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Research

Community-sourced knowledge improves biodiversity monitoring in Madagascar's National Parks

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Abstract
Local community members can contribute to biodiversity conservation, especially for rural yet critically biodiverse locations such as in Southern Madagascar. While collaborations with local communities were initiated by Madagascar National Parks (MNP) in 1996 to build local support for protected area management, such community-based approaches to monitoring biodiversity were underdeveloped, and to date their efficacy has not been studied. The objective of our study was to develop community-based monitoring of vertebrate biodiversity within six protected areas in Madagascar, and to assess whether the data recorded by local communities can be used for the monitoring of protected areas spanning dry to wet tropical rainforest ecosystems. We implemented a training program for each local community and validated community observations via surveys performed by professional scientists with taxonomic expertise. Across two years of surveys and six protected areas, scientists observed more species per survey (9.04) than community members (6.09). Yet collectively, community members observed more species (373) than scientists (354). Furthermore via multivariate modeling, we found that whether a biodiversity monitoring team was composed of scientists or community members had a non-significant effect on the number of species observed, which was more sensitive to the vegetation and climate of a location. Our study suggests that for biodiversity monitoring in Madagascar, professional scientists are likely more efficient, yet with sufficient survey effort, local community members can provide comparable estimates of species richness. We discuss the benefits and limits of incorporating community-based monitoring into surveys of vertebrate biodiversity in speciose tropical systems.

1 Introduction

Local knowledge systems, including the sophisticated sets of ecological knowledge and management practices generated by different communities, are a core component of socioecological systems [1]. Local knowledge systems have traditionally guided many interactions between humans and nature, disrupting or maintaining the integrity of aquatic and terrestrial ecosystems [2]. Given that some local communities play important roles in interacting with or managing biodiverse protected areas [3–5], local communities can impact conservation success and sustainability. Community-based monitoring (CBM),

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which integrates local communities and their goals into the monitoring of natural resources, can serve as an effective strategy to develop cost-effective and scalable methods of collecting reliable data in protected areas of high conservation value [6–9].

CBM can be an effective approach to systematically survey wildlife populations across large expanses or for long durations at a lower cost than the expenses necessary for professional researchers to do the same [10, 11]. Integrating community members into data collection can also lead to increased citizen engagement in conservation practices as well [12]. However, the quality of data collected via CBM may be poor or unreliable as compared to observations made by professional scientists [13]. Furthermore, even where efforts to integrate CBM into wildlife surveys have been successful, most such projects have occurred at temperate latitudes, with an emphasis on just a few target species and lacking the representation of diverse regions [10, 14]. Yet global initiatives, such as the Millennium Ecosystem Assessment, The Economics of Ecosystems and Biodiversity, and, more recently, the Intergovernmental Panel on Biodiversity and Ecosystem Services, have highlighted the importance of CBM for connecting humans with their natural environment, especially in biodiverse tropical regions [15].

Madagascar is a global hotspot of biodiversity [16, 17], with exceptionally high species diversity and levels of endemism in all major taxonomic groups [18]. Ecosystems across Madagascar are under continued pressure from human extractive activities such as slash-and-burn agriculture, given that most of the country's inhabitants are rural and poverty-stricken [19, 20]. The combination of biological richness and high percentages of degraded habitat makes Madagascar one of the highest priority regions globally for conservation and restoration [21–23], and much attention has been paid to determine effective approaches towards monitoring and reducing biodiversity loss across the island nation [16]. However, surveillance of many of the island's key biodiversity areas by professional scientists can be difficult or expensive, given that most of the island nation is difficult to access from major cities, roads or airports. For the same reasons, submissions to globally-extensive databases of citizen science observations—such as iNaturalist and eBird—are sparse across the island, and are insufficient for monitoring temporal population trends. Given that most protected areas have local communities living near them with extensive exposure to natural habitats, and that these habitats span a diverse ecosystem gradient from wet tropical rainforests in the East to dry savannas and spiny deserts in the West, Madagascar serves as an interesting testing ground for determining the utility of CBM in biologically diverse tropical regions.

In Madagascar, forests that are collaboratively managed with local communities are among the last remaining forests in Madagascar [24]. Collaborative conservation with communities has been in place for decades in Madagascar [25, 26] and the contribution of local communities to natural resource management has been promoted as one possibility to contribute to sustainable resource provisioning and to biodiversity conservation [24]. Madagascar National Parks (MNP), a Malagasy association under the supervision of the Ministry of the Environment and Sustainable Development that manages 2 million hectares across a network of 43 Protected Areas and special reserves, has a mission to establish, conserve and manage protected areas in a sustainable manner. Between 1996 and 1997, MNP initiated collaborations with local communities surrounding protected areas that continue to this day. Historically, these interactions were limited only to hiring community members to accompany park rangers on patrols, to raise environmental awareness, or to be used as temporary contractors to build conservation infrastructure. Although such collaborations have occurred throughout Madagascar for decades, a CBM program for monitoring biodiversity has not been deployed at a large scale.

Our study integrates community based monitoring (CBM) into Madagascar National Parks data collection in an extensive and systematic fashion, using a multi-taxonomic approach to better understand how biodiversity changes from wet to dry habitats in Madagascar. Here, we assess whether data recorded by local communities are accurate enough to be used for the management of protected areas. We provided standardized training on the identification of terrestrial vertebrates to community members, and demonstrate that after a short amount of training community members are able to find and correctly identify wildlife at a level of taxonomic accuracy that, when measured in aggregate across team members and surveys, is comparable to observations by taxonomic experts. We discuss the advantages and trade-offs in integrating community-based monitoring of biodiversity across a range of tropical ecosystems.

2 Methods

2.1 Study site

The study sites are within the protected areas network managed by Madagascar National Parks (MNP), and represent the high diversity of ecosystems and wildlife present throughout Madagascar, including both the island's wettest and driest regions (Fig. 1). These include two parks in rainforest (Ranomafana and Andringitra national parks), two in transitional forest between rainforest and dry forest (Isalo and Andohahela national parks) and two parks in dry forest (Tsimanampesotsa national park and Beza Mahafaly special reserve). Importantly, these sites all suffer from slash-and-burn agricultural practices thus necessitating consistent monitoring not just of wildlife but of all natural resource degradation within these areas. This study benefits from an existing community-based program called "Local communities of parks", which funds partnerships between MNP and CBM local collaborators for activities such as patrols for illegal resource extraction, wildlife surveillance, and construction in each protected area. For this project, MNP staff engaged with CBM organizations from 4 to 11 villages surrounding each park to solicit their interest in engaging in a new biodiversity monitoring program. Each village that agreed to collaborate chose their own project collaborators with the sole requirement being literacy. Community members were compensated for their collaboration on a daily basis.

2.2 Training on biological identification

For this study, we focused upon identification of terrestrial vertebrate fauna—mammals, birds, reptiles, and amphibians—as these taxa are of the highest conservation interest for management by MNP. In a series of knowledge exchange workshops, we cooperated with community members to associate local dialect names of wildlife to Linnaean taxonomy, and collectively decided upon ideal locations for biodiversity monitoring based upon local knowledge of wildlife locations. For each park, we established a guidebook comprised of photos for each species. Multiple photos were included to differentiate male, female, and/or juvenile characteristics when appropriate. An important component of training was to standardize local vernacular names of species with scientific nomenclature. For this, we provided photographs of organisms to community participants, and asked for the name of this organism in the local dialect. After compiling the list of local names for organisms, we then provided participants with the scientific name corresponding to each local name. In some cases, MNP staff had to create new vernacular names for several species that all had the same local vernacular name. The training was performed in three to five sessions over the course of three to five days depending on the number of species in the park, and is also further described in Price et al. [27].

2.3 Training on biological monitoring

After identification training, standardized transect methods were used to collect data on birds, mammals, reptiles and amphibians. For each protected area, we established between six and eight transects, each situated in locations that represented environmental conditions for the protected area, and also based upon known home ranges of lemurs (which are a high conservation priority). We chose line transect methods, as these would be easily communicable to a broad community member audience. For monitoring birds, ten-minute point counts were conducted, with ten point count locations per transect [28]. Based upon our prior avian monitoring experience in these regions, we estimated that surveyors would be able to detect birds within a 25 m diameter; coupled with 100 m spacing between the detection limits of point count locations as recommended by standard texts [28], this entailed the ten point count locations were spaced 125 m apart, for a total transect length of 1250 m. For mammals and reptiles, we used continuous visual encounter surveys (rather than discrete point counts) along the full extent of the same 1250 m transects as bird surveys. An additional two 500 m transects were established near bodies of water, specifically to monitor locations of high amphibian abundance and richness for the six protected areas.

During training, MNP staff explained the importance of standardized observation to community participants, and guided participants on conventions of effective naturalism and biological monitoring. Training occurred over five to seven days, and involved community members and other agents of protected areas. This included teaching of standardized data recording, start and end times of surveys, best practices for searching for animals of different taxa, and identifying animals to the species level. Over two separate days, community members then performed surveys at the same transect simultaneously with professional scientists, to simultaneously yet independently perform a trial survey to verify species encountered by community members. Scientists were experts for each major taxonomic group, and were all graduate-level students at the University of Antananarivo. Community members and professional scientists walked silently alongside each other on a transect and recorded all species they observed. If a community member 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 community

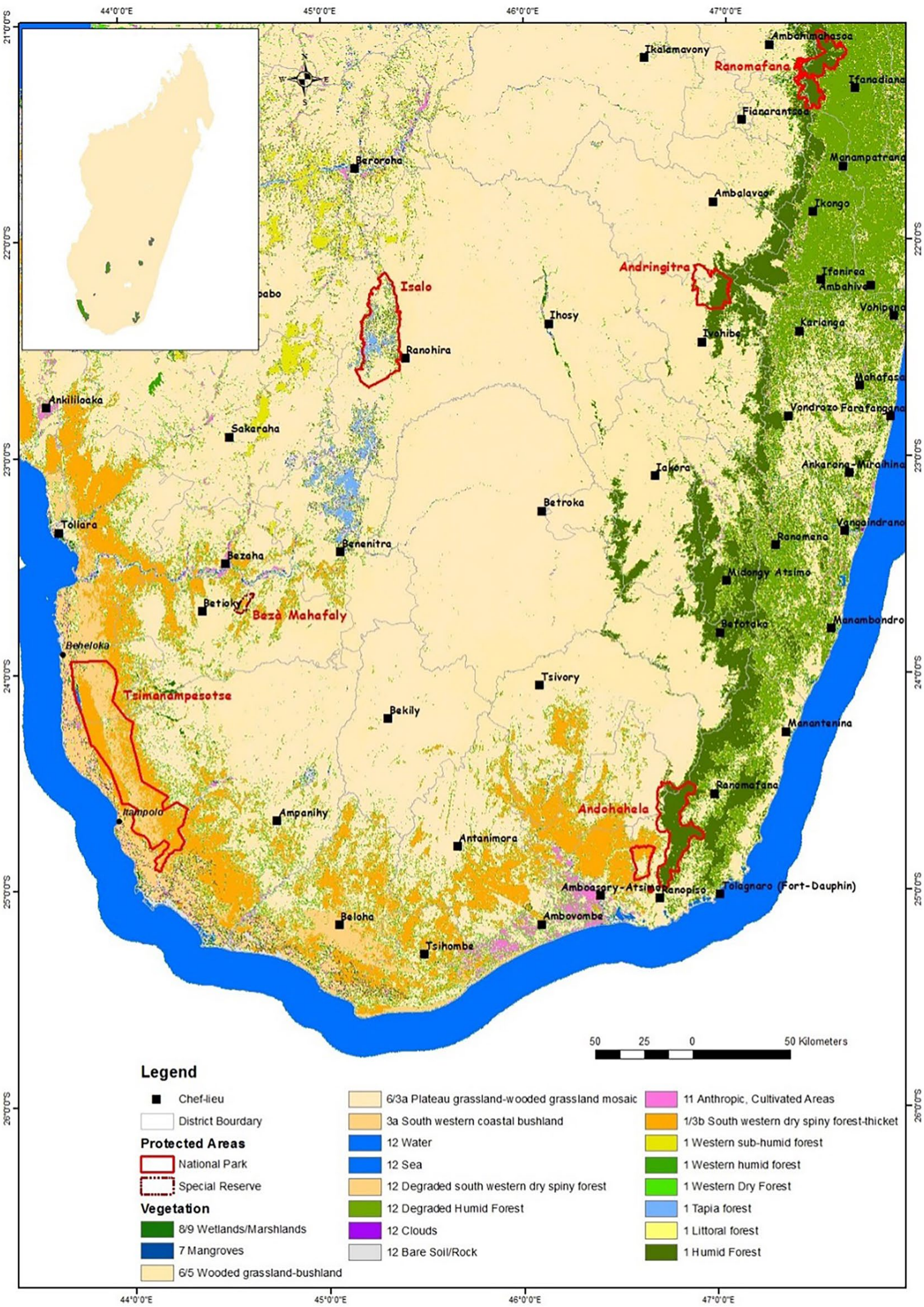

Fig. 1 Map of Southern Madagascar highlighting the protected areas monitored in this survey, representing wet, transitional, and dry forest ecosystems

members, yet we also performed further analytical steps to ensure there was concurrence between observations by community members and observations by scientists (see *Community Member and Scientist Observation Agreement*).

2.4 Data collection

Community members collected biodiversity data in teams of two people, while scientists performed surveys in teams of either one or two participants. Given that the collective performance of community members relative to the collective performance of scientists is the primary focus of this manuscript, rather than examining contributions of individuals or of the effect of team size, we explored biodiversity observations by each team rather than each individual. Each team recorded the number of individuals of birds, mammals, reptiles and amphibians that they observed, from which we quantified per-survey observations of species richness. Community participants performed two surveys monthly for 2 years following the standard survey protocols, and scientists performed surveys twice annually for two years.

2.5 Collection of vegetation and climate data

We also monitored vegetation and climate across all parks, to explore how such known drivers of biodiversity gradients influence observed species abundance and richness, relative to the influence of team composition (CBM collaborator or scientist) on observed species abundance and richness. Vegetation data were collected from January 17, 2019 to July 28, 2020 for the same survey transects as fauna. Ten point counts spaced 125 m apart were used for vegetation data collection. At each point count, we placed a 10 × 10 m quadrat to inventory all tree species. We recorded the diameter at breast height (DBH) and height of each tree using a Leica laser clinometer. Canopy cover was characterized at each point count by using a convex spherical type A densiometer (Forestry Suppliers Inc., Jackson, Mississippi) at the four corners of the quadrat. We then calculated the average DBH, height and canopy cover per point count and per transect.

Temperature and relative humidity measurements were recorded using Onset HOBO U24 Pro v2 sensor and logger devices. For each protected area, we placed one logger below closed-canopy forests within each protected area. We then calculated the annual range of temperature and relative humidity for each protected area.

2.6 Data processing

To compare the differences in observations between CBMs and scientists, we aggregated observational data per survey into two primary variables of interest: the species richness observed by each monitoring team at each transect, and the abundance of each species observed by each team. For analyses of abundance, we added zeros for all species that were not observed by a survey team at a given transect, but were observed by any team within the same park.

2.7 Community member and scientist observation agreement

We also quantified the agreement between biodiversity observations made by community members and scientists– an analysis that is described in Price et al. [27], but described here as well given that we provide further interpretation in this manuscript. Beyond the initial training period, community members and external scientists performed some surveys simultaneously (i.e. surveys performed by both parties along the same transect at the same time on the same day) when travel logistics would allow for this. To further confirm agreement between observations by community members and external scientists, we isolated such simultaneous surveys from the database of observations (62 surveys of a total of 2917 surveys across the six protected areas). For each species within each protected area, we then calculated the true positive rates (sensitivity), true negative rates (specificity), false positive rates, false negative rates, 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 [29, 30]. A positive observation by a community member for a given species was evaluated as a true positive when a scientist observed the species during the same simultaneous survey, and a negative observation by a community member for a given species was evaluated as a true negative when a scientist also did not observe that species during the same simultaneous survey. For denoting negative observations (species absences), only species that were found within a protected area at any time were accounted for– meaning, if a simultaneous survey was performed by community members and scientists in Ranomafana, only species found within Ranomafana yet not observed on that survey were considered absent, while species found only within other protected areas were not considered valid negative observations. This prevented inflation of true negative rates, as including species from all protected areas would have over-predicted community member performance.

2.8 Species richness and abundances observed by community members and scientists

Given that community member and scientist teams did not perform monitoring at the same place at the same time, observations from different teams needed to be grouped based upon spatiotemporal representation. Therefore we grouped observations of species richness and abundance by the same team, within the same month and year, and at the same transect within a protected area. We also grouped observations separately for each taxonomic clade of interest (amphibians, birds, mammals, reptiles).

We conducted Mann-Whitney tests (i.e. two-sample Wilcoxon test) to compare the number of species observed per survey by community members versus scientists. We conducted Mann-Whitney tests first using observations of all taxonomic clades combined, and also using observations of each clade separately. Tests that indicated a significant two-sided difference (i.e. either a significantly positive or negative difference in μ between community members versus scientists) were then followed with one-sample tests to determine the direction of the effect (e.g., whether community members observed significantly fewer species than scientists).

We then employed multivariate modeling to explore the contribution of observer-level, site-level, and temporal factors in explaining variation in monitoring. To do this, we constructed generalized linear models (GLMs) with one of two response variables: observed species richness per team per survey, and total abundance for each taxonomic clade per team per survey. Each of these response variables was assumed to be drawn from a Poisson distribution, given that these variables are positive integer counts and the mean was similar to the variance, and both richness and abundance datasets had better fit to Poisson distributions than to normal or uniform distributions according to chi-squared goodness of fit tests [31]. For environmental and climatic covariates we used transect averages of tree canopy height, transect averages of canopy cover, and annual ranges in temperature and relative humidity, all of which were included due to their known roles as drivers of biodiversity [32]. We also included as temporal covariates the month of observation (to capture temporal changes in wildlife abundance and richness largely due to seasonality of precipitation) and year of observation (to quantify possible improvements over time from 2019 to 2020). We also included monitoring team composition (scientist vs. community teams) as a fixed effect. Finally, we included an interaction term between year and monitoring team composition (community member vs. scientist), to determine if the magnitude of changes over years differed between community members and scientists. GLMs were fitted using all vertebrate observations collectively as well as separate models for each taxonomic clade.

3 Results

3.1 Community member and scientist observation agreement

We employed 83 community members and 27 professional scientists in this study. In simultaneous surveys performed by community member and scientist teams, community members were likely to miss species observed by scientists indicated by low true positive rates ($\bar{x} = 0.243$). Yet, community members also had high true negative rates ($\bar{x} = 0.912$), indicating that they 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 performance by community members, these values were low relative to common thresholds for these metrics for applications in species distribution modeling (0.7 and 0.6, respectively; [33, 34]), suggesting lower performance of community members relative to scientists given low true positive rates. However, the high true negative rates of community members, and therefore low rates of species misidentification, confirms our expectation that average species richness observed by community members can be used as a metric of performance, with increasing observed species richness entailing more complete observation of the biological community.

3.2 Species richness and abundances observed by community members and scientists

Collectively over the two years of monitoring, community members observed a total of 373 species, while scientists observed a total of 357 species. In addition, 99 species in total were observed by community members and never observed by scientists, while 83 species were observed by scientists and never observed by community members. Species richness observed by community members and scientists varied considerably across parks and taxonomic clades (Fig. 2).

Community members conducted surveys approximately six times more frequently than scientists, yet they observed fewer species than scientists per survey. On average across parks and taxonomic clades, community members observed 6.09 species per visit, while scientists observed 9.04 species per visit. These rates of species observed per visit varied across parks and taxonomic clades (Fig. 3). The Mann–Whitney test of observations of all taxonomic clades combined did not indicate a significant difference in the per-visit species richness observed by community members versus richness observed by scientists across all parks and taxonomic clades ($W=67{,}746$, $P=0.0959$). However for tests of observations for each taxonomic clade separately, one-sided Mann–Whitney tests indicated that per visit, scientists observed significantly more birds than community members ($W=1847.5$, $P<0.0001$) and significantly more reptiles than community members ($W=5964.5$, $P=0.0412$), yet there was no significant difference in amphibians ($W=1186$, $P=0.713$) or mammals ($W=5350.5$, $P=0.249$) observed per visit between scientists and community members.

GLMs, which account for sampling effort and environmental and climatic variation, did not indicate a significant difference in species richness observed by scientists versus community members (Tables S1, S2, S4, S5) with the exception of birds, for which scientists observed more species (Table S3). However, on average scientists observed higher per-species abundance than community members, and this held across all taxonomic clades (Tables S6–S10). For both community members and scientists, GLMs indicated that the number of species observed increased from 2019 to 2020 (Table S1). Although there was no apparent interaction between team composition and year (Table S1), the positive effect over time was of greater magnitude for scientists ($\beta=0.20$, $SE=0.042$) than for community members ($\beta=0.092$, $SE=0.021$). Yet this trend was the opposite for changes in observed abundance over time: observed abundance was lower in 2020 relative to 2019 (Table S6), and this decrease was stronger for scientists ($\beta=-2.79$, $SE=0.015$) than community members

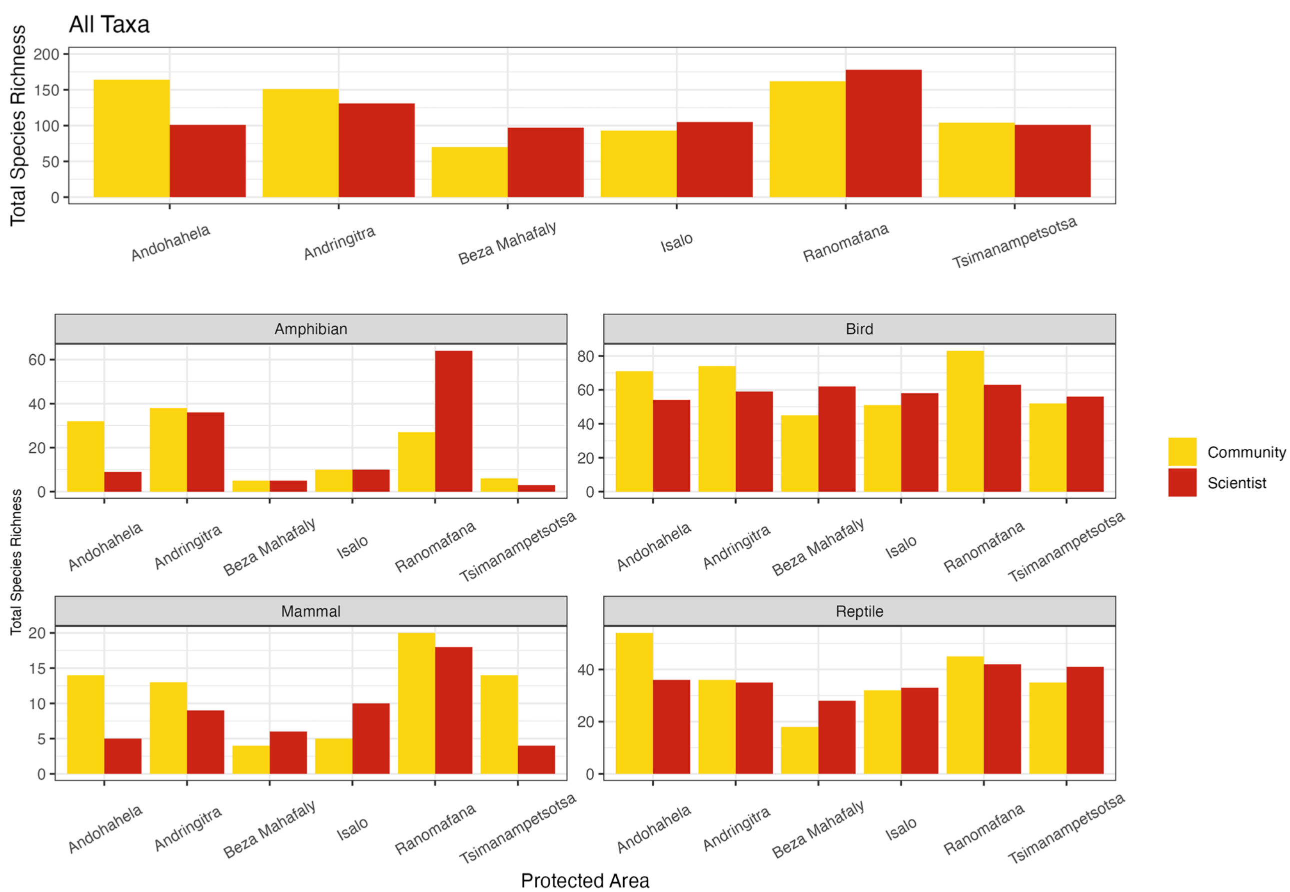

Fig. 2 The total species observed, across all visits, by community members and scientists, for each protected area (x-axis labels) and taxonomic clade (panels) separately. Community members observed higher cumulative species richness than scientists for most protected areas, but community members also conducted surveys 6.12 times as frequently as scientists

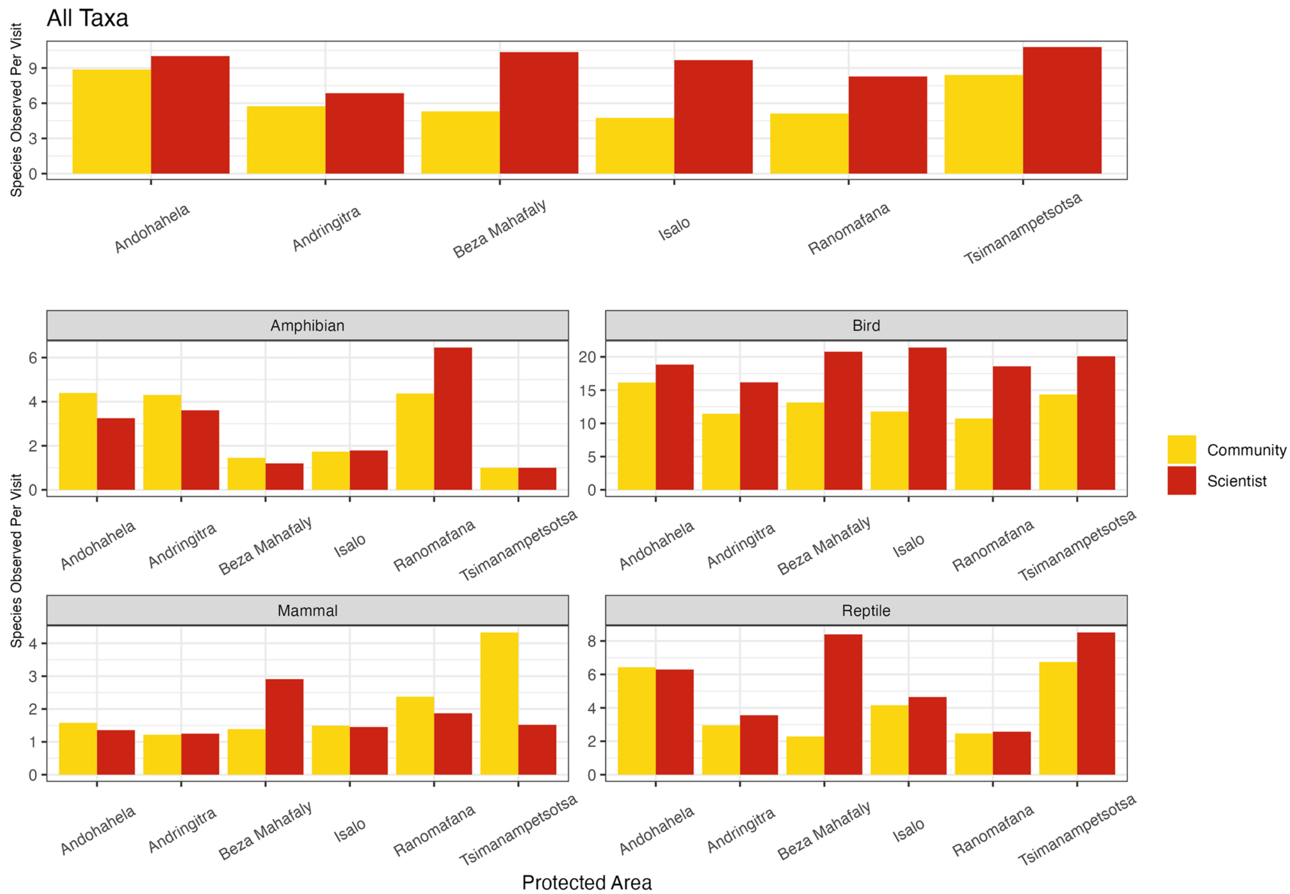

Fig. 3 The average number of species observed per visit by community members and scientists, for each protected area (x-axis labels) and taxonomic clade (bottom four panels) separately, and with all taxa combined (top panel). In most protected areas and for most taxonomic clades, scientists observed more species per visit than community members, most notably for birds. However notable exceptions in which community members observed more species per visit include mammals in Tsimanampetsotsa and Ranomafana, and amphibians in Andohahela and Andringitra

($\beta = -0.48$, SE = 0.0039). Environmental and climatic factors consistently were more important predictors of the number of species observed, and species abundance observed, than monitoring team composition (Tables S1–S10).

4 Discussion

Here, we studied the abilities of local community members, in relation to professional scientists with graduate training, at observing and identifying vertebrate wildlife in Southern Madagascar. Furthermore we explored how important any such differences in detection ability between community members and scientists were relative to the importance of environmental conditions (vegetation and climate). We found that although scientists generally observed more species, community members were effective as well. We also found that vegetation and climate were both more important than observer team composition (community member or scientist). Both of these findings suggest that community-based monitoring (CBM) may be an adequate tool for conservation management in Madagascar.

4.1 Community member and scientist observation agreement

Community members had low true positive rates ($\bar{x} = 0.243$), indicating that community members were likely to miss species observed by scientists. Local ecological knowledge of community members is often based on cultural and/or learned knowledge of wildlife species through practice (seeing, doing, and hearing) [35]. As such, community member-observed biodiversity may be closely aligned with morpho-species or morphological grouping of species, which differ from the detailed morphological identification of species that was employed by scientists in this study. This might explain the lack of detection of certain species by community members. However, community members also had high true negative rates ($\bar{x} = 0.912$), indicating that they were unlikely to misidentify species they observed. Local community members therefore displayed high performance at detection and identification of a subset of animal communities (given high true negative rates), albeit low performance at detecting all species (given low true positive rates).

Collectively over the two years of monitoring, community members observed a total of 373 species, while scientists observed a total of 357 species. In addition, 99 species in total were observed by community members and never observed by scientists, while 83 species were observed by scientists and never observed by community members. Given that community members conducted surveys 6.12 times as frequently as scientists, this suggests that scientists were more efficient at performing biodiversity surveys. Yet in the aggregate across two years of surveys, community members can observe a proportion of the vertebrate community comparable to (and here, greater than) that observed by scientists. Furthermore, the ease-of-access and cost-effectiveness of monitoring by community members, who live adjacent to protected areas, can provide more continuous monitoring effort than sporadic visits by external scientists (Fig. 4).

4.2 Spatial and temporal trends in biodiversity observations

Vegetation and climate gradients are important drivers of biodiversity across scales [32]. Multivariate analyses (Generalized Linear Models) indicated that the effects of vegetation and climate on the number and abundance of species observed were stronger than the effects of observer identity (i.e. whether an observer was a community member or scientist). This suggests that variation in the number of species and individual animals actually present in a given time at a given location is greater than the variation in how many species/individuals are seen by one observer team compared to others. Whether a monitoring team is composed of scientists or community members therefore may matter less than environmental factors that generate spatial patterns of biodiversity.

For both community members and scientists, GLMs indicated that the number of species observed increased from 2019 to 2020 (Table S1). Yet this trend was the opposite for changes in observed abundance over time: observed abundance was lower in 2020 relative to 2019 (Fig. 4, Table S6). Furthermore, the number of species observed by scientists actually increased more over time than it did for community members. This likely was due to the lower sampling frequency by scientists (twice annually, compared to twice monthly by community members), paired with high seasonal and annual turnover of species. Mann–Whitney tests indicated that scientists consistently saw more species per visit than community members. However collectively, community members were able to observe more species as scientists. This suggests that although scientists are able to perform better than community members for a single visit, community-based monitoring in the aggregate serve as a highly viable and cost-effective alternative for biodiversity monitoring to inform protected area management.

4.3 Considerations of incorporating community-based monitoring in biodiverse regions

Hiring community members to participate in biological monitoring of protected areas has many benefits that are not captured in simple comparisons of the species richness and abundance observed, such as lower costs to hire and transport community members, and also greater capacity to increase communication and collaboration between park managers and local communities. Additionally, our study occurred over a two-year period, and more research is required to describe longer-term trends in monitoring by communities compared to scientists; we expect differences in detection and identification between local community members and scientists to narrow over time.

Species identification also depends on each local community members' ability to recognize each species, which may be attributed to the amount of experience of each person as well as their individual willingness to learn to recognize species well. Local knowledge transmission also can differ across communities, generating variation in biodiversity observation abilities [4, 35]. In our study, communities surrounding each protected area have their own habits and customs, which influence the education level and way of seeing species. Across the six protected areas studied here, the community members in rainforest (Andringitra, Ranomafana) were more educated than those living adjacent to dry habitat protected areas (Tsimanampetsotsa, Beza Mahafaly). In Andohahela Park, the majority of community members are women (67%). Although women are less educated than men in southern Madagascar, they may be more meticulous in identifying species [27]. This could explain why community members encountered more species in Andohahela than scientists did.

Taxa-specific tests indicated that per visit, scientists observed significantly more birds than community members ($W = 1847.5$, $P < 0.0001$) and significantly more reptiles than community members ($W = 5964.5$, $P = 0.0412$), yet there

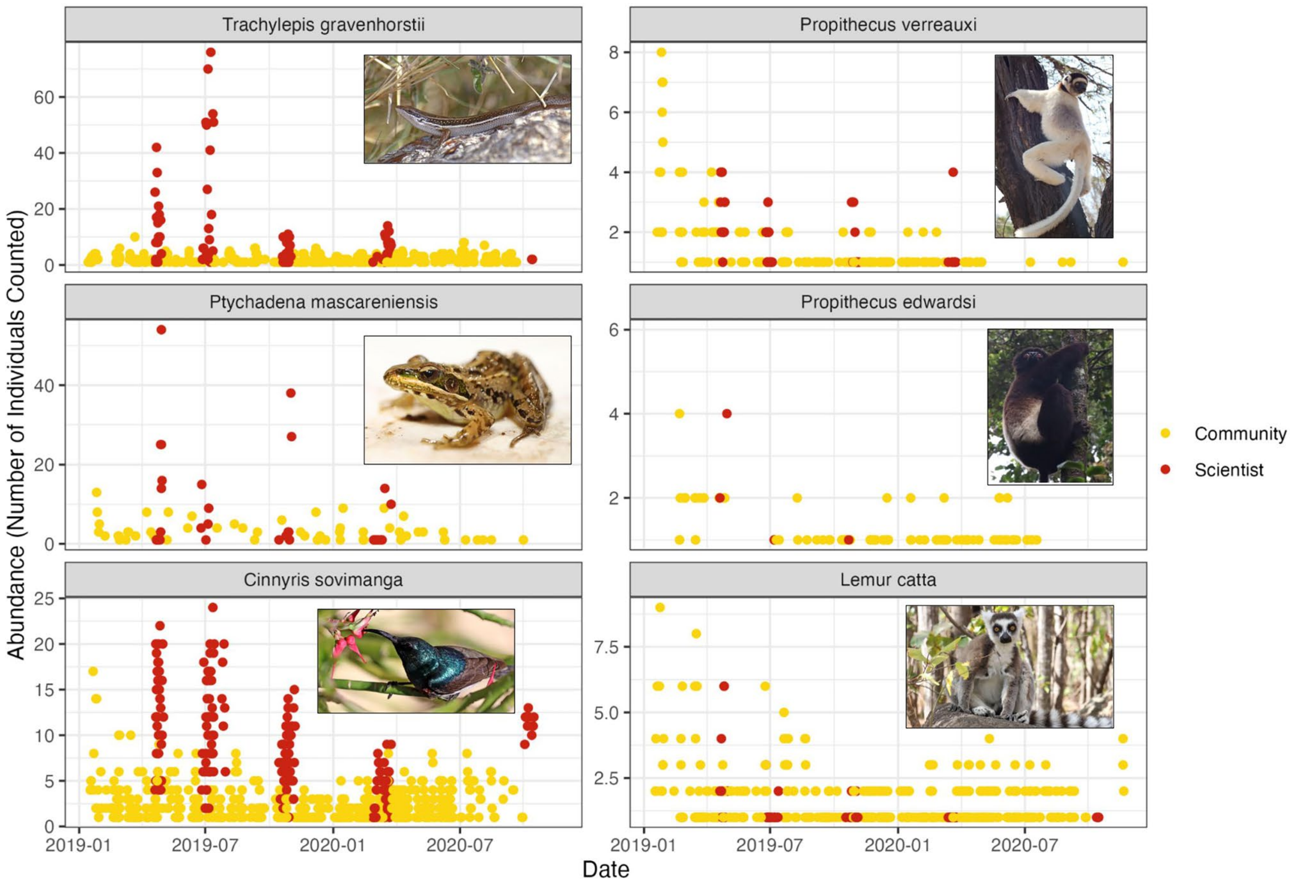

Fig. 4 Measurements of species abundance over time are improved by incorporating community-based monitoring. Each point indicates the number of individuals of a given species encountered during a single survey at a single transect by a single team; multiple transects were surveyed by each team on each date. For common species (left panels), scientists typically observed more individuals per survey than did community members, especially for reptiles and birds. Yet for key species of conservation interest (right panels; here all lemurs), which oftentimes are rare or have lower abundance, local community member observations can provide more temporally-continuous observations, when monitoring by professional scientists is necessarily sporadic given limited resources. Photo credits: *Cinnyris sovimanga*: Charles J. Sharp under 4.0 CC BY-SA 4.0 license; *Trachylepis gravenhorstii*: Bernard Dupont under CC BY-SA 2.0 license; all others David Klinges

was no significant difference in amphibians (W = 1186, P = 0.713) or mammals (W = 5350.5, P = 0.249) observed per visit between scientists and community members. Reptiles tends to be cryptic and difficult to observe without extensive field experience, and transect-based surveys may not entail full sampling of reptile communities [36]. Given that many amphibian species are nocturnal and live aboveground [37], our survey methods may also have entailed limited encounters with amphibian species [38], which may explain their low overall richness and abundance for both community members and scientists. Birds, for which more species were observed by scientists than community members, are inventoried more by listening than by visual observation [39]. Learning birds calls may be more challenging for novice surveyors such as our community members, given the absence of recordings of many vocalizations. Our data support this hypothesis: for the 82 species recorded by scientists but not community members, scientists were 20-fold more likely to have identified the species by audio rather than visual observation; for all specifies collectively, scientists were only twofold more likely to have identified the species by audio rather than visual observation (of note is that for most observations it was not recorded whether the species was identified by audio or visual observation). This suggests that a key skill set of some scientists, hearing and identifying vocalizations, is not as well represented among community members.

4.4 Conclusion

We designed our study to best fit a variety of logistical, financial, and cultural constraints and considerations, although several insights generated here apply more broadly to CBM in biodiverse locations. In light of our experiences, we provide the following recommendations for researchers who desire to establish a CBM project in Madagascar or in other biodiversity settings:

- While our resources only provided for community member surveys twice per month, higher visit rates and more transects per protected area would entail more exhaustive monitoring.
- We encourage more prolonged community training and taxonomic specialization. We found that some community members struggled to maintain species-level identification skills across all vertebrate clades, particularly for birds and reptiles. Just as most professional scientists are taxonomic specialists—including in our study—we recommend that CBM programs train different community members to focus on separate taxonomic clades to become experts themselves.
- We recommend explicit training on line transect walking speed and point count duration, both important for time-standardized surveillance, yet which may differ across communities without uniform guidance.
- In our study, community members and scientists conducted two days of simultaneous surveys during the training period to validate community member observations. We suggest that such paired surveys are conducted across longer durations (e.g. 10–15 days), to measure how community member performance changes over time and possibly calculate and ideal training period.
- We emphasize explicit consideration of demographic diversity of CBM projects. Recent work has found the integrating more women into wildlife monitoring improves efficacy [27], and including young participants also fosters community engagement with future generations for sustained impact.

Our study was conducted across diverse social, cultural and environmental systems. Combining scientists and local community members may improve the management plan for protected areas and strengthen collaboration between protected area managers, scientists and the local community [10, 11]. A willingness to understand and remain constantly aware of the social, economic, and political motivations of the local community to collect high-quality data is essential and adds an additional dimension to any management or biodiversity monitoring program [40]. Although we did uncover some deficits of local communities relative to scientists for select taxa and species, our project suggests that even a very short training window can build capacity of local communities to facilitate biodiversity monitoring. Our first two years of biodiversity surveys are a promising sign for future community-based monitoring, especially with continued support and training of communities. Such frameworks are vital to the effective co-production of knowledge that enhances conservation strategies.

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Animal welfare Wildlife studied here were observed *in-situ* without handling or intervention.

Author contributions L.R. acquired funding, organized and led community member training and data collection, oversaw data curation, and orchestrated all aspects of the project. D.H.K. curated data and conducted all analyses. S.R. led community member training, collected data, and curated data. B.R.S. assisted with acquiring funding and project management. L.R. drafted the manuscript with guidance from D.H.K. and B.R.S., and all authors reviewed the manuscript.

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Data availability Data are available at the following Zenodo https://doi.org/10.5281/zenodo.10051226.

Code availability Not applicable.

Declarations

Competing interests L.R. is an employee of Madagascar National Parks.

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