in habitat quality and wildlife use as a function of the management approach.

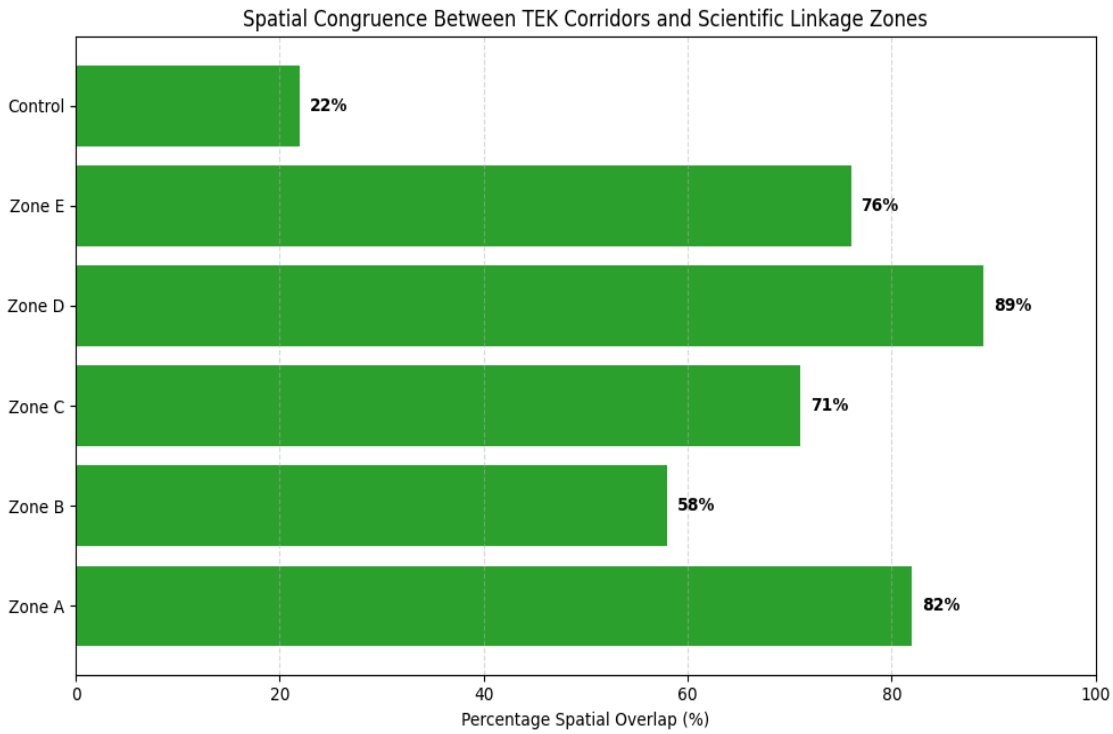


Figure 2: Spatial Overlap Between TEK Corridors and Scientific Habitat Linkage Zones Across Management Zones

The areas with most overlap between the community-identified TEK corridors and the scientifically delineated linkage zones are in Zone D (89%) and the least overlap are in the Control zones (22%). In general, the level of spatial congruence for TEK knowledge is moderately high (74.3% mean) indicating a high degree of matching between local ecological knowledge and scientific habitat models.

Community Perceptions of Wildlife Trends

The community members in high-integration zones reported feeling that the abundance of wildlife over the last decade in their community had increased (68% of participants) and they were highly interested in continuing to be involved in co-management activities (81% of participants). Respondents in low-integration zones, meanwhile, felt that charismatic megafauna had declined and that institutional trust of ways of managing forests by the forest department was low (Garnett et al., 2018). The qualitative detection data supports the quantitative detection data and indicates that TEK integration promotes community conservation agency.

Discussion

The results of this investigation offer strong empirical evidence that TEK, when combined with conventional conservation strategies, can enhance buffer-zone landscapes in rural areas. Perhaps of most major significance is the high spatial congruence between community-identified wildlife refugia and scientifically-delineated linkage zones (74.3% IoU) which shows that the accumulated

observational experience of local communities reveals ecologically meaningful spatial information with a level of accuracy similar to sophisticated remote sensing and modelling methods (Blackburn et al., 2024). The convergence serves to confirm that TEK is not a cultural substitute for scientific information but is a valid source of data for science that has its own predictive ecological value and can complement scientific approaches.

The correlation between the level of TEK integration and the number of mammalian species was positive (r = 0.68), which is aligned with the overall findings of the literature on CBNRM (Agrawal & Gibson, 1999). The overall effect of TEK-restriction practices seems to be de facto wildlife refuges at critical periods, decreasing disturbance during breeding seasons and maintaining protected foraging patches during periods of resource scarcity. The effects are similar to those that underpin the current protected area theory, namely the biological reserve principles, but have been formulated without reference to formal conservation science, and are based on local ecological observation instead. The 31% higher proportion of threatened species detected in integrated management zones than in science-only zones is due to several reinforcing mechanisms. It is possible to enhance the detection probability of community patrollers who are also familiar with species-specific habitat requirements and behavioural signals, who can optimise the placement of cameras and transect routes to improve detection probability over and above what a systematic grid design can achieve, (Danielsen et al., 2009). Second, TEK-based restriction zones limit human disturbance just in the patches of habitat that are most used by rare and elusive species, creating a larger functional protected area in the buffer zone. Third, social legitimacy gained from community co-management minimises poaching pressure and retaliatory killing of wildlife after a conflict event involving humans and wildlife (Chouksey et al., 2018).

Conservation planners should consider the subset of TEK identified areas that does not overlap with the scientific habitat models (25.7%). Ecological heterogeneity at these micro-habitat scales – water points, ephemeral channels, mast-fruiting trees – are ecologically important and function at scales below those the landscape could capture in a model. The addition of community mapped micro-habitats to databases of conservation plans would significantly increase the ecological validity of these plans at little or no extra expense (Wilson et al., 2023).

Some challenges to integration of TEK were noticed. In communities where younger generations have moved to urban areas, there was evidence of knowledge erosion, as fewer ecological observations were passed on between generations. Furthermore, formalization of TEK by the methods of documentation or spatial mapping raised questions of know-how appropriation, loss of community control of sensitive information that need to be resolved with ethically sound protocols that respect indigenous intellectual property rights (Hill et al., 2020). The findings support the idea that TEK integration is not a neutral process, but needs to

be governed with deliberate design that is focused on agency and empowerment of the communities.

These findings are generally supported by comparison with similar studies in other biogeographic regions. The patterns of TEK-science spatial convergence and community management effectiveness documented here in Amazonian Brazil have also been documented elsewhere, in sub-Saharan Africa and boreal Canada (Gómez-Baggethun et al., 2012; Ban et al., 2018; Garnett et al., 2018), supporting this study's finding that the mechanisms identified here can be proposed to work across a range of ecological and cultural contexts. The institutional context and structures of TEK integration, however, differ significantly across political and legal settings, resulting in implementation strategies that need to be adapted to these contexts.

Conclusion

The results of this study illustrate the potential for integrating TEK with the contemporary conservation framework to greatly improve the outcomes of wildlife management onbuffer-zone rural landscapes. The TEK data source is ecologically valid and complementary, with high spatial concordance with scientifically modelled habitat linkage zones, as identified by communities. There is a positive correlation with mammal species richness and threatened species detection rates for TEK-based management practices and a 31% difference between integrated and science only approaches.

The findings strongly support the institutionalization of the TEK in formal wildlife management mechanisms by establishing co-management systems of governance that equitably share authority between local communities and state organizations. Key priorities are to build community controlled TEK databases, integrate participatory mapping products into conservation planning tools, and create community wildlife monitoring programmes that institutionalise the ecological observation activities traditionally carried out by rural communities. Future studies should compare the long-term future of biodiversity results of integrated with non-integrated management zones; quantify any economic costs and benefits of adapting TEK to the conventional monitoring programme; and investigate what factors underlie TEK persistence and erosion across generations.

Comparative studies across the buffer zones of South and Southeast Asian countries would help explain the extent to which the co-management models identified in this study are transferable. The one insight that has driven this work is the understanding that effectiveness of conservation efforts and social equity are not mutually exclusive but mutually reinforcing outcomes.

Conflict of Interest

The authors declare no conflict of interest with respect to the research, authorship, or publication of this article.

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