



Review

Women's local knowledge: An important factor in effective community-based wildlife management

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ABSTRACT

In many societies, men and women play diverse roles in environmental management and may consequently hold different, but often complementary, local knowledge. It is therefore key that knowledge systems of both men and women are considered in studies of community-based natural resource management and conservation decisions. However, due to social, economic, cultural and other factors, the local knowledge held by women is often less well-known, understood and applied in such groups. We aimed to help address this gap by collating case studies of community-based wildlife management (CBWM) groups from across the globe that demonstrated a level of participation by women that allowed them to share their knowledge with community-based wildlife management group decision-makers. Focusing on 32 selected case studies, we aimed to explore three main themes: (i) The application of women's knowledge in resource management practices; (ii) Ways in which women's knowledge was shared; and (iii) How these inputs impacted wildlife conservation outcomes. We found for most of the case studies that women's participation contributed to positive conservation outcomes as measured by their group's fulfilment of one or more of the 2023 CBD Kunming-Montreal Global Biodiversity Conservation Framework goals for 2050. These included positive outcomes for species conservation, habitat restoration, equitable sharing of benefits, and for investment by and collaboration with external experts and organisations. We suggest that the greater inclusion of women in community-based wildlife management groups, at a level where they can actively share their knowledge with policy and decision-makers, is key to advancing equity and conservation effectiveness of community-based wildlife management groups.

1. Introduction

Local knowledge is increasingly being integrated into environmental decision-making to enhance sustainability and resilience in community-based natural resource management (Molnár and Babai, 2021; Silvano et al., 2023). Both women and men hold traditional and local knowledge, yet there are often gaps in recognizing and including the local knowledge of women. This can result in a partial understanding of the full spectrum of local knowledge available in any given community about the sustainable use of natural resources (Zweifel, 1997; Bhattacharyya et al., 2017). The implications of this for both sustainable livelihoods and wildlife conservation can be significant.

The term "local knowledge" can embrace many different concepts including, among others, local ecological knowledge, Indigenous knowledge, Indigenous ecological knowledge, traditional ecological knowledge, and Indigenous biocultural knowledge (Berkes et al., 2000;

Ens et al., 2015; Nalau et al., 2018; Ramirez-Santos et al., 2023). The valuable role of local knowledge in achieving resource use sustainability and resilience has been recognised internationally by the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES, 2021). In response to the need to simplify this diverse, but related, terminology, the IPBES has included the different terms under an umbrella phrase termed *Indigenous and Local Knowledge* (ILK). Indigenous and Local Knowledge is defined by the IPBES as the "dynamic bodies of integrated, holistic, social and ecological knowledge, practices and beliefs pertaining to the relationship of living beings, including people, with one another and with their environments" (IPBES, 2021). This is the definition of local knowledge adopted for use in this paper.

Indigenous and Local Knowledge can vary in depth and scope across different members of a given community depending on age, gender, roles, ethnicity, status, length of residence in the community and many other factors (Ruddle, 2000; Meinzen-Dick et al., 2014; Ramirez-Santos et al.,

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2023). One of the most important of these intersectional categories for natural resource management is *gender*. This is because an understanding of gender is key to understanding how other intersectional factors influence environmental management. For example, Leach (1994, p. 22, cited in Elias, 2015, p. 28) points out: "...examining gender helps us to understand how other forms of social difference influence rural environmental management, not just as 'proxy', but because other differences such as age, wealth or origins operate in gender-differentiated ways." Further, Rocheleau et al. (1996, p. 4, cited in Elias 2015, p. 28) indicate: "Gender is 'a critical variable in shaping resource access and control, interacting with class, caste, race, ethnicity to shape processes of ecological change'," and Elias (2015, p. 28) states: "Throughout the world, use, knowledge, access, preferences and management of natural resources are primarily organised along gender lines."

Previous studies have shown that women often use the environment, and consequently understand and value it, differently from men. Women and men may use different spaces in the environment at different times of the day or year for different purposes and durations compared with men. They may also use different species of plants, animals or fungi, or different parts of individual species than those used by men (Pfeiffer and Butz, 2005; Reyes-García, V. et al., 2020). Notably, however, while women's and men's knowledge and use of and their relationship with the environment and its resources may differ, they can also be complementary (Meinzen-Dick et al., 2014; Elias, 2016; Santos, 2015). For example, Yang et al. (2018) and Assé and Lassoie (2011) suggest that women are in some cases more aware than men of regulating ecosystem services, such as water flow protection, and supporting services such as biodiversity conservation and habitat protection and management. Similarly, Staples and Natcher (2015) and Turner et al. (2000) point out that women's wildlife knowledge is more relational or ecosystem-based than men's and includes, for example, knowledge of the seasonal influences and changes in wildlife food sources and habitats of wildlife populations. Further, the valuation criteria men and women use to measure the importance of these services, as well as their perceptions about how management affects the sustainability of socio-ecological systems, can also be different (Delgado-Serrano and Escalante Semerena, 2018; Cruz-García et al., 2019; Mponela et al., 2023).

In community-based natural resource management groups, such as community-based wildlife management groups, there is an opportunity for the resource information sharing commonly observed at the household level to be scaled up and exchanged amongst group members (Pathak and Gour-Broome, 1999; Ruddle, 2000; Kabeer, 2005; Goldman and Little, 2015; Lastarria-Cornhiel et al., 2017; Hyle et al., 2019), or even across neighbouring community-based natural resource management groups having similar resource interests (Berkes et al., 2000; Turner et al., 2000). As with household levels of knowledge sharing, such information exchange among different stakeholders in community natural resource management groups can also play a key role in ensuring the effectiveness of the community's adaptive management and resilience in the face of impacts from climate change or unexpected alterations in resource availability (Berkes et al., 2000; Aregu et al., 2016; Nalau et al., 2018).

Due to several socio-economic factors, different stakeholders' levels of empowerment and agency within community-based natural resource management groups can vary significantly. This applies particularly to women, where participation levels can vary between very limited in some groups to having full decision-making power within others (Agarwal, 2009; Leisher et al., 2017; Chambon et al. 2023). Agarwal (2001) provides a useful typology distinguishing the different levels of women's engagement (Table 1) as observed in community natural resource management groups. Women's engagement in management at

Table 1

Level of opportunity for women to share their knowledge in community-based natural resource management decision-making according to Agarwal's (2001) participation typology.

Participation category	Description	Level of opportunity
Nominal participation	Membership in the group	Very limited. Knowledge shared within household only
Passive participation	Being informed of decisions, <i>ex post facto</i> , or attending meetings and listening in on decision-making, without speaking up	Very limited. Knowledge shared within household only
Consultative participation	Being asked an opinion in specific matters without guarantee of influencing decisions	Limited
Activity-specific participation	Being asked (or volunteering) to undertake specific tasks	Limited
Active participation	Expressing opinions, whether or not solicited, or taking initiatives of other sorts	Somewhat limited
Interactive (empowering) participation	Having voice and influence in the group's decisions	Unlimited

(Adapted from Agarwal, 2001).

Agarwal's last two 'active' levels is required for effective knowledge sharing in such groups.¹ As seen in Table 1 and it is only when women's participation has reached these higher levels that there is a real opportunity for women to interact in discussions and decisions with other members of the group and to have their views seriously considered.

Research into the association between women's active inclusion in community-based natural resource management groups and ecological and socio-economic outcomes has been undertaken for common-pool resources, such as forests (Westermann et al. 2005, Agarwal, 2009, 2010; Mwangi et al., 2011; Meola, 2013; Leisher et al., 2017; Ray et al., 2017; Begum et al., 2022) and for small-scale fisheries (Sultana and Thompson, 2008; Harper et al., 2013, Kleiber et al., 2015, 2017; Gissi et al., 2018, Torre et al., 2019, Galappaththi et al., 2022; House et al., 2023, Chambon et al., 2023). However, to date very little research has been undertaken on the outcomes associated with the role of women's knowledge and active participation in community-based wildlife management.

Given the importance of finding ways of enhancing wildlife conservation and management outcomes in the face of rapid rates of global habitat loss, over-harvesting and the impacts of climate change, the lack of research on the role of women's active participation and knowledge-sharing in community-based wildlife management represents a significant gap. The aim of our paper is to help fill this gap by examining, through a review of the existing literature, how the management practices, knowledge sharing and conservation outcomes from the active involvement of women in community wildlife management can better inform decision-making in community-based wildlife management. In this study "wildlife" refers to the community management of *terrestrial* vertebrates, for example, mammals, birds, reptiles, and amphibians, and terrestrial invertebrate fauna such as insects, spiders, molluscs and other invertebrates. Fish were not included in this study. The definitions of 'wildlife', 'knowledge', 'community-based wildlife management' and other terms used in this paper are provided in the Glossary at the end of the paper.

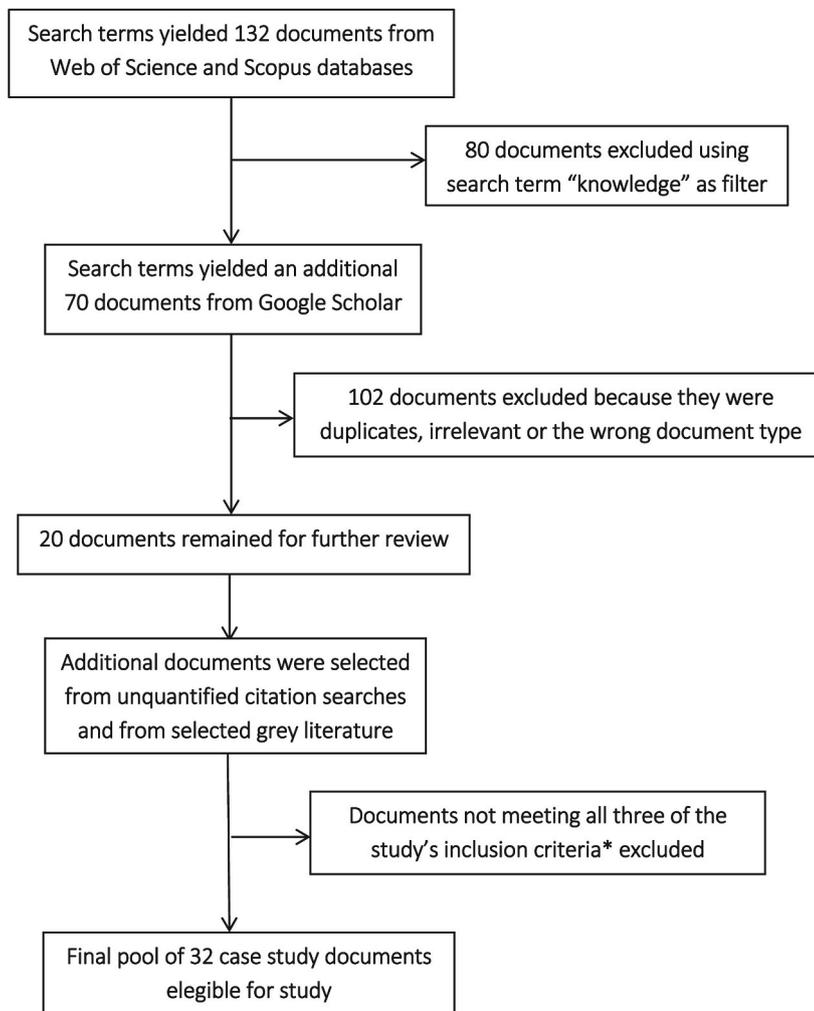
¹ Agarwal excludes "Activity-specific participation" from her 'Active' participation categories, as it is a level of participation in CBNRM which is not *interactive* (Agarwal, 2001, p. 1629).

2. Methods

A literature search was carried out between October 2023 and May 2025 using the Web of Science (Clarivate Analytics) and Scopus (Elsevier) databases in the University of Queensland library. The following search terms were used in the initial Web of Science ‘TOPIC’ and Scopus ‘ARTICLE-TITLE-ABS-KEY’ searches: (“community-based” OR “co-management”) AND “wildlife” AND (“gender” OR “women”). The search term “knowledge” was then applied to the 132 results. This yielded a pool of 52 documents. A search using Google Scholar was also undertaken. Due to the constraints of this database, we used the search terms “gender” OR “women” AND “wildlife”, in its Advanced Search

‘TITLE’ page. This yielded a further 70 documents for a total of 122 documents. Only peer-reviewed articles, books, and book chapters in English were included in the search. Conference proceedings and academic theses were excluded. There were no restrictions on the date of publication or geographical location of the studies.

After the removal of duplicates, documents covering irrelevant subject areas, and those of an incorrect document type, the remaining pool of documents from the database searches numbered 20. These were supplemented by documents obtained from citations searches and from unquantified searches using the search term “gender” of selected grey literature. These included briefs, reports, working papers and newsletters from: The International Union for the Conservation of Nature



*To be selected for final review, documents needed to meet the following inclusion criteria:

- (i) Have a primary focus on women in community-based wildlife management;
- (ii) Include evidence of women participating actively in community-based wildlife management either as defined in Agarwal’s (2001) ‘active’ participation categories (Table 1) or demonstrating ‘agency’ in these groups as outlined by Kabeer (1999); and
- (iii) Have findings supported by empirical data

Fig. 1. Flow diagram showing the case study documents selection process.

(IUCN), Gland, Switzerland; the International Institute for Environment and Development (IIED), London; The Worldwide Fund for Wildlife (WWF), Gland, Switzerland; the Consultative Group on International Agricultural Research (CGIAR), Montpellier, France, and the Center for International Forestry Research (CIFOR), Nairobi, Kenya.

To be selected for the final review, the collated documents from these searches needed to meet the following inclusion criteria: (i) have a primary focus on women in community-based wildlife management; (ii) include evidence of women participating actively in community-based wildlife management either as defined in Agarwal's (2001) 'active' participation categories (Table 1) or demonstrating 'agency' in these groups as outlined by Kabeer (1999); and (iii) have findings supported by empirical data. Items exploring more generally the need for greater participation of women or the inclusion of their knowledge more extensively in community-based wildlife management were excluded. This review resulted in a final pool of 32 papers (Fig. 1). These were geographically wide-ranging, being distributed as follows: Africa 34 % (n = 11), Asia 31 % (n = 10), Latin America (Mexico, Central and South America) 19 % (n = 6), Australia 13 % (n = 4), and North America 3 % (n = 1).

These 32 papers were then categorised and described using an adaptation of the Berkes et al. (2000) typology for analysing traditional ecological knowledge as adaptive management (Table 2).

Data collection involved recording *verbatim* statements from the selected publications. These described women's practices in community-based wildlife management and the social mechanisms surrounding the generation, accumulation and transmission of ecological knowledge which supported these practices. (The *verbatim* statements abbreviated in the text can be read in full in the Supplementary Materials, Table S-1).

To understand how the inclusion of women's management practices and local knowledge in the selected case studies affected conservation outcomes, a thematic analysis (Braun and Clarke, 2006) of the data from each case study that related to conservation outcomes was undertaken. The results were then matched against the main themes of each of the four goals of the Kunming-Montreal Global Biodiversity Framework (GBF) for 2050 (Convention on Biological Diversity (CBD), 2023). These are summarised as: A. 'Protect and Restore' (Protection and restoration of genetic diversity, species and ecosystems); B. 'Prosper with Nature'

Table 2

Women's management practices in community wildlife management based on local ecological knowledge and supporting social mechanisms.

Management practices based on ecological knowledge
(i) Management of particular species
• Total protection of certain species
• Protection of vulnerable life history stages
• Protection of specific habitats
• Temporal restrictions of harvest
(ii) Ecosystem-based management strategies
• Multiple species management: maintaining ecosystem structure and function
• Resource [use] rotation
• Succession management
• Management of landscape patchiness
• Watershed-based management
• Managing ecological processes at multiple scales
• Responding to and managing pulses and surprises
• Nurturing sources of ecosystem renewal
(iii) Practices applying to both (i) and (ii)
• Monitoring resource abundance and change in ecosystems
Social mechanisms behind management practices
(Generation, accumulation, and transmission of local ecological knowledge)
• Reinterpreting signals for learning
• Revival of local knowledge
• Folklore and knowledge carriers
• Integration of knowledge
• Intergenerational transmission of knowledge.
• Geographical diffusion of knowledge

(Adapted from Berkes et al., 2000).

(Sustainable use and management of biodiversity); C. 'Share Benefits Fairly' (Ensuring the benefits from genetic resources and of the traditional ecological knowledge associated with those genetic resources are shared equitably); D. 'Invest and Collaborate' (Adequate investment and collaboration in capacity building and scientific and technical information to facilitate the implementation of the GBF Framework for 2050) (Convention on Biological Diversity (CBD), 2023).

The broad-based definition of 'conservation' as outlined in the Global Biodiversity Framework for 2050 was appropriate for our study as many of the case studies are located in developing countries where wildlife is regarded not only as important in its own right and as an integral part of the environment, but also as a vital economic resource supporting local livelihoods. We are also fully aware of and appreciate the many important intrinsic and social justice values of women's local ecological knowledge described extensively in the literature (e.g., Rocheleau et al., 1996; Kabeer, 2005; Meinzen-Dick et al., 2014; Elias et al., 2024; Hidrobo et al., 2024). Our primary focus here was to explore how we may better understand how the inclusion of women's local knowledge in community wildlife management can improve outcomes for both wildlife and communities.

The paper is organised around three main themes: 1) How women's knowledge is applied in community-based wildlife management; 2) How women's knowledge is shared in community-based wildlife management; and 3) The conservation outcomes from applying women's knowledge in community-based wildlife management.

3. Results

3.1. How women's knowledge is applied in community-based wildlife management

The studies reviewed provided multiple examples of the many ways women apply their local knowledge in community wildlife management practices. To help organise the results, an adaptation of the Berkes et al. (2000) typology of such knowledge-based practices (Table 2) has been used in the following text and in Table 3.

The studies reviewed found that women used their extensive knowledge of wildlife in the application of all of the management practices listed in the Berkes et al. (2000) typology (Table 2). These management practices were broadly focused either on the conservation of particular species or on the ecosystem as a whole. The most important of these (in the case studies reviewed here) were those practices that focused on the conservation of particular species, for example, the protection of snow leopards (*Panthera uncia*) in the Himalayas (Alexander et al., 2022) or the protection of endangered sea turtles, including the hawksbill (*Eretmochelys imbricata*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*) and olive ridley (*Lepidochelys olivacea*) turtles in Central America (Massey et al., 2022). Many of these types of case studies described the work of women rangers and their role as monitors of rules compliance surrounding wildlife protection, their community conservation education and development roles, as well as the overseeing of the equitable distribution of financial benefits from conservation within the community (WWF; Pillai and Suchintha, 2006; UNDP, 2013; Hubschele and Scheuring, 2018; Danoff-Burg and Ocaña, 2022; Ewaso, 2024; Graham, 2022; Sommerville et al., 2022; Mkono et al., 2023, Table 3).

The studies reviewed described additional species protection related management practices listed in the Berkes et al. (2000) typology (Table 2). These included women's involvement in *ex situ* conservation of endangered species, for example, the management of sea turtle nests and hatchlings in Costa Rica (Imbach and Gutiérrez, 2000a), as well as the 'Protection of vulnerable life history stages', such as the protection of turtle hatchlings from predation in Costa Rica and El Salvador (Imbach and Gutiérrez, 2000a, Massey et al., 2022), and the supplementary feeding of stingless bees in Bolivia (Adler et al., 2023). Women also undertook the 'Protection of specific habitats', for example, turtle nesting beaches in Costa Rica (Imbach and Gutiérrez, 2000a) and the

Table 3

Examples from the case studies of women's community-based wildlife management practices based on local ecological knowledge.

Practice category	Examples from case studies	Source
Monitoring resource abundance and change in ecosystems	<ul style="list-style-type: none"> • Lion monitoring, Mama Simba, Ewaso Lions, Kenya • Aboriginal women's assessment of vegetation condition, Australia • Resource monitoring, CBNRM programs in conservancies, Namibia 	<ul style="list-style-type: none"> • Ewaso, 2024 • Davies et al. (2018) • Flintan (2001, 2003)
Total protection of certain species	<ul style="list-style-type: none"> • All ranger groups: e.g., Black Mambas, Akashinga, Mama Simba, Team Lioness, Dongqing women rangers, etc. • Non-lethal controls of protected predatory species of livestock Himalayas and Andean Chile • Aboriginal control of feral cats and fire management of habitat central, western and northern Australia • <i>Ex situ</i> conservation of the green iguanas, Nicaragua • Beekeeping in the Chaco region, Bolivia. 	<ul style="list-style-type: none"> • Danoff-Burg and Ocaña (2022); Mkono et al., (2023); Ewaso, 2024; Graham 2022; Hubschle and Schearing (2018); Kahler and Rinkus 2021; Pillai and Suchintha (2006); Sommerville et al. (2022); UNDP 2013; WWF; etc. • Alexander et al. (2022, 2023); Almuna et al. (2022); Locher (2006) • Davies et al. (2018); O'Leary and Walter (2018); Daniels et al. (2022) • Imbach and Gutiérrez (2000b) • Adler et al. (2023) • Imbach and Gutiérrez (2000a) • Massey et al. (2022) • Adler et al. (2023) • Imbach and Gutiérrez (2000a) • Imbach and Gutiérrez (2000a)
Protection of vulnerable life history stages	<ul style="list-style-type: none"> • Sea turtle eggs and hatchlings, Costa Rica, • Sea turtle eggs and hatchlings, El Salvador • Beekeeping, Chaco region, Bolivia 	<ul style="list-style-type: none"> • Imbach and Gutiérrez (2000a) • Massey et al. (2022) • Adler et al. (2023)
Protection of specific habitats	<ul style="list-style-type: none"> • Cleaning and protection of sea turtles nesting beaches, Costa Rica 	<ul style="list-style-type: none"> • Imbach and Gutiérrez (2000a)
Temporal restrictions of harvest	<ul style="list-style-type: none"> • Control and monitoring of time of sea turtle egg harvesting in Costa Rica 	<ul style="list-style-type: none"> • Imbach and Gutiérrez (2000a)
Multiple species management, maintaining ecosystem structure and function	<ul style="list-style-type: none"> • Aboriginal women's burning of 'country' to avoid destructive hot wildfires, central and western Australia 	<ul style="list-style-type: none"> • O'Leary and Walter (2018); Davies et al. (2018)
Resource rotation	<ul style="list-style-type: none"> • Sustainable management of palm trees, thatch and other craft species growing in wildlife habitat, conservancies, Namibia 	<ul style="list-style-type: none"> • Flintan (2001)
Succession management	<ul style="list-style-type: none"> • Reducing illegal timber extraction and shifting cultivation to help maintain old growth forest for wildlife habitat, Chunutí Reserve, Bangladesh • Aboriginal women's burning practices, central Australia • Aboriginal women's burning practices, central Australia 	<ul style="list-style-type: none"> • UNDP (2013) • Davies et al. (2018) • Davies et al. (2018); Daniels et al. (2022); O'Leary and Walter (2018), Ens (2012) • Torri (2010)
Management of landscape patchiness	<ul style="list-style-type: none"> • Restoration of forest on water catchment not only to increase tiger habitat but also to control land degradation negatively affecting water quality and quantity Sariska region, Rajasthan, India 	<ul style="list-style-type: none"> • Davies et al. (2018)
Watershed-based management	<ul style="list-style-type: none"> • Martu women's burning practices in the Western Desert, Australia, used to lower the risk of large-scale wildfires and encourage habitat quality at the local scale for the smaller generalist species which women hunt for subsistence 	<ul style="list-style-type: none"> • Davies et al. (2018)
Management of ecological processes at multiple scales	<ul style="list-style-type: none"> • Unsuccessful iguana captive breeding project, Nicaragua • Indigenous women fencing off sacred sites, e.g. billabongs, from feral animals, central Australia 	<ul style="list-style-type: none"> • Imbach and Gutiérrez (2000b) • Ens (2012)
Responding to and managing pulses and surprises	<ul style="list-style-type: none"> • Ecological restoration of wildlife habitat in Popenquine National Park buffer zone, Senegal, • Tree nursery keeping, Kachenjunga Conservation Area, East Nepal • Wetland habitat restoration, Azraq Oasis, Jordan • Aboriginal women's burning practices, central Australia • Beekeeping, Chaco region, Bolivia 	<ul style="list-style-type: none"> • Abbot et al. (2000) • Locher (2006) • IUCN 2011 cited in Broeckhoven and Cliquet (2015), p. 732 • Davies et al. (2018) • Adler et al. (2023)

'Temporal restrictions on harvesting' of particular species, for example, the enforcement of time restrictions on egg harvesting, Costa Rica (Imbach and Gutiérrez, 2000a). Also included in the case studies were examples of women's management of interactions and conflict between humans and wildlife, for example, between livestock herders and snow leopards and wolves in northern India (Alexander et al., 2022, 2023), as well as the control of feral introduced predators such as feral cats that threatened protected native species, in Indigenous Protected Areas (IPAs) in Australia (O'Leary and Walter, 2018, Table 3).

The second broad area of focus in the case studies reviewed was in women's wildlife management practices that were ecosystem-based, rather than being focused on the protection of certain species. Many of the case studies reviewed in this second group of categories were drawn from Australia (Table 3, Table S-1), and described diverse practices of Aboriginal women's management of Country using their knowledge, such as of the responses of local vegetation and fauna to fire (Ens, 2012; Davies et al., 2018; O'Leary and Walter, 2018; Daniels et al., 2022). The other major focus of ecosystem-based management practices of women who did not use fire as a management tool was mainly reported outside of Australia (Table 3). It included practices restoring wildlife habitat through vegetation re-planting, for example, in Popenquine National Park, Senegal (Abbot et al., 2000), protecting old-growth forest from illegal agricultural clearing, such as in Chunutí Wildlife

Sanctuary, Bangladesh (UNDP, 2013) and practices establishing and maintaining tree nurseries for reforestation purposes, such as in Kachenjunga, Nepal (Locher, 2006).

The Berkes et al. (2000) management practice category, which was applied by women in both single species and ecosystem-based management included 'Monitoring resource abundance and change in ecosystems' (Flintan, 2001; Davies et al., 2018, (Ewaso, 2024). We also found an example of women's management practices that could be categorised as 'Watershed-based management' (Torri, 2010, Table 3, Table S-1).

3.2. How women's knowledge is shared in community-based wildlife management

Based on the case studies, it was clear that there are many different social mechanisms that support women's generation, accumulation and transmission of knowledge in community-based wildlife management. As in the previous section, an adaptation of Berkes et al.'s (2000) typology of such mechanisms was applied in the following text and in Table 4.

Integration of knowledge: From the case studies reviewed of social mechanisms that supported women's resource management practices, the category 'Integration of knowledge' (Table 2) provided the greatest

number of examples. This category included different work groups sharing their knowledge with other groups in relation to a resource of common interest, for example, exchange of information between turtle harvesters and a women's conservation group in El Salvador (Massey et al., 2022); women and family groups sharing knowledge about wildlife through casual conversations as they interacted during the day (Davies et al., 2018); inter-ethnic groups sharing of knowledge in order

to solve a common wildlife conservation problem (Almuna et al., 2022); village women using their strong social alliances to share knowledge in order to improve their ability to work more effectively together in managing natural resources (Flintan, 2001; Table S-1), and formal, government involved, groups sharing knowledge about wildlife management (Staples and Natcher, 2015).

An important sub-category within 'Integration of knowledge' was

Table 4

Examples from the case studies of the social mechanisms supporting the generation, accumulation and transmission of local ecological knowledge used by women in their wildlife management practices.

Social mechanism	Examples from case studies	Quote and reference
Reinterpreting signals for learning	Women's participation in group meetings to assess progress from the previous year in the snow leopard conservation program, Spiti Valley, India	"We call a general meeting every year for discussions on protecting wildlife and maintaining cleanliness. We also discuss the work done in the previous year. Like last year, in the interest of protecting wildlife and maintaining cleanliness we shall create awareness among villagers", cited in Alexander (2022, p. 184)
Revival of local knowledge	Aboriginal women rangers in central Australia running programs to revive knowledge amongst school children about local species of fish and birds	"Indigenous ecological knowledge has developed over tens of thousands of years, but can be lost in an instant. Gurindji traditional owners are addressing this through projects to share their knowledge to younger generations. The Murnkurrumurnkurru Women Rangers have worked with a steering committee, the local school and a linguist to share their knowledge of local fish and birds with younger generations.", cited in O'Leary and Walter (2018, p. 250)
Folklore and knowledge carriers	Accessing information from outside experts through the input of knowledge from village study circles, Maharashtra state, India	"These informal groupings act as forums for frank and in-depth discussions on various issues ranging from immediate village problems and their solution, to wildlife conservation, and experts on relevant subjects are invited from outside the village. This interaction and exchange of information helps in the making of informed decisions during the gram sabha*", cited in Pathak and Gour-Broome (1999, p. 39)
Integration of knowledge	(a) inter-ethnic knowledge sharing on raptor management, Andean Chile (b) A collaborative women's and turtle harvesters' sea turtle conservation group, El Salvador (c) Knowledge sharing through casual conversations with other women and family during subsistence activities, Warlpiri women in Arnhem Land, Australia (d) Ensuring that women's distinct knowledge of wildlife ecosystems is heard within the government's mixed wildlife management decision-making forums, Yukon, Canada	(a) "The work here was carried out mainly with campesinas** and a mixture of Mapuche indigenous and non-indigenous families, which helped create a space for cross-cultural knowledge exchange. In this opportunity, non-lethal methods for managing human-raptor conflict were assessed", cited in Almuna et al. (2022, p. 5) (b) "When discussing Barra de Santiago's challenges around natural resources and endangered wildlife, all respondents (100 %), including the tortugueros, shared knowledge about local sea turtles and their threats", cited in Massey et al. (2022, p. 13) (c) ".... the women would walk close enough to talk to each other about what they were seeing and which direction to go. Monitoring and assessing country in this way was a vital practice for the women, increasing their knowledge and familiarity with country. They would share that knowledge later with family and use it to plan future trips. Similarly when driving to hunting locations, women's discussions would be wide ranging, covering jukurpa and customary ownership of particular areas of country, availability of plant and animal resources, past visits to places, and information about country passed on from other family members", cited in Davies et al. (2018, p. 47) (d) "As one female participant told us, "Women, you know, a lot of them are harvesters of a different nature, you know, the berry patches, and the roots and the medicinal plants, so the nature of what brings them onto the land brings them to different places than the men" (current staff member, personal interview, August 15, 2013). While these activities may not directly involve fish and wildlife, they do provide unique knowledge of the ecosystem that humans share with wildlife", cited in (Staples and Natcher, 2015, p. 362)
Intergenerational transmission of knowledge	Arrangement of workshops where a facilitator was appointed to invite senior women to share their cultural and ecological knowledge with younger people about the sustainable use and protection of wild resources in Indigenous Protected Areas (IPAs), Australia Inter-generational transmission of knowledge at beekeeping workshops organised for women by local NGOs in the Chaco region, Bolivia.	"... .. employing a Warlpiri woman in a new position of community engagement officer to support senior women's interests in IPA management, holding targeted workshops and consultations with senior women to promote their understanding and involvement in IPA management planning, resourcing women's country visits from IPA Program resources, and paying senior women to burn country. Senior women were also paid from IPA Program resources for their work as mentors, cultural advisors and teachers to the Wulain Rangers and to non-Indigenous community staff and their children." cited in Davies et al. (2018, p. 48) "This initiative helps indirectly to homogenize the knowledge of younger and older people on one hand through workshops (in this case is mostly formal knowledge). On the other hand, these workshops may serve as platforms for the exchange of knowledge between the participants." cited in Adler et al. (2023, p. 12)
Geographical diffusion of knowledge	Aboriginal women rangers sharing knowledge with other Indigenous rangers across the drylands in Australia.	"In 2016, Nolia was part of the Kiwirrkurra-hosted Ninu Festival, a gathering of Indigenous land management groups operating across the deserts of Western Australia, South Australia and the Northern Territory. There, Nolia demonstrated cat-tracking techniques to a group 120 Indigenous rangers from 20 different ranger groups, scientists, conservation organisations and government representatives", cited in O'Leary and Walter (2018, p. 42)

*The gram sabha is the village assembly made up of equal numbers of men and women from families in the village.

**Female farm workers

intra-conjugal knowledge sharing about wildlife between spouses at the household level. This knowledge sharing enabled the improvement of the household's harvesting effectiveness and overall livelihoods (Staples and Natcher, 2015; Lastarria-Cornhiel et al., 2017; Davies et al., 2018). A number of case studies in the literature reviewed (e.g., Ens, 2012; Goldman and Little, 2015; Lastarria-Cornhiel et al., 2017, Table 4, Table S-1) indicated how women's spouses and male friends provided an indirect route for ensuring their knowledge and views were heard within formal all-male community wildlife management groups. For example, this approach was applied by Indigenous women rangers in Australia in situations where women addressed cultural issues or felt unable to tell men what to do. A suggested solution was to put ideas to male friends and family and ask them to talk to the decision makers (Ens, 2012, p. 30).

Inter-generational transmission of knowledge: This was another important social mechanism which facilitated the sharing of women's local knowledge, especially in Aboriginal groups in Australia (Table 4). There were a number of case studies outlining projects to facilitate a greater exchange of knowledge between elders and young people among these groups (Davies et al., 2018; Daniels et al., 2022). Often it is the older women who were most actively involved with this inter-generational transmission of knowledge of Country as they not only have a lifetime of experiences to draw upon, but also value their own knowledge for traditional, ecological and cultural reasons (e.g., Daniels et al., 2022). Since the older women may possess biocultural knowledge of Country specific to women (O'Leary and Walter, 2018), the inter-generational knowledge sharing by these women through their teaching of mixed-gendered groups of children and youths may potentially be an alternative route for communicating women's knowledge indirectly to men (Table 4, Table S-1).

An extension of this is illustrated by the many groups of women in the studies reviewed, particularly the rangers and wardens, who pass on traditional knowledge not only via the schools, but also via community outreach programs in which the value of wildlife is taught to children as well as to adults of both genders (Danoff-Burg and Ocaña, 2022; Graham, 2022, Table 4, Table S-1). Similarly, formal beekeeping workshops organised for women by NGOs in the Chaco region of Bolivia provided opportunities for inter-generational transmission of traditional knowledge about native stingless bees (*Meliponini* group) and beekeeping. While there was no indication whether this involved mixed gender groups, it was stated to be highly likely (Adler et al., 2023).

Revival of local knowledge: Another important social mechanism supporting women's resource management practices that was especially important for Aboriginal women's groups in Australia was 'Revival of local knowledge' (Table 4, Table S-1). This was important for both cultural and ecological reasons as the two are inseparable in traditional Aboriginal culture in most areas of Australia (Ens et al., 2015, Davies et al., 2018; O'Leary and Walter, 2018; Daniels et al., 2022). There were many examples of this social mechanism in the case studies of Aboriginal women rangers in Australia (O'Leary and Walter, 2018).

Geographical diffusion of knowledge: In Aboriginal societies in Australia exchanging knowledge over large geographical distances was very important traditionally as different groups across the country interacted through their extensive trading links (Blainey, 1983). More recently this exchange of knowledge has been facilitated by arranged formal meetings of different land and sea management ranger groups, for example, the Northern Australia Indigenous Land and Sea Management Alliance (NAISMA) wishing to share knowledge and experiences about resource and environmental management issues (Sithole et al., 2008; O'Leary and Walter, 2018, Table 4).

Two additional categories (Berkes et al., 2000) of social mechanisms facilitating women's knowledge sharing were evident in two of the case studies reviewed. Alexander et al. (2022) described in a study in the Spiti Valley in northern India, how women, through their annual group meetings, were *Reinterpreting signals for learning* in order to devise more effective conservation practices in subsequent years as ecological and

socio-economic conditions changed. The other, *Folklore and knowledge-carriers*, was evident in a study from Maharashtra state, India (Pathak and Gour-Broome, 1999), where outside experts on a particular wildlife management topic were often invited to share their knowledge with the community, including women, at formal village meetings (Table 4). While it is unclear whether the visiting experts included women, this community social mechanism benefited not only the men in the host village, but also the women, as they too were present at the formal meetings and thus able also to access knowledge about wildlife management from the visiting experts.

3.3. The conservation outcomes from applying women's knowledge in community-based wildlife management

The outcomes from applying women's knowledge in community-based wildlife management were important for conservation. The case studies reviewed were varied with regard to the type of outcomes reported against Global Biodiversity Framework 2050 goals (Convention on Biological Diversity (CBD), 2023). Fourteen included wildlife conservation outcomes only, five reported socio-economic outcomes only, seven projects with socio-economic GBF goals had no reported outcomes, and six cited both. Five of the case studies reporting socio-economic outcomes described these only in terms of the opportunities they provided for potentially positive wildlife conservation outcomes in the future. These last types of socio-economic outcomes included greater active engagement and participation of women in community wildlife management and/or improved benefits for women from conservation.

Eight studies provided quantitative data on outcomes, with data in the remainder being qualitative or anecdotal. This conforms with the findings of Roe and Booker (2019) in their work on the role of communities in combatting the illegal trade in wildlife. The important outcomes for conservation identified in our review resulted from the many different practices used by women in community wildlife management, which were built on their own experiential and shared knowledge of wildlife. Examples of case studies from the review are outlined below and their outcomes are listed according to the four main goals of the Kunming Montreal Global Biodiversity Framework (GBF) for 2050, summarised as: A. 'Protect and Restore'; B. 'Prosper with Nature'; C. 'Share Benefits Fairly'; and D. 'Invest and Collaborate' (Convention on Biological Diversity (CBD), 2023).

3.3.1. Protect and restore

Twenty-five of the 32 case studies examined in the review were focused on this first GBF goal (Table 5).

Positive conservation outcomes were achieved in two case studies where women's groups, using their extensive knowledge of the local pastoral economy and environment, had achieved reduced conflict between protected predators and humans, for example in the Chilean Andes (Almuna et al., 2022), in Himalayan India and in Tost, Mongolia (Alexander et al., 2023, Table 5). Also, significant reductions in poaching were achieved by ranger groups in South Africa (Danoff-Burg and Ocaña, 2022; Graham, 2022, Table 5) and Zimbabwe (Mkono et al., 2023, Table 5). Aboriginal women in the Kiwirrkurra Indigenous Protected Area (IPA) of Western Australia applied their hunting skills and wide knowledge of local environments to reduce predatory invasive species, such as feral cats, threatening endangered native species (O'Leary and Walter, 2018, Table 5). In El Salvador and Costa Rica, significantly increased numbers of eggs and young were produced through the turtle protection project (Imbach and Gutiérrez, 2000a; Massey et al., 2022, Table 5). Similar conservation success was observed in women's beekeeping projects in the Chaco region, Bolivia (Adler et al., 2023, Table 5).

There were three case studies that documented successful outcomes from the work of women's community wildlife management groups protecting specific wildlife habitats. These included the protection of sea

Table 5

Conservation outcomes in the community-based wildlife management case studies listed against the Global Biodiversity Framework Goals.

GBF goal*	Case study goals	Outcomes	Quotes and references (listed by author in alphabetical order)
A	Wildlife habitat restoration project, Popenguine National Park, Senegal	Scaling up of wildlife habitat regeneration and the return of useful plant species	<i>“The women co-opted the assistance of young men to help with reforestation activities, which have extended around the park as more communities have set up their own groups and merged with a co-operative group. This multi-village institution has now been officially recognised by the park authorities and has the authority to be involved in maintaining and guarding the reserve, as well as economic activities including tourism and rights of entry Vegetation cover has regenerated, including useful plants that had previously disappeared”</i> , cited in Abbot et al. (2000, p. 40)
A + B	Beekeeping in the Chaco region, Bolivia, to supplement native stingless bee numbers and improve livelihoods	Improved methods of beekeeping allowed managers to increase hive numbers more effectively with consequent increase in bee numbers Reduced pressure on wild populations of native bees	<i>“... there was a greater success rate in comparison with communities that only used traditional methods to divide the hives. Pat-Fernandes et al. documented a success rate of only 20 % from the divisions made by the indigenous people from communities in Campeche, Mexico, similarly, Villanueva- Gutiérrez et al. [29, 66] documented a success rate of only 17 % in communities within the Zona Maya of Quintana Roo. These figures may be compared to the 47 % success rate of the women in Muyupampa.”</i> , cited in Adler et al. (2023, p.12) <i>“... another 39 % of the interviewees said that the bee population had actually increased in the last 5 years mostly because of artificial breeding”</i> , cited in Adler et al. (2023, p. 9)
A	Snow leopard (<i>Shen</i>) protection in Himalayan India in human-wildlife conflict area	Increased snow leopard conservation awareness and actions which lower risk to wildlife	<i>“Between 2016; 2019, Shen participant women recorded 33 self-directed conservation and environment protection actions Many actions took place sporadically to prevent activities posing risks to wildlife. These included preventing the hunting of blue sheep or birds, preventing the collection of wild plants and supporting the building of predator-proofed corrals”</i> , cited in Alexander et al. (2022, p. 183)
A	Protection of snow leopards, Tibetan wolves and red pandas in a human-wildlife conflict area, Tost, Mongolia.	Development of a non-lethal method of protecting livestock from snow leopards and wolves	<i>“Our community conservation records show that women serve as active participants in community conservation planning, with a particular focus on the insurance of livestock against predator losses (a key snow leopard conservation intervention)—for example, 30 % of livestock insurance program members are women. In addition, women have been assigned leadership positions for four out of the seven (57 %) livestock insurance committees In addition, women have taken on formal roles in local affairs, including biodiversity conservation, through their engagement as elected representatives of the district government (Hawkins and Seager, 2010). ... The responsibilities of these representatives include taking decisions on the local application of regulations for the protection of biodiversity and natural resource management and overseeing their implementation “</i> , cited in Alexander (2022, pp. 4–5)
A	The development of non-lethal methods of protection from local predators by pastoral women in Andean Chile.	Increased use of non-lethal methods to control raptor predation on small livestock resulting from increased opportunities for inter-ethnic knowledge exchange	<i>“The work here was carried out mainly with campesinas and a mixture of Mapuche indigenous and non-indigenous families, which helped create a space for cross-cultural knowledge exchange. In this opportunity, non-lethal methods for managing human-raptor conflict were assessed”</i> , cited in Almuna et al. (2022, p. 5)
A	Restoration of Azraq Oasis, Jordan, by a nationally influential women's group.	Improved biodiversity habitat through wetland restoration	<i>“Although many ecological challenges remain for the Azraq Oasis, including prolonged droughts and salinization, the project has contributed to the improvement of the threatened ecosystem in that area and to the livelihood and environment of the local community.”</i> IUCN (2011), cited by Broeckhoven and Cliquet (2015, p. 732)
C	Empowerment of young Aboriginal women in caring for country, Arnhem Land, Northern Territory, Australia.	Significant improvements in knowledge of local species	<i>“The learning assessment showed that over the 3 years of the project, the Ngukurr Yangbala rangers knowledge of 20 species (in three different languages) increased, as shown by survey responses from 11 (de-identified) Yangbala participants ...”</i> , cited in Daniels et al. (2022, p. 58)
A	Reduction in wildlife poaching, Balule Nature Reserve, South Africa.	Significant reduction of poaching especially those areas where rangers run children's conservation education programs.	<i>“Since their founding in 2013, the Mambas have helped reduce the number of documented wildlife poaching, snaring, and poison in activities by over 89 % and rhino poaching events by 62 % “</i> , cited in Danoff-Burg and Ocaña (2022, p. 480)
A	Equity in Indigenous conservation management, Northern Territory, Australia.	Improvement in wildlife habitat and populations.	<i>“Martu women typically burn country while they are tracking and digging for goannas and other small game</i>

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Table 5 (continued)

GBF goal*	Case study goals	Outcomes	Quotes and references (listed by author in alphabetical order)
D	A national survey of women rangers in Australia sharing ideas and knowledge about their work.	(Not reported)	(Bird et al., 2004). Repeated episodes of Martu women's hunting and burning have generated landscapes with significantly finer scale habitat diversity that support higher population densities of the women's target prey than occur in landscapes where lightning has been the main ignition source (Bliege Bird et al., 2008)", cited in Davies et al. (2018, p. 42) Ens (2012)
C + D	Improving women's community resource monitoring skills.	Increased inclusiveness of women in community-based natural resource management decision-making in wildlife conservancies in Namibia resulting from increased respect of male leaders of women's biodiversity knowledge	"The CRMs** who were visited during this study appeared confident and happy with their work. It was also clear that in East Caprivi they were seen as having some status within the local society. This was also confirmed for West Caprivi, by Rena Mushavanga (pers. comm., 2001) – a CRM there – who said that she felt that CRMs had improved women's position in the community. Women had more confidence, they contributed to local meetings and gave support and encouragement to other women to do the same", cited in Flintan (2001, p. 14)
B + C	The appointment of women as community resource monitors (CRMs) in selected conservancies of Namibia	Improved attitudes of women towards conservation and increased empowerment	"Information flow was a vital and successful component achieved through the CRMs. As women became more drawn into the conservation processes they took on greater roles in and responsibilities for sustainable natural resource use" (Flintan (2003, p. 33) Goldman and Little (2015)
C + D	Maasai women empowerment in a community resource management group, northern Tanzania.	(Not reported)	
A	Reduction in the illegal wildlife trade.	Significant reduction in poaching levels especially by the Akashinga, Zimbabwe, Black Mambas, South Africa, and women rangers in Nepal.	Akashinga. "The female ranger position is highly respected and sought after within the community with more younger women who aspire to become rangers. They now have over 150 rangers who have conducted nearly 200 arrests and contributed to the country's 80 % reduction in poaching rate.", cited in Graham (2022, pp. 38–39) Black Mambas. "Approximately 30 women have been recruited into service to date and contributed to a reduction in poaching and snaring events in the areas that they patrol by 76 %, which far exceeded what all-male units typically accomplished in a similar-sized area.", cited in Graham (2022, p.39) Women rangers, Nepal "Thanks in part to these female units, Nepal's protected areas achieved near-zero poaching of rhinos (Rhinoceros unicornis) during 2011–2018", cited in Graham (2022, p. 40)
A	Reduction in illegal wildlife trafficking	Reductions in rhino horn poaching achieved by the Black Mamba women rangers' group, Balule Nature Reserve, South Africa	"Although Balule Nature Reserve has not achieved a zero rhino poaching rate, the Black Mambas have been successful. For example, they have identified and demolished several poachers' camps and kitchens for preparing bush meat, and reduced snaring and poisoning activities substantially", cited in Hubschele and Scherring (2018, p. 29)
A + B	Protection of turtles, their nesting beaches, hatchlings and sustainable harvesting of their eggs, Ostional, Costa Rica	Reduction in both illegal egg harvesting and the sale of illegal eggs in local markets	"Both men and women eventually transport the bags of eggs to the collection centre, where they are sold cheaply, so that other eggs from other beaches cannot compete with those of Ostional on the market. In addition, the community undertakes tasks that improve the conditions for turtle reproduction: beach cleaning, protection of the beach so that no illegal egg collection occurs, and protection of the new-born turtles against predators the community is committed to keeping the beaches clean, taking care of nests and protecting turtle hatchlings" Imbach and Gutiérrez, 2000a, cited in Roe and Jack (2001, p. 54)
A + B	Captive breeding of the green iguana for the export pet trade, Nicaragua	The captive breeding program itself failed but after the project finished participants used mangrove forest resources and iguanas more sustainably	"Although the iguana initiatives were not successful in the long-term for the communities involved they did have a number of positive impacts: While the initiatives were active the extraction of forest resources diminished considerably. In the community of Luis Andino, those involved in the project extracted firewood for home consumption only, and devoted themselves to alternative activities, such as the small-scale growing of crops. Community management of the green iguana offered some protection to wild populations largely as a result of a clear change of attitude among the campesinos involved. For both groups involved, once the iguana initiatives had ended, they still refrained from cutting mangroves and developed other alternatives." Imbach and Gutiérrez, 2000, cited in Roe and Jack (2001, pp. 55–56)

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Table 5 (continued)

GBF goal*	Case study goals	Outcomes	Quotes and references (listed by author in alphabetical order)
D	Facilitating the capacity of women to help reduce the illegal wildlife trade, Team Lioness, Kenya.	Greater numbers of women with the role of wildlife “protectors” reporting wildlife crimes.	“... . Although this is only a 2-year pilot programme with limited evidence, it acknowledges the direct and indirect roles women play in wildlife conservation and has exhibited positive results, creating a network of trusted women to whom other women can turn for reporting wildlife crime and welfare (Chiu, 2019)”, cited in Kahler and Rinkus (2021, p. 839) Lastarria-Cornhiel et al. (2017)
C	Study of tribal women's empowerment with socio-economic change in the Gran Chaco, Bolivia	(Not reported)	
B	Study of the level of interest of women in participating in the administration of wildlife conservancies linked to the level of benefits received from the conservancies, Namibia.	(Not reported)	Lendelvo et al. (2012)
C	WWF initiated nature conservation project to improve greater inclusivity of women in conservation activities in Kanchenjunga region, E. Nepal	Increased awareness of women in conservation issues with consequent increased participation in conservation activities	“... . they are amenable to information on conservation awareness. Many of them seem to incorporate very well the respective knowledge provided in diverse KCAP activities. With their increased conservation awareness, women contribute to the main aims of the WWF. They give advice on sustainable use of forests, advocate a halt to slash-and-burn practices, promote restrictions on collection of certain medicinal plants, and work in tree nurseries”, cited in Locher (2006, p. 273)
A	Lion habitat restoration, community and school education programs, and lion numbers monitoring by women rangers' group, Mama Simba, Kenya.	Significant improvement of lion habitat	“Restoring the soil: In 2021, the Mama Simba ladies joined partners to reseed the rangelands of Westgate Conservancy. In 2022, they took this work further by digging large semicircular bunds, in their Lokere, to trap moisture from rain and spur the growth of grass. ... Lion Monitoring and Conflict Management The ladies have also informed herders of lion locations so herders are better able to avoid those areas and also have reported all conflict they have heard of (lions attacking livestock) Digging waterholes: When the Ewaso Nyiro River dried up, the Mama Simba ladies arranged and supported digging waterholes efforts both in SNR and Westgate Conservancy. These waterholes help both livestock and wildlife”, cited in Ewaso Lions (2024, p.2)
A	Women's community development group's (AMBAS) initiation of a sea turtle protection and sustainable egg harvesting project, El Salvador	Reduction in illegally harvested turtle eggs	“All AMBAS respondents (100 %) that filled out the survey indicated that they believe the hatchery system is a viable long-term solution to reduce illegal egg poaching, which reinforces the theme inferred from the interviews with AMBAS members and tortugueros”, cited in Massey et al. (2022, p. 21)
A	The formation of the Akashinga women's ranger group, Zimbabwe, to reduce wildlife poaching as well as reduce social issues such as domestic violence in local communities	Significant decrease in poaching	“While it is too early to meaningfully assess the success of the Akashinga model as a long-term conservation tool, from the organisation's claims, there are promising signs. According to the IAPF*** website, “in the first 2.5 years Akashinga helped drive an 80 % downturn in elephant poaching in Zimbabwe's Lower Zambezi Valley, one of the largest remaining populations left on earth.” It is further claimed that the project has delivered a 350 % increase in wildlife numbers. These figures, if accurate, indicate significant success in the anti-poaching effort and recovery in wildlife populations”, cited in Mkono et al. (2023, p. 1101)
A	Protection of endangered species, Western Australia	Feral cat control and greater bilby habitat enhancement	“Tracking surveys across the Kiwirrkurra IPA have revealed that threatened species like the bilby and great desert skink are now only found in the areas where Nolia's community regularly goes hunting for cats, and conducts her fine-scale burning”, cited in O'Leary and Walter (2018, p. 42)
A + C	Protection of endangered species and habitat through the establishment of a women's ranger group, Periyar Tiger Reserve, Kerala, India	Reduction in biomass extraction by local communities from the reserve	“Their presence in the forest during daytime not only discourages illegal entry but also controls biomass extraction. Periyar is emerging as a role model of women empowerment for biodiversity conservation”, cited in Pillai and Suchintha (2006, p.338)
A	The empowerment of tribal women in Maharashtra state, India, in community resource management	Improvements in forest wildlife habitat	“The villagers now have fixed rules about resource extraction, with penalties for those who do not abide by the rules The forests have been protected from commercial activities ... encroachments by the villagers in the surrounding forest area have largely been stopped”, cited in Pathak and Gour-Broome (1999, p. 39) Somerville et al. (2022)
C	Study of the processes towards empowerment of women as community scouts or rangers, Zambia	(Not reported)	

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Table 5 (continued)

GBF goal*	Case study goals	Outcomes	Quotes and references (listed by author in alphabetical order)
C	Demonstration of the importance of women's active involvement and knowledge-sharing on the government's wildlife management board, Yukon, Canada	(Not reported)	Staples and Natcher (2015)
A + B	Improvement in both the environment and livelihood opportunities for communities in the region of the Sariska Tiger reserve, Rajasthan, India, through the reforestation work of a local women's group.	Increased biodiversity habitat and improved soils and agricultural productivity	"The women in the villages have also given an important contribution to plant an area of about 5000 around the reserve, a number that approximately corresponds to 6 % of the surface of the whole reserve. The improvement of soil quality, a consequence of the conservation in Sariska, has resulted in an increase in land productivity and the extension of agricultural activities in the region. Before these initiatives, in the village of Bhaonta-Kolyala, 140 of the total 221, that is to say more than half, were classified under the category of banjar bhumi (non-cultivable plots)", cited in Torri (2010, p. 7)
A + C	The empowerment of women in Chunut National Park co-management, Bangladesh and the formation of women patrol groups and conservation educators in their communities.	Increased sightings of different species of wildlife and improvements in wildlife habitat	"Biodiversity benefits have resulted from the conservation work undertaken in and around the sanctuary, with observed increases in sightings of birds and elephants within the sanctuary. Understory forest growth has increased, and migratory elephants are spending a greater portion of their time within the sanctuary", cited in United Nations Development Programme (2013, p. 9)
C	The establishment by the Dongning Forestry Bureau of an all-female rangers group to reduce wildlife poaching in the forests of Heilongjiang province, China.	(Not reported)	WWF (World Wildlife Fund) 2020. Annual Report. <i>Doubling Wild Tigers</i> , pp. 35–36, available at: https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Asien/WWF-Report-Doubling-Tigers-2020.pdf/

*GBF goals: 'A' Protect and Restore, 'B' Prosper with Nature, 'C' Share Benefits Fairly, 'D' Invest and Collaborate.

**Community resource monitors.

***International Anti-Poaching Foundation.

turtle nesting beaches in Costa Rica (Imbach and Gutiérrez, 2000a, Table 5), and lion (*Panthera leo*) habitat improvements in Kenya (Ewaso, 2024, Table 5). The green iguana (*Iguana iguana*) project in Nicaragua (Imbach and Gutiérrez, 2000b) indicated partial success as the extraction of mangrove forest resources diminished significantly when, following the project, fuelwood from the mangrove forests was extracted only for home consumption (Table 5).

The restoration of wildlife habitat within the buffer zone of Popen-guine National Park in Senegal is another example of a case study with a successful outcome, with surveys showing some species of plants important to wildlife reappearing after being unseen for many years (Abbot et al., 2000, Table 5). Similarly, in the Azraq Oasis project in Jordan, the Arab Women Organisation (AWO) was able to achieve both its original objectives of greater engagement of women in decision-making, as well as improved conservation of water resources and wildlife habitat quality (IUCN, 2011, cited in Broeckhoven and Cliquet, 2015, p. 732; Table 5).

The maintenance and enhancement of the endangered greater bilby's (*Macrotis lagotis*) habitat by Aboriginal women rangers in the Kiwirrkurra IPA (O'Leary and Walter, 2018) and by Martu women in the Western Desert (Daniels et al., 2022) of Australia were built on their extensive knowledge of the ecology of landscape burning. Martu women's knowledge of landscape burning benefitted the endangered greater bilby not only by increasing its habitat, but also by creating mosaics of vegetation complexity, which improved the habitat for many other species the women and their families relied upon for subsistence (Daniels et al., 2022, Table 5, Table S-1).

3.3.2. Prosper with nature

The educational programs of the all-women Black Mambas rangers in South Africa and the Akashinga rangers in Zimbabwe, as well as their programs of distributing financial benefits from conservation, were strongly linked to a positive change in the attitude of communities towards wildlife and consequent reductions in poaching rates. This was especially true of the children's conservation education programs, which resulted in notably significant declines in poaching in the communities

(Danoff-Burg and Ocaña, 2022, Table 5). Similarly, greater 'knowledge integration' between the Indigenous *Mapuche* people and non-Indigenous local people in the Chilean Andes case study resulted in a change of attitude toward wildlife and a reduced use of lethal methods to control predatory protected raptors (Almuna et al., 2022). Also, with greater conservation awareness promoted by women, a more positive attitude towards protected wildlife developed over time in the Himalayan snow leopard conservation project (Alexander et al., 2022, Table 5, Table S-1).

Through their inclusion in a community resource monitoring project, the women in the East Caprivi conservancy in Namibia (Flintan, 2001; 2003) had the opportunity to see for the first time the livelihood benefits from effective management of wildlife. A similar improvement in awareness resulting from participation in community wildlife management was evident in the captive breeding of green iguanas case study in Nicaragua (Imbach and Gutiérrez, 2000b). Although this project's main objective was not achieved, nevertheless it had some long-term conservation benefits for iguanas through the improved conservation attitudes of local people (Table 5).

3.3.3. Share Benefits Fairly

A particularly significant outcome from the community monitoring program in the Namibian conservancies case study (Flintan, 2001; 2003) was the recognition by male community wildlife management decision-makers of the value of women's knowledge of local biodiversity. This recognition meant that women were increasingly able to make decisions regarding all aspects of community-based natural resource management activities within the conservancy. Similarly, the increased empowerment of tribal women in Maharashtra state, India (Pathak and Gour-Broome, 1999) led to reduced illegal agricultural encroachment on forest habitats and to overall improved forest condition. Also, in Chunut Wildlife Sanctuary, Bangladesh, the empowerment of women led to the setting up of women's patrol groups and appointment of women as community conservation educators to improve community knowledge about the value of wildlife. Both initiatives have resulted in significantly increased wildlife sightings in the sanctuary (UNDP, 2013). Likewise, in

northern Australia, through the training provided by elders and local IPA rangers, a group of young Aboriginal women became more aware of the conservation issues on their Country and, with their enhanced knowledge, gained the confidence to take on leadership roles as rangers on Country (Daniels et al., 2022, Table 5).

3.3.4. Invest and Collaborate

The Akashinga rangers project's success in reducing wildlife poaching in Zimbabwe was attributable in part to the strong emphasis by an overseas NGO, the International Anti-Poaching Foundation (IAPF), on the training and capacity building of the group's members, mainly disadvantaged women, so they could achieve empowerment, employment and independence as wildlife rangers (Mkono et al., 2023). Training and capacity building provided by U.S. Agency for International Development (USAID) also helped empower women in Zambia to become engaged with wildlife conservation as wildlife 'scouts' or rangers by overcoming barriers such as community gender norms and domestic violence (Sommerville et al., 2022, Table 5).

4. Discussion

For effective knowledge sharing and decision-making within and across community-based natural resource management groups, studies of other common-pool resources, such as forests and fisheries in Africa, Asia and Latin America (Agarwal, 2001; Sultana and Thompson, 2008; Mwangi et al., 2011; Coleman and Mwangi, 2013; Leisher et al., 2017), have suggested that to allow sufficient levels of women's empowerment and agency, it is essential that a significant proportion of group members, usually at least 30% or more, should be female (Leisher et al., 2017). This level of representation better allows women to freely share their resource knowledge with other group members in an inclusive way and can give advice about the most effective management approaches.

Much of the success of community-based natural resource management groups with a significant percentage of women members is due to their effectiveness in monitoring rule compliance in the community. Rule compliance monitoring is an area where women have often been officially granted agency, for example, as members of formally paid groups such as government rangers in South Africa, Zambia and Zimbabwe, or in informal voluntary groups such as wardens appointed by national or international non-government organisations, or by the local community itself (Graham, 2022). While the causal pathways for the improved forest condition observed in inclusive forest management groups, for example, are not yet clear, it has been hypothesised that, in addition to women's abilities to manage conflict and to regulate resource use efficiently in such groups (Westermann et al., 2005), the integration of women's specialised forest resource knowledge into group decision-making may also be a factor (Leisher et al., 2017). This review of women's inclusion in community-based wildlife management groups supports this hypothesis.

The frequency of the types of women's management practices in community-based wildlife management described in this review varied. For example, some practices, such as 'Nurturing sources of ecosystem renewal' in the Berkes et al. (2000) typology (Table 2), were relatively scarce (in only five of the case studies reviewed) (Table 3), perhaps because they fitted in less well with women's daily subsistence livelihood activities. This was also observed by Mwangi et al. (2011), who found that ecological restoration by women's forest users' groups was far less common than restoration by men's and mixed groups. Restoration activities are highly labour intensive and time consuming, making these practices very difficult for women to undertake along with all their other subsistence and family responsibilities. Interestingly, the successful wildlife habitat restoration case study from Popenguine National Park, Senegal, employed local young men to assist with the restoration activities (Abbot et al., 2000).

In contrast to restoration actions, rules compliance monitoring was more readily undertaken by women both in wildlife and forest

management groups. Practices noted in this review which required compliance monitoring such as 'Total protection of certain species', as well as 'Protection of vulnerable life history stages' and 'Protection of specific habitats', could often be undertaken by women sporadically, when they could make time available (Alexander et al., 2022; 2023). Similar findings relating to women's time availability were found for Aboriginal women's wildlife hunting and conservation activities in the Western Desert, Australia (Bliege Bird and Bird, 2008).

The frequency of the types of women's management practices described in our review could also differ from that found in the management of other common-pool resources. For example, our review indicated that practices categorised under 'Monitoring resource abundance and change in ecosystems' in the Berkes et al. (2000) practices typology (Table 2), were readily applied within women's community wildlife management groups in Kenya (Mama Simba, Ewaso Lions, 2024), Namibian conservancies (Flintan, 2001) and amongst several Australian Aboriginal groups (Davies et al., 2018). By contrast, however, in published case studies of forest resource users' groups, less frequent resource monitoring was observed in women's groups than in men's or mixed groups (Mwangi et al., 2011).

Previous studies have found that the higher the governance level where resource management practices need to be applied, such as might be found with resource governance at higher geographical scales, the less likely it is that these will involve women (Colfer et al., 2015; Goldman and Little, 2015; Elias et al., 2021; Mansourian, 2021). Our findings conform with these studies. Nearly all of the practices by women's community wildlife management groups identified in this study were undertaken at the household and community level. The two exceptions were a case study of women involved in 'Watershed-based management' (Torri, 2010) and the participation of First Nations women on the Yukon government's wildlife management board, in which management decisions applied to territory-wide issues (Staples and Natcher, 2015).

The diversity of ways in which women share their knowledge in community wildlife management was both direct or indirect. To achieve ecosystem-based natural resource management and more resilient livelihoods, as well as greater empowerment of women in decision-making, direct information sharing between men and women in formal, public community wildlife management groups is vitally important. To do this, it is essential to facilitate the participation of women in formal community wildlife management groups at the highest level possible, i.e., at Agarwal's 'active/interactive' participation level (Agarwal, 2001, Table 1). Some studies in our review, for example, women's involvement in a community resource monitoring project in Namibian conservancies (Flintan, 2001), indicate that with greater participation of women in formal communal wildlife management groups, men show an increased appreciation of the value of women's wildlife knowledge to the group. The significance of this is increasingly recognised by some currently single-gendered resource management groups, including Aboriginal groups in Arnhem Land, Australia (Sithole et al., 2008) and women rangers working on Indigenous Protected Areas (IPAs) (O'Leary and Walter, 2018; Table S-1). Direct inter-gender information sharing at this level is also beginning to occur with First Nations women participating as members of a formal wildlife management board in Yukon, Canada (Staples and Natcher, 2015).

Overall, we found only six other published examples of direct inter-gender information sharing in formal mixed-gendered community wildlife management groups. Previous studies of women in such groups support this finding. For example, Hunter et al. (1990) and Goldman et al. (2021) noted the lack of active participation and opportunity for inter-gender knowledge sharing in such groups. Any knowledge sharing that did take place in formal community wildlife management group settings was seen mainly in women-only groups, which would seem to do little to further the inter-gender information exchange essential for a more ecosystem-based, resilient approach to natural resource management or for furthering women's empowerment in community wildlife

management (Zweifel, 1997; Robinson et al., 2009; Kleiber et al., 2015).

For women unable to share their knowledge directly in mixed gender groups, there were a number of examples of alternative *indirect* routes available to achieve this. For example, women often conveyed information to formal community wildlife management groups through their spouses acting as intermediaries (Espinosa, 2010; Goldman and Little, 2015). This approach used by women has also been observed in other resource management systems such as agriculture (Meinzen-Dick et al., 2014; Elias, 2015) and small-scale fisheries (Galappaththi et al., 2022; Kitolelei et al., 2022).

Other indirect approaches to transmitting women's knowledge to mainly male-dominant community wildlife management groups occurred via community conservation education programs such as those run by women rangers (Danoff-Burg and Ocaña, 2022). In this regard, 'Intergenerational transmission of knowledge' was shown to be particularly important. The reduction in poaching rates achieved by the Black Mambas women rangers in South Africa was highest in those communities where they organised children's conservation awareness programs (Danoff-Burg and Ocaña, 2022). Similar findings were found following the commencement of children's wetlands awareness programs in the Seychelles, where significantly positive knowledge, behavioural and attitudinal changes in the children's parents towards wetlands were also observed (Damerell et al., 2013). In Aboriginal groups in Australia, this 'intergenerational transmission of knowledge' to mixed-gender groups is likewise considered very important to ensure conservation of Country (Ens, 2012; O'Leary and Walter, 2018). Also, in some Indigenous North American cultures, inter-generational knowledge transmission, not gender-defined, was noted by Turner (2003) during her studies of Indigenous women's use of plants in British Columbia, "... when Mary Thomas was a child, her grandmother used to take her and her brother [emphasis added] and sister root digging" (p. 140). In Australian Indigenous groups, programs to facilitate inter-generational knowledge transmission are currently being undertaken with some sense of urgency as some of the primary carriers of local knowledge are elderly (Davies et al., 2018; O'Leary and Walter, 2018). The concern about the loss of local knowledge and with it the vital information about local species and ecosystems with the passing of community elders is of great concern to many other societies in the region and elsewhere (Cinner et al., 2007; Turner and Turner, 2008; Aswani et al., 2018; Reyes-González et al., 2020; Kitolelei et al., 2022).

Knowledge sharing, or information exchange, is a two-way process that provides women as well as men the opportunity to learn from each other (Assé and Lassoie, 2011; Elias, 2015). For example, the community education programs run by women rangers and others within community forums allow men and women to hear each other's ideas and views on wildlife issues. It has been noted elsewhere that such community education programs provide an opportunity for information exchange to occur between men and women that traditionally might not have occurred otherwise. In this way, such programs present a new and different way of providing greater resilience to the community (Ohmagari and Berkes, 1997).

This is further supported by a study of equity in Indigenous conservation management in IPAs in Northern Australia where the senior men expressed an awareness of the importance of both men and women working together in conservation partnerships in the management of Country (Davies et al., 2018; Table S-1). An interesting variant of this inter-gender knowledge sharing is provided in a study of the Tsimane hunters of the Bolivian Amazon. Here, through songs sung by both men and women, information is shared about wildlife ecology and behaviour, as well as about gender roles associated with hunting (Reyes-García and Fernández-Llamazares, 2019).

While the case studies reviewed in this study showed mainly positive results in conservation outcomes as measured by the Kunming Montreal Global Biodiversity Framework (GBF) for 2050 (Convention on Biological Diversity (CBD), 2023), the conservation of wildlife species *per se* was often not the main motivation for women to initiate community

wildlife management groups. More frequent motivations were generally social, cultural and economic in nature. They included: 1) Concerns that women's interests were not being considered by male decision-makers, for example, conservancy community resource monitors in Namibia (Flintan, 2001), Akashinga rangers group, Zimbabwe (Mkono et al., 2023), Azraq Oasis restoration, Jordan (IUCN, 2011 cited in Broeckhoven and Cliquet, 2015, p. 732), and community scouts, Zambia (Sommerville et al., 2022); 2) Concerns about declining status of wildlife populations valuable to local livelihoods, due to habitat destruction, over-harvesting, and/or illegal trade and poaching, for example, sea turtle protection and egg harvesting group, El Salvador (Massey et al., 2022); 3) Concerns about protected wildlife impacts on livelihoods, for example, human-wildlife conflicts with livestock predators in Andean Chile (Almuna et al., 2022) and in Himalayan India and Tost, Mongolia (Alexander et al., 2023); 4) Interest in wildlife's potential for increasing women's income and/or food security, for example, wildlife tourism benefits and wildlife product marketing, community conservancies, Namibia (Flintan, 2003; Lendelvo et al., 2012) and captive breeding of green iguanas in Nicaragua (Imbach and Gutiérrez, 2000b); and 5) Cultural reasons, for example, the important cultural role of local wildlife species, such as the lion, for the Maasai (Ewaso, 2024).

While there were a number of women's self-generated community wildlife management groups initiated in response to these concerns, for example, the wildlife habitat restoration group, Senegal (Abbot et al., 2000) and the forest protection and habitat restoration project in the Sariska Tiger Reserve in Rajasthan, India (Torri, 2010), many women's community wildlife management groups arose from pre-existing local women's self-help groups, for example, the restoration of the Azraq Oasis, Jordan (IUCN, 2011; cited in Broeckhoven and Cliquet, 2015, p. 732), the sea turtle protection and egg harvesting group in El Salvador (Massey et al., 2022) and the Periyar Tiger Reserve, Kerala, India (Pillai and Suchintha, 2006). The case studies reviewed also indicated the key role of external agents such as governments and NGOs in the initiation of many women's community-based wildlife management groups (Hidrobo et al., 2024). Examples included government organisations such as the wildlife management board in the Yukon, Canada (Staples and Natcher, 2015) and the Dongning Forestry Bureau women rangers, China (WWF, 2020). NGO-initiated groups included: the International Fund for Animal Welfare (IFAW) for Team Lioness, Kenya (Koot and Veenbos, 2023); the International Anti-Poaching Foundation for the Akashinga female rangers, Zimbabwe (Mkono et al., 2023); Maasai Women's Development Organization (MWEDO) and Ujamaa Community Resource Team (UCRT) in the empowerment of women in two development projects in Northern Tanzania (Goldman and Little, 2015); *Shen* (a local word for snow leopard), a group initiated by overseas researchers to work with the local community for snow leopard protection, India (Alexander et al., 2022); and the World Wildlife Fund (WWF) in the Kanchenjunga conservation area in Nepal (Locher, 2006).

NGOs and governments acting as 'bridging' organisations (Berkes, 2009; Hidrobo et al., 2024) had two significant roles here. Firstly, they were catalysts for assisting many of the case study groups in initiating and organising as a group to achieve resource management goals. Secondly, as agents external to the community, NGOs and government organisations were often able to support greater inclusion of women in new mixed-gender groups than might have occurred ordinarily in the community. Once the women were included, with further training provided by the NGO or government agency, the women were more likely to gain confidence and influence within the group and to encourage other women to join (Hyle et al., 2019). However, despite many women being skilled observers of wildlife, with their knowledge of species of importance to government and NGOs often surpassing that of men, for example, women's superior knowledge of native bees in West Bengal (Bhattacharyya et al., 2017) and of the natural control of agricultural insect pests (Mugisha-Kamatanesi et al., 2008; Payne et al., 2020), not all governments and NGOs have been positive about including women in community wildlife management (Goldman et al.,

2021).

The positive attitudes towards conservation by the women involved in all the community-based wildlife management groups investigated in this review provide a marked contrast to the attitudes of some women living in communities adjacent to state-controlled protected areas for wildlife. Compared to men, women living adjacent to such protected areas receive fewer financial benefits from tourism projects associated with the protected areas and are often less knowledgeable than men about the ecological benefits of such areas (Hartter et al., 2014). Because of subsistence crop raiding and threats of personal injury from the wildlife emerging from parks, women often incur higher livelihood and personal costs from wildlife than men. Also, unlike the men, the women in such areas often have little or no role in the decision-making in the management of protected areas which is almost entirely controlled by the state (Lepp and Holland, 2006). Consequently, many of the women in these areas often have a more negative attitude than men towards protected areas and wildlife conservation generally (Bragagnolo et al., 2016). As with community-based wildlife management, women's agency in decision-making in the management of state-controlled protected areas could be an important factor affecting women's conservation attitudes and knowledge about wildlife. This is an area where further work initiated by local community members, including women, can achieve significant changes that benefit both equity and wildlife conservation.

5. Conclusions

Active engagement of women is key to achieving equity and positive conservation outcomes in community-based wildlife management. In this review, we examined selected case studies from across the world where there existed empirical evidence of women actively participating in community-based wildlife management. We focused specifically on the role of women's wildlife management practices in such groups and how their specialised knowledge of wildlife was shared both within and outside the groups. We also explored the reported outcomes from including women's active participation and knowledge-sharing in community-based wildlife management. Our review showed that outcomes for conservation and livelihoods in such groups were mainly positive. Our review also confirmed the findings of studies of other common-pool resource management groups, such as those concerned with forests and small-scale fisheries, that while significant benefits can result from the inclusion of women in such groups, there remain considerable socio-economic and cultural challenges facing women in actively participating in them.

While the review showed that published examples of direct inter-gender knowledge sharing in formal community wildlife management groups are still relatively few, it also suggests that women use a number of indirect routes for sharing their knowledge with such groups. These studies are still few in number, but with further research, important information could potentially be gained for a greater understanding about how the transmission of women's knowledge in community-based wildlife management groups occurs and how it can be facilitated and promoted. Also, while preliminary, our findings indicate a need for further research into the causal pathways to the success observed in community-based wildlife management groups in which women are actively engaged and their knowledge recognised. In this regard, women's roles in other forms of environmental management also need further investigation and understanding.

This review suggests that, ultimately, greater active engagement of women and integration of their knowledge into community-based wildlife management group decision-making will be needed to better manage the wider socio-ecological systems upon which resilient, sustainable livelihoods and improved wildlife conservation outcomes depend.

CRediT authorship contribution statement

Margaret Chapman: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nancy J. Turner:** Writing – review & editing, Resources. **Salit Kark:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Glossary of terms used in the paper

Agency – as defined by Kabeer (1999) is the ability to not only define one's own personal goals, but also to act upon them. It also encompasses the meaning, motivation and purpose surrounding this process.

Community-based wildlife management or community wildlife management – as defined by Roe and Jack (2001) is the controlled use of natural resources by one or more local stakeholders to distinguish it from the term 'wildlife management', which refers more to those management practices designed, initiated and controlled solely by a state entity. Community-based wildlife management can include a wide variety of practices including.

- Local community management of wildlife within and around protected areas and on communal or private land outside of protected areas.
- Consumptive (e.g., trophy hunting)
- Non-consumptive (e.g., photo-tourism)
- Subsistence (e.g., non-timber forest production collection)
- Commercial (e.g., trade in wildlife or wildlife products)
- Traditional (e.g., protection of sacred landscapes)
- Non-traditional (e.g., game ranching) (Roe and Jack 2001).

Conservancy – A conservancy is a community wildlife management area established for the protection of local wildlife species mainly for non-consumptive purposes such as tourism, but also occasionally for consumptive purposes such as trophy hunting.

Knowledge – Indigenous and local knowledge (ILK). ILK is defined by the IPBES (2021) as the “dynamic bodies of integrated, holistic, social and ecological knowledge, practices and beliefs pertaining to the relationship of living beings, including people, with one another and with their environments.”

Resource rotation – involves the rotation of harvesting or livestock grazing pressure to different areas to allow recovery of habitats and ecosystems. Examples include the spatial rotation of fishing, hunting, and grazing areas to maintain ecosystem integrity across the entire landscape.

Succession management – involves typically the sequential clearing of small areas land to grow food and non-food crops or encourage the growth of habitat for game animals.

Wildlife – in this paper refers to terrestrial animals, including

vertebrates such as birds, reptiles, amphibians and mammals, as well as terrestrial invertebrate fauna, such as insects, spiders, molluscs and other invertebrates.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jenvman.2026.128559>.

Data availability

No data was used for the research described in the article.

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