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Enhancing demographic diversity of scientist-community collaborations improves wildlife monitoring in Madagascar

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ABSTRACT

Community-based monitoring (CBM)– programs that integrate community members and their values into biodiversity and/or natural resource monitoring– is an effective tool for conservation. Wide inequities exist in CBM collaboration, and monitoring abilities may vary between collaborators of different backgrounds. Therefore exploring the demographic composition of CBM collaborators, and how demographics shape individual monitoring efficacy, can help improve both diversity in CBM representation and program outcomes. Yet, few studies have focused on CBM collaborator demographics, especially in low-income countries. We implemented a CBM project co-designed by protected area managers and local community members in the geographically, biologically, and culturally diverse Southern Madagascar. The project involved 27 scientists and 83 community members who collectively generated 69,429 observations of birds, mammals, amphibians and reptiles across two years (2917 surveys). Using linear regressions and mixed-effects models, we examined how collaborators' demographics (gender, age, and level of formal education) and their prior amount of biological monitoring experience impacted their efficacy, measured as the number of observed species. For both scientists and community members, monitoring teams with women, despite being underrepresented, on average observed more species than male-only teams. Among community members, age and level of formal education had smaller positive effects on efficacy. Our results suggest that CBM projects should actively engage a broad array of community members, including those with marginalized identities, to provide diverse perspectives. Inclusive initiatives offer both tangible (lower project costs) and intangible (community engagement, education, and enhanced collaboration) benefits for local communities and conservation managers alike.

RÉSUMÉ

Le suivi communautaire (CBM) – les programmes qui intègrent les membres de la communauté et leurs valeurs dans le suivi de la biodiversité et/ou des ressources naturelles – est un outil efficace pour la conservation des aires protégées. De grandes inégalités existent dans la collaboration du CBM, et les capacités de suivi peuvent varier entre les collaborateurs de différentes origines. Par conséquent, l'étude de la composition démographique des collaborateurs dans le CBM et de la manière dont les données démographiques influencent l'efficacité du suivi individuel peut contribuer à l'amélioration à la fois de la diversité du représentant du CBM et les résultats des programmes. Pourtant, peu d'études se sont concentrées sur les caractéristiques démographiques des collaborateurs dans le CBM, en particulier dans les pays en voie de développement. Nous avons mis en œuvre un projet de CBM conçu conjointement avec les gestionnaires de Aires protégées et les membres de communautés locales dans le Sud de Madagascar, une région géographiquement, biologiquement et culturellement très diversifiée. Ce projet a impliqué 27 scientifiques et 83 membres de la communauté qui ont collectivement engendré 69 429 observations d'oiseaux, de mammifères, d'amphibiens et de reptiles en deux ans (2 917 suivis). À l'aide des régressions linéaires et des modèles à effets mixtes, nous avons analysé comment les caractéristiques démographiques des collaborateurs (genre, âge et niveau d'éducation formelle) et leur expérience antérieure en

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matière de suivi biologique ont eu un impact sur leur efficacité de suivi, qui a été mesurée par le nombre d'espèces observées. Que ce soit les scientifiques ou les membres de la communauté, les équipes de suivi composées de femmes, bien que sous-représentées, ont toutes observé en moyenne plus d'espèces que les équipes composées uniquement d'hommes. Par ailleurs, l'âge et le niveau d'éducation formelle pour les membres de la communauté avaient des effets positifs moins importants sur l'efficacité. Nos résultats suggèrent que les projets de CBM devraient impliquer activement une large éventail de membres de la communauté, y compris ceux ayant des identités marginalisées, afin de fournir des perspectives diverses. Les initiatives inclusives offrent des avantages à la fois tangibles (coûts de projets réduits) et intangibles (engagement communautaire, éducation et collaboration améliorée) entre les communautés locales et les gestionnaires de la conservation.

Mots clés: Suivi communautaire; demographiques; égalité; genre; Madagascar; connaissance locale.

1. Introduction

Community-based monitoring (CBM) – although definitions vary – integrates local community members and their goals in the monitoring and management of resources, and has become increasingly popular for more extensive and better informed surveillance of natural systems (Johnson et al., 2015; Whitelaw et al., 2003). Recent global advocacy for the decentralization of natural resource governance (i.e. redirection of resource control to local actors) has encouraged the spread of CBM programs (Bernedo Del Carpio et al., 2021). CBM goals include gathering new and broader information on the resource/environment and its users, centering decision-making on local communities, and reinforced structure to hold both authorities and community members accountable for responsible management (Conrad and Hilchey, 2011; Purnomo et al., 2003; Standa-Gunda et al., 2003). CBM can also contribute accurate biodiversity data needed for targeted, flexible ecosystem management (Danielsen et al., 2014). Additionally, when travel costs for visiting conservationists are high, observations from community members in close proximity to target ecosystems offer a scalable complement to monitoring from formally-trained researchers (Aristeidou et al., 2021; Callaghan and Gawlik, 2015).

While CBM programs are intended to enhance the social capital of local communities (Conrad and Daoust, 2007), they may instead relegate community members as inferior compared to professional conservationists. Existing biases in conservation, such as elitism, classism, and racism (Rudd et al., 2021; Wyborn and Evans, 2021), may infiltrate CBM projects, especially those implemented in rural, impoverished areas, where the social, economic and cultural divides between external conservationists and local community members can be vast (McComb et al., 2018). Placing more power in the hands of "expert scientists" than community members heightens divides, weakens professional development, and reduces knowledge exchange; such projects are not community-*based* monitoring, but entrench existing hierarchies of power (Enns et al., 2014).

To determine whether a CBM program propagates or counteracts historic biases, evaluating who is involved in the program is key. Few studies have examined the demographic composition of CBM programs, or how CBM collaborator demographics shape their efficacy at natural resource monitoring. Yet without targeted study of how both collaborator demographics and the amount of prior natural resource monitoring experience impact efficacy, system-specific recommendations cannot be made, let alone general guidelines of how to construct inclusive monitoring and management plans. If existing biases entail selection for collaborators of only certain demographics, this can narrow the breadth of perspectives gained from people who directly interact with, and are affected by, their ecosystems (Hecker et al., 2018; Khelifa and Mahdjoub, 2021).

Including diverse local perspectives in conservation is of great importance in rural locations of high biodiversity, such as regions on the island nation of Madagascar (Waeber et al., 2020). Madagascar is a "hotspot" of biodiversity (Myers et al., 2000), with estimates of over 12,000 native plant species and 6830 non-marine animal species (Goodman and Benstead, 2005, 2007). However, Madagascar suffers from intense deforestation and poverty (Jones et al., 2019). As the leading conservation entity in the country, Madagascar National Parks (MNP) is charged with conducting robust monitoring across the two million hectares of land that it manages. Biodiversity monitoring is primarily conducted by park rangers and (prior to this study) does not yet efficiently integrate community members in the monitoring process: rangers patrol protected areas to survey for illegal resource extraction (e.g. timber), monitor a few target conservation species (namely lemurs), and record observations of other species only on opportunistic encounters. Although prior efforts have been made in Madagascar to implement CBM that engages with community leaders to determine project goals and decision making for biodiversity monitoring, these consultations frequently selected for more formally educated, older, and male community members at the expense of women, younger individuals, and migrants (Gardner et al., 2018; Pollini et al., 2014). Such homogeneous participation perpetuates unjust exclusion of marginalized voices from community monitoring and conservation (Virah-Sawmy et al., 2014). MNP's protected area management therefore has further potential to integrate local community members as partners in expanding ecological monitoring capacity across biodiverse regions. As Madagascar's socioeconomic conditions (Herrington and Coduras, 2019) and range of climatic conditions and geographies (Vences et al., 2009) bear some similarities to other regions, knowledge accrued in our study can inform CBM globally.

The complex social and cultural context of Madagascar (Dewar and Wright, 1993) also compels managers to explicitly consider the value of local knowledge, which in this manuscript we define as knowledge about a place, held by communities within proximity of the place (Brondízio et al., 2021). With highly agrarian and subsistence populations, Madagascar's rural communities are largely dependent on local landscape and natural resource integrity (Ghimire, 1994; Waeber et al., 2020); the country's forest resources support roughly 65 % of the total population (Razafindratsima and Dunham, 2015). Local knowledge is key to several Malagasy cultures, such as understanding ecosystem integrity and forms of sustainable harvest (Whande et al., 2003). If environmental managers integrate local knowledge, they may better balance resource use and preservation, rather than continue the colonial model that prioritizes preservation over human livelihoods (Egunyu, 2023; Whande et al., 2003).

Here, we explore how demographic factors of local community members and external scientists determine an individual's ability to monitor biodiversity in six protected areas across Madagascar, in an effort towards establishing more just and diverse CBM collaboration. We use the term "scientists" to refer to project collaborators with ecological academic training at the graduate level or higher, and "local community members" as project collaborators who live in close proximity to studied protected areas who do not have graduate-level academic training. However, in general, community members can indeed be scientists and vice versa, and "science" is not necessarily attributable to just academic training. Furthermore, we note that here "CBM" does not refer to the community of base associations (COBA), which are a prevalent form of grassroots conservation governance in Madagascar (Thielson, 2016) – COBAs were not involved in the project studied here, but instead we collaborated with Local Committees of the Park (CLP; see Methods for definition and background). We organized knowledge exchange workshops that acquainted park managers and scientists (n = 27) with local knowledge bases, and acquainted community members (n = 83) with standardized wildlife monitoring and species identification via Linnaean taxonomy. We then compared two years of biodiversity observations from these scientists and community members, and explored the relative impacts of collaborator age, education level, gender, and total number of monitoring surveys conducted on biodiversity monitoring efficacy (measured by the number of species observed). These variables were selected because they may impact both attitudes towards conservation in Madagascar (Ratsimbazafy et al., 2012) and level of ecosystem knowledge (Randrianarivony et al., 2017), and because representing diverse identities is integral for equitable project implementation (Douglass et al., 2019). Our hypotheses were:

1. Older collaborators, having lived longer and being more connected to local ecological knowledge in Madagascar than younger collaborators (Lyon and Hardesty, 2012; Rakotondrabe and Girard, 2021), will be better wildlife surveyors.
2. More educated community members will observe more species due to greater exposure to environmental education programs in Malagasy schools (Schüßler et al., 2019).
3. Given pre-existing social advantages that men receive, such as how forests in Madagascar may be male-dominated spaces (Shrestha, 2022), men will observe more wildlife species.
4. More monitoring visits performed – regardless of a collaborator's demographics – will enhance monitoring efficacy, as surveyors will be practiced at locating and identifying animals (Jonides, 2004).

Exploring how demographic factors impact monitoring ability can help determine the best methods of enhancing diversity of representation in CBM projects. Specifically, understanding how age, gender, education, and amount of experience impact monitoring ability encourages us to examine how cultural norms regarding who is "fit" for conservation and research may improperly constrain our pool of selected community collaborators, thereby undermining cohesive collaboration between park authorities and community members for designing inclusive management. While our research specifically focuses on communities in Madagascar, insights gained here on how demographic composition influences success at wildlife monitoring can be applied to inform community engagement in conservation globally.

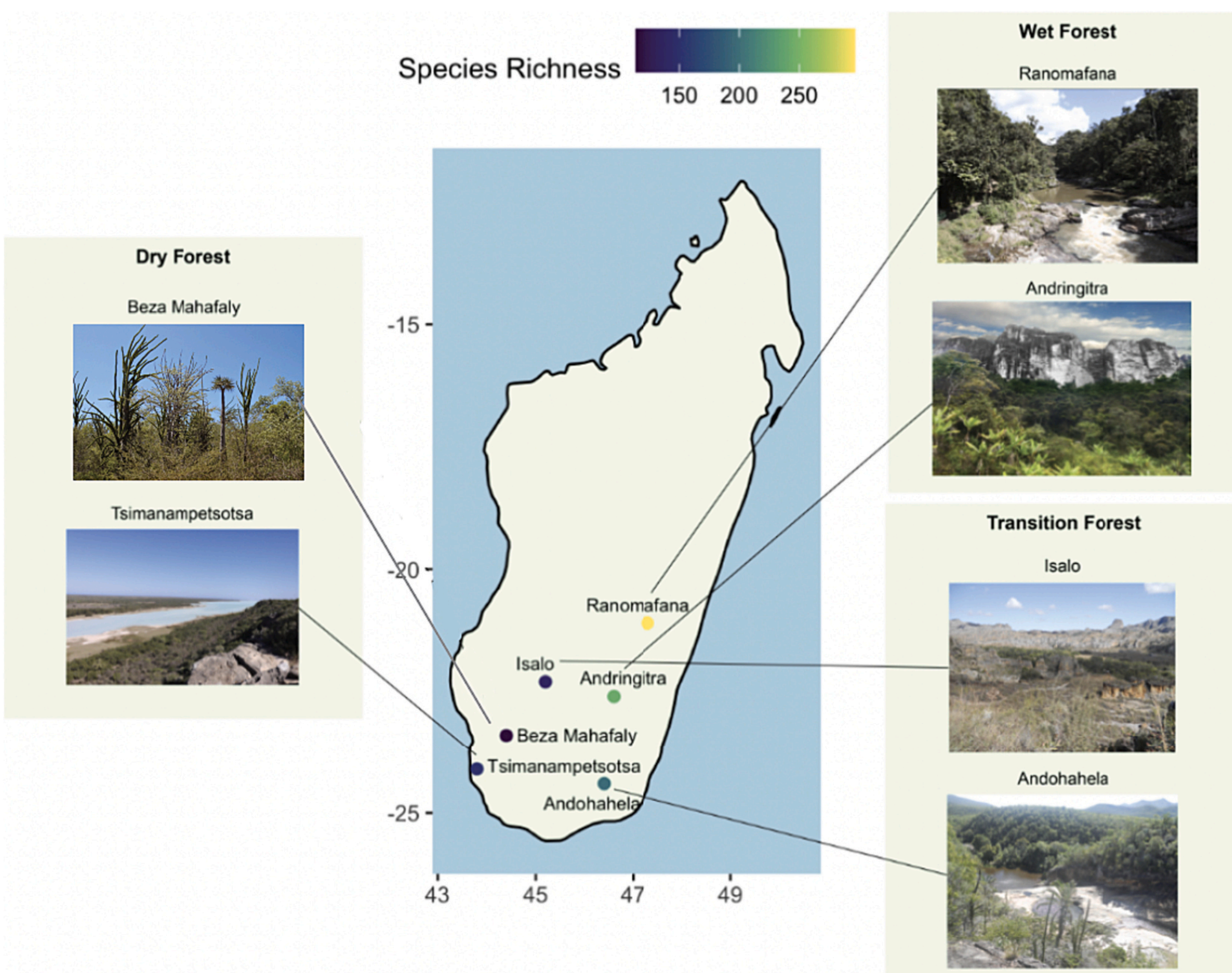

Fig. 1. Map of Madagascar showing the six protected areas investigated in this study, which varied in species richness (values indicated here are drawn from scientist surveys as part of this study). These protected areas are situated across a precipitation gradient thereby composing three forest types: wet forest, transition forest, and dry forest.
(Photo for Beza Mahafaly provided by Mikoja Rambinintsoa. Photo for Andringitra provided by Wikimedia Commons under CC BY-SA 4.0 license (https://creativecommons.org/licenses/by-sa/4.0/deed.en); all other photos provided by authors.)

2. Methods

2.1. Study sites and recent management history

Our study focused on six protected areas across Southern Madagascar with distinct biological communities representing three ecosystem types (Waeber et al., 2020): dry woodland/forest (Tsimanampetsotsa and Beza Mahafaly), transitional forest composed of both dry and wet forest (Andohahela and Isalo), and humid rainforest (Andringitra and Ranomafana; Fig. 1). Although management designations differ for each protected area, for simplicity we will refer to them all as "parks". Forms of both sustainable and unsustainable natural resource use, including timber extraction, hunting, and conversion of forest to agriculture via slash-and-burn *tavy* methods, occur within and in proximity to each park (Martin et al., 2022; Wright, 1992). All six parks have been under the jurisdiction of MNP for over 30 years. Prior to this, policies initiated under French colonial occupation included many restrictions of natural resource use by local people, such as charcoal production, with limited consultation of local communities (Pollini, 2011). Policies in the 1990's and 2000's, such as the National Environmental Action Plan, encouraged more rigorous, wide-scale protection in collaboration with Malagasy communities (Waeber et al., 2016). Yet as international support decreased during Madagascar's 2009–2013 political turmoil, economic insecurity increased especially in Southern Madagascar (World Bank, 2022). As nationally coordinated conservation efforts faltered (Waeber et al., 2016), some projects turned instead towards sustainable development centered on the distinct needs and values of each local community (Razanatsoa et al., 2021).

To engage local communities in decision making for monitoring the biodiverse and endemic wildlife along with ecosystem degradation, all six parks studied here have collaborated with Local Committees of the Park (CLP). CLP members, who are chosen by their communities and are typically local leaders in other capacities as well, are responsible for assisting with, and advising, monitoring activities. While MNP is the executive body that oversees resource management within parks, MNP staff consult CLPs for guidance in prioritizing development interventions, park use, restoration, and community needs, thereby incorporating community perspectives into the development of park monitoring and management goals (see Gardner et al., 2018; Mansourian et al., 2016 for more). These consultations occur 2–3 times a year and include a report provided by MNP on park activities followed by an open discussion and knowledge exchange with CLPs. This network of speciose ecosystems therefore offers a unique opportunity to explore CBM efficacy across geographic, biological, and conservation contexts.

2.2. Co-design and knowledge transfer

The project studied here, initiated by MNP managers yet also consulting CLPs throughout design, sought to determine the agreement between local community members and external scientists at observing wildlife biodiversity, as a step towards understanding how best to incorporate local community members in natural resource monitoring and management. Our study included wildlife observations from two classes of stakeholders: academically-trained taxonomic experts (henceforth "scientists") and members of each local CLP (henceforth "CBM collaborators"). The scientists were wildlife biologists from the University of Antananarivo (with training at the graduate student level or above), each with at least six months of full-time biological monitoring experience within the parks of this study, and at least two years of scientific research experience (although most with far more experience). Despite this formal training, it should be noted that these scientists may be *less* adept at accurately identifying species than CBM collaborators, as the latter of which may have more extensive familiarity with their local ecosystems. For this project, MNP staff engaged with CLP organizations from 4 to 11 villages surrounding each park to solicit their interest in engaging in a new biodiversity monitoring program. Each CLP organization that agreed to collaborate chose their own CBM collaborators, with the sole requirements provided by MNP consisting of a desire to collaborate with MNP and the ability to read and write. MNP specifically encouraged women to volunteer, however only one park (Andohahela) had female CBM collaborators. CBM collaborators were compensated for their collaboration on a daily basis.

All CBM collaborators were familiar with the names of wildlife species in local dialects, yet not necessarily the corresponding scientific names. Before beginning monitoring surveys, MNP staff including study co-authors sponsored workshops to connect scientists and CBM collaborators. During these workshops, we cooperated with CBM collaborators to associate local dialect names of wildlife to Linnaean taxonomy, and collectively decided upon ideal locations for biodiversity monitoring based upon CLP knowledge of wildlife locations. We co-produced resources such as handbooks with the local name, Linnaean name, and species photo(s), which were used for guiding collaborators and also broader education initiatives (Figs. A1–A2). In addition, MNP staff and scientists provided guidance on standardized methods of transect-based surveys for wildlife observation (see below for details on survey protocols). For data quality assurance after completion of workshops, each CBM collaborator was paired with a scientist to simultaneously yet independently perform a trial survey. These observers walked silently alongside each other on a transect and recorded all species they observed. If a CBM collaborator observed and correctly identified at least 50 % of the species observed by the scientist, they were invited to initiate formal monitoring as part of this project; otherwise they continued to partake in scientific training and repeated this exercise until successful. Use of such a low threshold (50 %) to designate completion of training enabled collaboration by a greater diversity of CBM collaborators, yet we also performed further analytical steps to ensure there was concurrence between observations by CBM collaborators and observations by scientists (see Section 2.5). Sharing and interpreting project results with CLPs is ongoing, to inform future collaborations.

2.3. Monitoring protocol

After knowledge transfer workshops, CBM collaborators and scientists visited a series of transects (6–8 transects per park) between January 2019 and December 2020. Drawing from workshop discussions, survey transect locations were designated based on known home ranges of lemur species that are considered high conservation priorities, yet also coincided with a variety of habitats representative of each park. Each transect was 1250 m in length and 200 m apart from the next transect. For monitoring mammals and reptile populations, surveyors slowly walked along the transect and recorded the name of each individual animal observed, the distance from the observer, the distance from the transect start, and the GPS coordinates of the animal. Survey teams continued until they reached the end of the transect. Therefore, observations were standardized based upon spatial area and effort, which has been demonstrated as more generalizable and robust for multi-taxonomic surveys than time-based standardization (Hoffman et al., 2019). For monitoring birds, ten-minute point counts were conducted along the same transects (ten point counts per transect, 125 m apart). Amphibian monitoring occurred at two separate 50-m transects in parallel to prominent streams and rivers. CBM collaborators performed two of each survey per transect per month, and scientists performed two of each survey per transect per year, barring a few instances of impermissible weather. These assessments were performed during both the wet and dry seasons.

To measure collaborator efficacy, we summed the number of species recorded by each monitoring team (either one or two members per team) for each month per transect separately. Species richness was then used as a response variable in models driven by geographic and demographic parameters to determine variation in CBM program success (see "Mixed-effects modeling and linear regressions" below). We calculated efficacy for the combination of all surveyed animal clades (amphibian, bird, lemur, non-lemur mammal, reptile), as well as for each clade separately. Given the conservation focus of lemurs in Madagascar, we analyzed and visualized lemur observations separately from other mammal species.

2.4. Demographic data

During knowledge exchange workshops, we received informed consent and recorded the age, education level, and gender of all CBM collaborators, and the genders of scientists (scientist ages and education levels were not extensively obtained). Here, "gender" refers to the socially-constructed identity of a person; although all collaborators in this study identified according to a binarized and static gender (man or woman), gender can be inclusive of a broader spectrum of identities and be dynamic over time. This set of demographic variables was chosen based on factors found to be important in explaining social dynamics, such as leadership networks in rural communities or political participation, and for explaining environmental knowledge and viewpoints (Kideghesho et al., 2007; Larson et al., 2016; Müller et al., 2015; O'brien et al., 2010; Willits and Luloff, 1995; Xu et al., 2010). Education levels were evaluated on an ordinal scale (no formal school = 1, primary school = 2, secondary school/college = 3), and for two-person teams, the education score was averaged (mean) across the two individuals' respective education levels. Age for two-person teams was also averaged. Given that gender cannot be easily averaged, we classified each team based upon whether there was a woman observer present or not. CBM collaborator teams with only one woman and no men, and scientist teams with two men, were excluded from analyses given low number of surveys performed by these team compositions (n = 2 and n = 7, respectively).

2.5. Agreement between CBM collaborator and scientist observations

CBM collaborators and scientists performed some surveys simultaneously (i.e. surveys performed by both parties at the same time and place) when travel logistics permitted. To confirm agreement between observations by CBM collaborators and scientists, we isolated simultaneous surveys from the database of observations (62 surveys of a total of 2917 surveys across the six parks). We then calculated the rates that CBM collaborators and scientists both observed a given species on the same survey (sensitivity), the rates that CBM collaborators and scientists both did not observe the species on the same survey (specificity), Cohen's kappa, and the true skill statistic (TSS) – accuracy metrics of binary rating observations that are frequently employed for validating species presence/absence data and species distribution models (Allouche et al., 2006; Cohen, 1960; Guisan and Thriller, 2005). Although for this analysis of agreement we evaluated observations by scientists as a more accurate standard relative to community member observations, we recognize that scientists are still fallible and may have imperfect detection of wildlife (MacKenzie et al., 2002). In some cases, CBM collaborators used a local name for an animal, rather than a Linnaean name. We used a linking key of local and Linnaean names to confirm species identification. "Misidentification" was when a CBM collaborator recorded a Linnaean name not recorded by the scientist surveying at the same time, or the CBM collaborator recorded a local name that did not align with any of the Linnaean names recorded by the scientist. "Missed species observation" refers to a discrepancy between the number of species observed between CBM collaborators and scientists.

For denoting species absences, only species that were found within a park at any time were accounted for; for example, if a simultaneous survey was performed by CBM collaborators and scientists in Ranomafana, only species found within Ranomafana yet not observed on that survey were considered absent, while species found only within other parks were not considered valid negative observations. This prevented inflation of true negative rates, as including species from all parks would have over-predicted CBM collaborator efficacy.

2.6. Mixed-effects modeling and linear regressions

We used Generalized Linear Mixed-effects Models (GLMMs) to explore the roles of demographic drivers on observer efficacy, given their common use in sociological and ecological studies (Tesema et al., 2021; Wang et al., 2017). GLMMs expand upon linear regressions to allow for link functions between the predictors and response, and to estimate separate intercepts for each random effect level. Average species richness observed per team per transect in each month served as the response variable with a Poisson distribution as the link function, and demographic variables were used as predictors. We interpreted observations of higher species richness as higher efficacy, given that in simultaneous surveys performed by CBM collaborators and scientists, rates of species misidentification by CBM collaborators were lower than rates of missed species observation by CBM collaborators (see results below). Summary statistics are provided in Tables A1–A3.

The first model ("model 1") – which included observations and demographics only of CBM collaborators – was fit to species richness data as a function of the average age, education (as an ordinal factor), gender, total number of visits performed by each monitoring team, and team size, with park as a random effect. A random effect is estimated with partial pooling, while a fixed effect is not, therefore the park in which data were collected was included as a random effect to group observations based upon the natural differences in park conditions without undermining statistical inference drawn from demographic traits (Liu et al., 2016). To control for possible regional differences across biomes, we also adapted this model to have the dominant biome (wet forest, dry forest, and transition forest) as a random effect, as well as a fixed effect, and also fit a model using community member observations just from Andohahela, the one park with women on community member teams.

In a second model ("model 2"), we examined the impacts of gender, team size, and total number of visits (all modeled as fixed effects) on the average number of species observed only by scientists, again with park as a random effect. As with model 1, we also fit model 2 first with biome as a random effect and second with biome as a fixed effect.

Additionally, to isolate the individual impacts of demographic variables on observed species richness, we performed two sets of univariate linear regressions, each with either average age or number of visits performed as predictors and observed species richness as the response, for all observations combined and for each park and taxonomic clade separately.

2.7. Software

All data processing and analyses were performed in R (version 4.0, R Core Team, 2021). The following R packages were employed during data curation and analysis: tidyverse (Wickham et al., 2019), lme4 (Bates et al., 2015), dplyr (Wickham et al., 2022), ggplot2 (Wickham, 2016), ggpubr (Kassambara, 2020), moonBook (Moon, 2015), terra (Hijmans, 2022), ggrepel (Slowikowski, 2021), broom (Robinson et al., 2022).

3. Results

3.1. Composition of observations and observer demographics

Overall, there were a total of 69,429 distinct animal observations by scientists and CBM collaborators across 24 months spanning 2917 surveys. These observations were of a total of 34 lemur species, 48 non-lemur mammal species, 221 bird species, 144 amphibian species, and 196 reptile species. There were 83 CBM collaborators (72 men, 11 women) and 27 scientists (8 men, 19 women). CBM collaborator ages ranged from 20 to 57, and most CBM collaborators had little to no formal schooling (no formal school = 12 %, primary school = 46 %, secondary school/college = 35 %; 7 % of CBM collaborators were excluded from demographic analyses due to missing education data). Although far fewer surveys were performed by CBM collaborator teams with women (n = 365) than by CBM collaborator teams with only men (n = 1969), CBM collaborator teams with women on average observed more species (μ = 11.56) than CBM collaborator teams with only men (μ = 7.99; Table A1). Scientists also consistently observed more species than CBM collaborators (Table A2).

3.2. CBM collaborator and scientist observation agreement

In simultaneous surveys performed by CBM collaborators and scientists, CBM collaborators had low sensitivity ($\bar{x}$ = 0.243), indicating that CBM collaborators did not record many species observed by scientists. Yet, CBM collaborators had high specificity ($\bar{x}$ = 0.912), indicating that CBM collaborators were unlikely to record observations of species that were not recorded by scientists, and unlikely to misidentify species they observed. Although average Cohen's kappa (0.154) and TSS (0.154) were both higher than 0, indicating better than random monitoring performance by CBM collaborators, these values were low relative to common thresholds for these metrics for applications in species distribution modeling (0.7 and 0.6, respectively; McPherson et al., 2004, Tooth and Ottenbacher, 2004), suggesting lower efficacy of CBM collaborators relative to scientists. However, the high specificity of CBM collaborators, and therefore low rates of species misidentification, confirms our expectation that average species richness observed by CBM collaborators can be used as a metric of efficacy, with higher observed species richness entailing more complete observation of the biological community.

3.3. Mixed-effects modeling and linear regressions

The GLMM examining demographics only among CBM collaborators (model 1) demonstrated that the presence of women on a monitoring team (β = 0.109, SE = 0.028) and team size (β = 0.212, SE = 0.008) significantly increased the number of species observed (Fig. 2, Tables A4–A5). Collaborator age, education, and total visits performed also had significant positive impacts on observed species richness, with the same findings when biome instead of park was used as a random effect (Table A5) and fixed effect (Table A6) except that education had a slight negative significant effect in the latter two models.

Our GLMM using only observations from scientists (model 2) showed that the presence of women on a monitoring team (β = 0.172, SE = 0.037) and team size (β = 0.550, SE = 0.114) significantly increased the number of species observed. The total number of visits had a non-significant, slight negative impact (β = −0.005, SE = 0.015) (Fig. 3, Tables A7–A9). Table A10 shows that the presence of women significantly increased the number of species observed when looking at Andohahela only (the one park with female CBM collaborators).

In each park, the mean age of a monitoring team had a positive correlation with the mean species richness observed per team, yet none of these correlations were statistically significant except for Isalo (Table A11). Across taxonomic clades, however, age had a positive correlation for every clade except lemurs (Table A12). Total number of visits performed by each monitoring team for all parks combined had a non-significant correlation with average species richness for community members (β = 0.234, SE = 1.005) and scientists (β = −0.603, SE = 1.196). In each park except Isalo, number of visits was positively (but non-significantly) correlated with average species richness for CBM collaborators (Table A13). Across taxonomic clades, there were positive correlations between total number of visits with species richness observed by CBM collaborators (Table A14), yet all of these correlations except for lemurs were non-significant.

4. Discussion

Our study examined the roles of collaborator demographics in

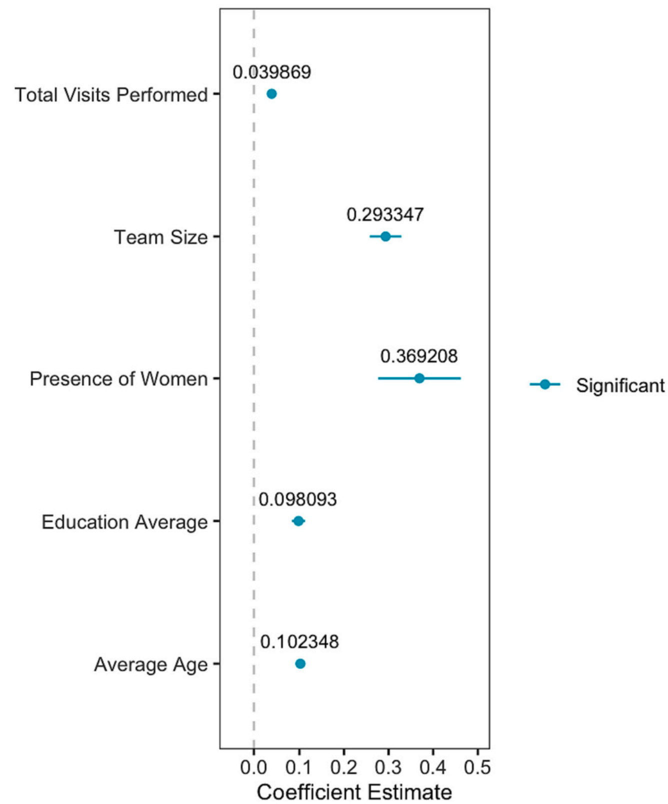

Fig. 2. Coefficient estimates for the effect of demographic and experience predictors on observed species richness corresponding to Model 1 (observations from CBM collaborators only), including the total visits performed by a team, the team size (one or two members), presence or absence of a woman on the team, average education level of team members, and average age of team members. The horizontal lines show standard errors for each predictor; all points have error bars, but some error bars are too slim to be seen. All covariates had statistically significant effects on the number of species observed by a team (i.e. 95 % confidence intervals of the coefficient estimate did not cross zero), with the presence of a woman having the highest positive impact on observed species richness.

shaping biodiversity monitoring efficacy to inform protected area management in the rural and biodiverse Southern Madagascar. Our mixed-effects modeling indicated that monitoring teams with women, and more experienced monitoring teams, tended to observe more species, while age and level of formal education had smaller, positive effects on observed species richness. Synthesizing our results with past research on community engagement, we argue that community-based monitoring (CBM) that incorporates diverse demographics and perspectives may not just enhance monitoring efficacy, but also contribute to more equitable conservation decision making and professional development of local community members.

4.1. Gender roles in wildlife monitoring

We found that monitoring teams with women saw more wildlife species than male-only teams, for both CBM collaborators and scientists (Fig. 4). Given that only one of the parks (Andohahela) had female CBM collaborators, we have limited inference on the role of gender identity in local community member involvement in wildlife monitoring programs. However, our finding of higher efficacy by female scientists was robust across all parks. We hypothesized that men would observe greater species richness, as traditional gender norms in some Malagasy communities reinforce the man's role as the family breadwinner, requiring more time spent in forested areas to extract resources (Moreira et al., 2017). Additionally, collecting forest resources is an important aspect of

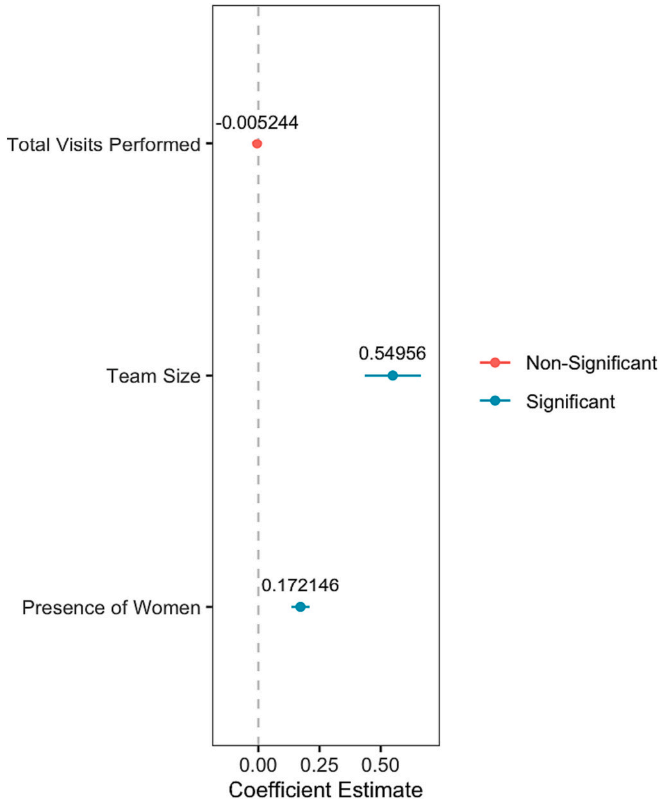

Fig. 3. Coefficient estimates for the effect of demographic and experience predictors on observed species richness corresponding to Model 2 (observations from scientists only), including total visits performed by a team, team size (one or two members), and presence or absence of a woman. Horizontal lines show standard errors for each predictor (note: error bar for visits performed is too slim to be seen). Covariates of team size and presence of a woman had statistically significant effects on the number of species observed by a team (i.e. 95 % confidence intervals of the coefficient estimate did not cross zero).

traditional masculinity in Madagascar, so much so that in interviews conducted by Järvilehto (2005), women voiced opinions that forests were intended for men and were hesitant to discuss it. Some Malagasy women also have voiced concern that they are more likely to be caught extracting resources than are men when laws limiting resource extraction are in place (Razafindratsima and Dunham, 2015). These findings may suggest that men have more exposure to forest wildlife, and are more comfortable in protected forests.

However, we found that men did not outperform women at biodiversity monitoring. This insight could be due to differences in how men and women value wildlife and conservation (Larson et al., 2016; Liordos et al., 2021). Although for some Malagasy communities the forest is important for men in terms of their own identity, women perceive the forest as important to the environment (Järvilehto, 2005). Women may therefore be more attentive to forest species, rather than focus on their place in the forest. Given conventional gender roles in Southern Madagascar, another plausible explanation for higher efficacy of teams with women is that women were more motivated to succeed than men, when provided such an opportunity to partake in conservation. Women in Madagascar typically are responsible for domestic tasks (Douglass et al., 2019; Järvilehto, 2005; Lawson and Lahiri-Dutt, 2020), and are less involved in the labor market (Nordman and Roubaud, 2009); they may have worked harder to monitor species to gain social and economic mobility.

The increased efficacy of monitoring teams with women indicates that women should be more consistently included in CBM, especially for conservation programs that can provide them with unique professional development. Given social divides in responsibilities and experiences between genders, women can provide unique perspectives and knowledge in CBM programs. Long-term success of conservation initiatives will be most feasible if all resource users are integrated in an equitable manner (Duffy et al., 2021; Razafindratsima and Dunham, 2015).

4.2. *The impact of age on monitoring species richness*

Our results support our hypothesis that older collaborators would see higher species richness. Fifty-two year old collaborators observed the most species ($\mu = 16.7$ species per visit) - more than collaborators under 30 years old ($\mu = 10.5$ species per visit). Older individuals, who have had more time to learn “indigenous ways of living in nature” (Aikenhead and Ogawa, 2007), may be more adept at species recognition. It is likely that most members of the rural communities surrounding these parks have lived there for an extended period of time, if not their whole lives; much of the migration in Madagascar is to the capital of Antananarivo in search of employment opportunities (Rakotonirina and Cheng, 2015), or from the south to the north for better agricultural production (Ghimire, 1994), rather than migration between rural communities. Older individuals who remain in Southern Madagascar are likely to have grown up in the same or nearby communities, leading to lifelong exposure to their local ecosystems.

CBM projects could be improved by including older community members, thereby incorporating accrued local knowledge (Byg and Balslev, 2001). However, the positive correlation between age and species richness did not hold true for all taxonomic groups, as older CBM collaborators observed fewer lemur species than younger collaborators. As some people age, they become more sensitive to noise and therefore may hear more sounds in their surroundings than younger counterparts (Herrmann et al., 2018). Older members may therefore have been better at locating animals based on sounds (such as birds and amphibians), and less adept at using eyesight (such as spotting lemurs). However more research is needed to investigate underlying mechanisms for how age shapes wildlife monitoring efficacy.

4.3. *How experience affects observed species richness*

As expected, scientists saw a higher number of species than CBM collaborators. Because the scientists had extensive ecological training, it is intuitive that they would be more adept at biodiversity monitoring than CBM collaborators who had not conducted monitoring on a frequent, professional basis prior to this project. Those without academic training, due to their comparatively lower familiarity with Linnaean organization of taxonomy, have been shown to “lump” species together, thus decreasing observed species richness (Oldekop et al., 2011). Despite recording fewer species, we believe the benefits of local collaboration (see Section 4.4 for benefit details) are still valuable and that, with practice, this scientist-community member efficacy gap can be closed. Additionally, local community members may have more intimate familiarity with their local ecosystems than do visiting scientists, and may record anecdotal observations that visitors may not recognize (e.g. occurrences of some species in novel locations or habitats, river water levels relative to historic conditions, or damaged/logged vegetation).

Our study also indicated that more surveying practice for CBM collaborators increases observed species richness, suggesting that practice benefits CBM collaborators. To increase retention of CBM collaborators, and thereby increase monitoring practice, a variety of incentives could be offered, such as monetary compensation (as was done in our study), food, or ensuring rights to resources and/or land (Beyene, 2015). Additionally, the majority of CBM teams had two members; these teams performed far better than those with one member. Future CBM projects should take optimal team size into consideration when designing monitoring projects; pairing community members together may increase monitoring efficacy especially when collaborators are new to a program, and may also make the experience more social and enjoyable.

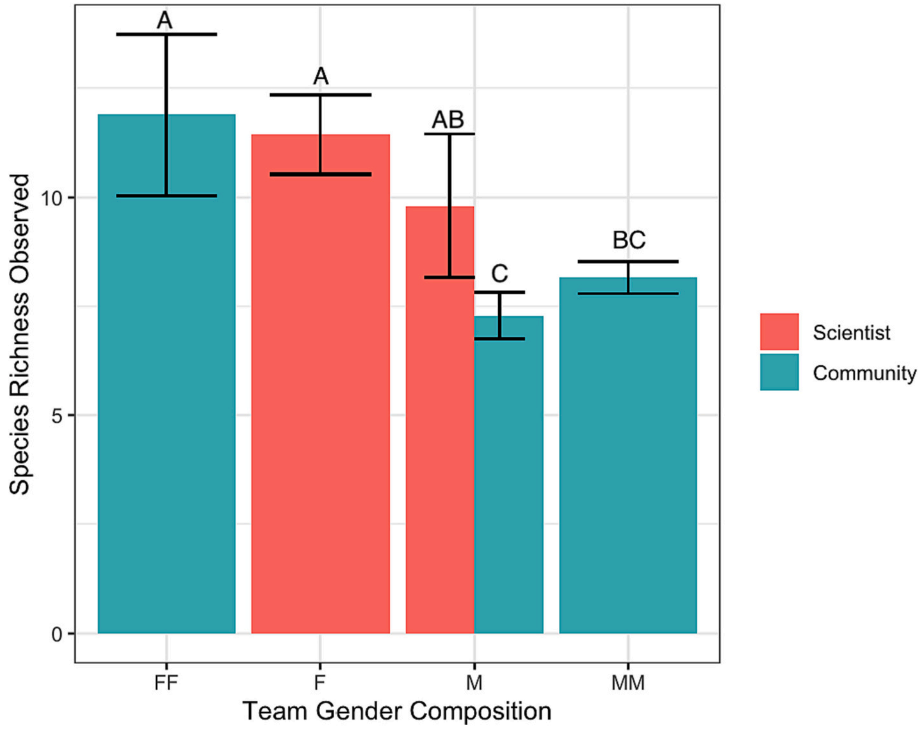

Fig. 4. Relationship between gender and observed species richness, for scientists and CBM collaborator teams separately. "F" and "M" refer to female and male collaborators on a survey team, with combinations of either one- or two-person teams presented. Black uncertainty bars indicate 95 % confidence intervals of their means, and letters above bars indicate which groups had overlapping 95 % confidence intervals.

The average level of formal education of a monitoring team had a small positive impact on observed species richness in our community member-only GLMM (model 1). It should be noted that education levels varied greatly across parks. However in our other formulations of model 1 (with biome as a fixed or random effect, rather than PA; Tables A4–A5), the effect of formal education on monitoring ability was negative, thereby making the correlation between education and monitoring ability inconsistent across models. We expected that the level of formal education would positively correlate with monitoring ability, as education helps improve identification and critical thinking skills, both of which are necessary for biodiversity monitoring (Pascarella et al., 2014). However, despite ongoing efforts, environmental education is often still lacking from curricula in Madagascar (Richter et al., 2015). The inconsistent impact of formal education on monitoring ability indicates that collaboration in community-based monitoring should not be restricted to formally educated individuals; all collaborators may have the capacity to monitor effectively, regardless of access to education. Furthermore, it suggests that conservationists and park managers may benefit from valuing both formal education and local knowledge when hiring or organizing committees and workshops to initiate CBM programs.

4.4. Benefits of CBM for local communities, environments, and land managers

Engaging with community members to monitor biodiversity has been successful in many conservation implementations (Bernedo Del Carpio et al., 2021; Bonney, 2021; Chandler et al., 2017). Employing community surveyors can benefit the communities themselves through increased knowledge and appreciation of the ecosystem. CBM programs have been shown to encourage "protective actions" within communities, due to increased awareness, enthusiasm, and scientific literacy (Conrad and Hilchey, 2011). By including community members, who are often the most directly impacted by local environmental changes, in natural resource monitoring, the socio-ecological system itself becomes more resilient as community members come to be more empowered to conserve such ecosystems (Fernandez-Gimenez et al., 2008).

Additionally, inclusive CBM can grant community members with more power in the land management decision-making process, as has been shown by the collaboration between the Village Council (comprised of local community members) and the District Forest Office over resource use in Iringa District, Tanzania (Fernandez-Gimenez et al., 2008; Topp-Jørgensen et al., 2004). Here, the Village Council approves all monitoring reports from the District Forest office, increasing trust and transparency. Land managers also benefit from the inputs of community members by gaining a clearer understanding of the state of ecosystems and of conservation goals. This collaboration has the potential to change ecological and social assumptions and foster a better relationship between land managers and the communities (Bernedo Del Carpio et al., 2021; Fernandez-Gimenez et al., 2008). Relative to land management programs that place all decision-making power in the hands of national or foreign institutions, community involvement in environmental monitoring can help "democratize" the environment by facilitating exposure of a larger set of local individuals to it, which provides more decision-making privilege and ownership to a broader set of stakeholders and facilitates information exchange between external scientists and community members (Conrad and Hilchey, 2011). Such exchange de-links the production of knowledge from colonial institutions: knowledge accepted as "true" is no longer considered to be generated only from Western academies, corporations and states, but also from the local people on which these studies are centered (Mignolo, 2007).

Yet involving communities in such projects does not necessarily entail "co-management," as collaborations with conservation authorities and communities can heighten power imbalances between these groups (Kepe et al., 2005). Elevating voices of local communities in a web of coloniality is insufficient for the transformation of science. If authentic co-management is absent, CBM projects are in danger of purely focusing on land preservation without regard for the relationships between local people and the lands being preserved. Known as "fortress conservation," this only serves to amplify problems such as poverty and deforestation (Rudd et al., 2021). A more foundational shift entails engagement between local communities and park authorities at all stages of project design, implementation, and evaluation (Scales, 2014).

Our project involved free training to CBM collaborators on wildlife observation and identification, which provided concrete skills to community members that improved project implementation and increased future career prospects as ecotourism guides or park rangers. In turn, external Malagasy scientists gained a greater understanding of local knowledge and perceptions of the parks. Additionally, our project facilitated knowledge transfer and open communication between CBM collaborators, as well as between the communities and MNP. After the project, park managers returned to communities to present the results of observations and solicited input from community members on future actions, and this process remains ongoing at present.

Given the high costs of travel and compensation for scientists and rangers, employing CBM collaborators can also be an economic benefit to protected area managers, as was the case for MNP. Due to a lack of continuous sampling and insufficient personnel - problems facing protected areas globally (Appleton et al., 2022) - training community members to assist in monitoring (with proper compensation) can be cost-efficient for park management, allow personnel to focus more intensively on data analysis and public communication, and provide an alternative source of income for community members. Cost-benefit analyses that are strictly financial can, however, overlook intangible yet critical gains from increased cooperation between park managers and communities. For example, when community members are more informed on scientific terminology and standardized monitoring, and when park managers are more familiar with local vernacular, all parties come to use a common vocabulary, helping facilitate communications and identify mutual goals. This is a critical step towards creating spaces that welcome a wide array of backgrounds and demographics to decision-making.

4.5. Improving studies of CBM collaborator diversity

To further study the relationship between demographics and monitoring ability, it would be beneficial to collect a broader set of demographic variables. Collecting information about income and wealth before and after project implementation would provide socioeconomic context and can be used to measure how a CBM project promotes economic mobility (Blake et al., 2020). Collecting demographic information on marital status, household size, and socioeconomic status may indicate an individual's level of power and social capital within a community (Xu et al., 2010), to help understand how CBM involvement may change social capital. Furthermore, in our study only one park (Andohahela) had female CBM collaborators. By recruiting more women to perform CBM surveys, we can gain a better understanding of how gender impacts wildlife monitoring (and increase the inclusivity of the CBM program). Additionally, the limited temporal duration of this study (2019–2020) makes it difficult to gain a comprehensive understanding of the roles of demographics in monitoring efficacy (Şekercioğlu, 2012). Lastly, measuring vision or hearing level of collaborators could help estimate less-than-perfect detection of species (Pollock et al., 2002).

It should be noted that in biologically and culturally diverse nations such as Madagascar, environmental and social differences may exist between parks (Baker et al., 2013; Kottak, 1971; Waeber et al., 2020), shaping wildlife monitoring success. For example, it may be easier to identify species through the thinner vegetation of dry forests relative to wet forests (Sussman and Rakotozafy, 1994). Although our reported trends hold across parks, we encourage further research into the relationship between geographic location and demographic impact on biodiversity monitoring ability.

5. Conclusions

We explored how demographics and amount of monitoring experience impacted efficacy at observing animal biodiversity across six biologically rich protected areas in southern Madagascar. Understanding the correlation between traits of CBM collaborators and monitoring abilities can help improve monitoring projects so that park managers can more effectively, inclusively, and economically conserve biodiversity in collaboration with (and ideally led by) local communities. We found that including women in CBM significantly increased observed species richness, and (to a lesser degree) older and more experienced CBM collaborators also observed more species. Our study demonstrates that including a diversity of demographics increases monitoring success, suggesting that CBM projects should be opened up to community members willing to learn and practice wildlife observation skills. Emphasizing diversity when selecting CBM teams has the added benefit of incorporating underrepresented perspectives in conservation efforts, many of which are from those most impacted by environmental changes. Ultimately, CBM provides many benefits to local communities and park managers, such as education, empowerment, and equity, all of which will lend greater resilience to monitoring efforts.

CRediT authorship contribution statement

Fiona Price: Conceptualization, Formal Analysis, Visualization, Roles/Writing – original draft.

Lalatiana Randriamiharisoa: Project administration, Conceptualization, Methodology, Investigation, Data Curation, Funding acquisition, Writing – review and editing.

David H. Klinges: Conceptualization, Methodology, Data Curation, Formal Analysis, Visualization, Roles/Writing – original draft, Writing – review and editing, Supervision.

Declaration of competing interest

The authors have no conflicts of interest to report.

Data availability

Data are available at the following Zenodo DOI: 10.5281/zenodo.10051226

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.110377.

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