A Multicountry Assessment of Tropical Resource Monitoring by Local Communities

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The rapid global growth of conservation schemes designed to incentivize local communities to conserve natural resources has placed new importance on biological monitoring to assess whether agreements and targets linked to payments are being met. To evaluate competence in natural resource monitoring, we compared data on status and trends collected independently by local-community members and trained scientists for 63 taxa and five types of resource use in 34 tropical forest sites across four countries over 2.5 years. We hypothesized that the results would vary according to differences in the education and value systems of the monitors. We found that, despite considerable differences in countries, cultures, and the types of natural resources monitored, the community members and the scientists produced similar results for the status of and trends in species and natural resources. Our findings highlight the potential value of locally based natural resource monitoring for conservation decisionmaking across developing countries.

Keywords: participatory monitoring, precision, reliability, sampling accuracy

Global concern over the loss of biodiversity; the potential impacts of climate change; and the unsustainable use of land, forests, and other natural resources has given rise to numerous international conservation initiatives. One group of initiatives offers financial payments to local communities living in biologically rich areas as compensation for their willingness to regulate or reduce their use of globally significant natural resources. Such *payment for ecosystem services* (PES) programs (Jack et al. 2008) include the United Nations Framework Convention on Climate Change Reducing Emissions from Deforestation and Forest Degradation mechanism (UNFCCC 2012) and more local PES schemes—for example, for water (Fisher et al. 2010) or wildlife (Clements et al. 2010). These programs rely on frequent monitoring at multiple scales to facilitate decisionmaking and to assess whether communities have met established conservation benchmarks and have thereby earned financial or other rewards. Whether such monitoring can and should be the domain of local people or professional scientists is the subject of a large and growing debate (e.g., Luzar et al. 2011). In addition, one of the functions of the newly established Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services is to bring different knowledge systems, including indigenous and local knowledge systems, to the science–policy interface (UNEP 2012). Here, we evaluate the potential of locally based monitoring of natural resources for informing conservation decisionmaking and intergovernmental mechanisms by comparing the results of paired local and professional monitoring efforts in forest habitats in four tropical countries.

How did we get here?

Scientists trained in biological sampling design and field data collection techniques are generally expected to collect data on natural resource trends more accurately than do local people, who may lack formal education (Penrose and Call 1995). Local people are also expected to be less objective than are external scientists when they record the status of natural resources, because of vested interests in their use of those resources (figure 1; Root and Alpert 1994). Given such concerns, the ability of participatory environmental monitoring to accurately detect changes in natural resource populations

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Figure 1. A Miskito community member recording his sightings and signs of mammals and birds during a foot patrol in Nicaragua. Photograph: Sune Holt.

or patterns of resource use has been widely questioned. If monitoring by local communities is inaccurate or biased, it may not be reliable for assessing trends in the natural world, and management interventions may be directed inappropriately (Burton 2012, Nielsen and Lund 2012).

Debates over the types of policy interventions that best protect natural resources contain an emerging consensus that the monitoring of resource status and use is necessary to achieve sustainability (Ostrom and Nagendra 2006, Ostrom 2009). Within this literature, species and habitat monitoring by local communities or external agencies has often been assumed to yield the same results (Coleman and Steed 2009), but little empirical testing of this assumption exists. Other literature suggests that the immense amount of monitoring required to measure natural resource trends around the world will, by necessity, require local monitoring (Sodhi and Ehrlich 2010).

Previous investigations in which the accuracy of natural resource information generated by local communities in developing countries was assessed have been qualitative studies, individual case studies, or limited by small sample sizes (tables 1 and 2). All of the individual case studies and those with small sample sizes have been restricted to small geographical areas. Most have been focused on a comparison of static findings—for example, population density at a single point in time. Few have involved trends over time, which is critical when resource monitoring is intended to inform natural resource management and sustainable use (Jones et al. 2008). From our review, in only eight studies were field data collected by local groups and those collected by external groups from the same areas and at the same time of year compared (tables 1 and 2). Taken together, these previous studies provide cautious support for the idea that monitoring of natural resources by local people can provide accurate data.

How did we study this issue?

To resolve the ongoing uncertainty concerning the role of local communities in natural resource monitoring, we conducted a quantitative comparison of data collected on the status of and trends in selected natural resources by trained scientists and community members across multiple countries. These data were collected simultaneously by the two monitoring groups, which included 7 university-trained scientists and 128 local people, mostly with no more than a primary-school education, over 2.5 years in tropical forests of Madagascar (figure 2), Nicaragua, the Philippines, and Tanzania (figure 3). The three monitoring programs included in our study were locally based, long-running, and formalized schemes used to guide resource management decisions. In these cases, we established parallel, scientist-executed schemes in the same areas. In one country, where no local monitoring scheme existed, one scheme was established in collaboration with the local communities.

Our focus in this study was to compare resource abundance data collected by local community members with those collected by external scientists. Likewise, we focused on the information most relevant to natural resource management decisions, such as the status of and trends in abundance indices. We did not assess the reliability of either group against some base measure.

Our working hypothesis was that measures of the abundance of natural resources would differ when they were assessed by community members and trained scientists. We tested this hypothesis by comparing data from patrols by community members (figure 4) and line-transect surveys by trained scientists along the same or adjacent survey routes in the same forest areas and over the same 3-month period.

What data did we collect?

We collected field data from January 2007 to June 2009 across 34 sites (table 3). The study sites were located opportunistically on the basis of existing locally based forest-monitoring schemes, except in Nicaragua, where we established a local monitoring scheme for the purpose of this study. The area and boundary of each study site was agreed on by the

Table 1. Sampling size of published comparisons of the accuracy of community member– and trained scientist–executed natural resource monitoring in developing countries.

Study	Country	Communities or sites surveyed	Type of data collected	Number of community members	Attribute	Status or trend
Hellier et al. 1999	Mexico	2 communities	Interviews	57	Forest cover and harvested species	Trend[a]
Noss 1999	Central African Republic	1 village	Counts	–	Abundance and density of game species	Status
Gavin and Anderson 2005	Peru	3 communities	Interviews	67 families	Plants and animals harvested	Status
Uychiaoco et al. 2005	The Philippines	8 communities	Counts	–	Reef benthic cover and fish abundance	Status[b]
Lunn and Dearden 2006	Thailand	Villages in 1 national park	Interviews	70	Fish catch and effort	Status
Halme and Bodmer 2007	Peru	1 village	Interviews	26	Forest types	Status
Holck 2008	Tanzania	4 sites in one forest reserve	Counts	16	Forest disturbance	Status
Jones et al. 2008	Madagascar	1 village	Interviews	22 households	Crayfish (*Astacoides*) and firewood collection	Status
Léopold et al. 2009	Fiji	1 customary rights area	Counts	2	Reef fish abundance	Status
Acharya et al. 2009	India	3 1000-meter transects	Counts	4	Bird species richness	Status
Yasué et al. 2010	The Philippines	1 village	Interviews	79	Reef fish abundance	Trend
Mueller et al. 2010	Niger	1 village	Interviews	–	Species richness, diversity and height of grasses and trees	Status
Rist J et al. 2010	Equatorial Guinea	1 village	Interviews and counts	55	Bushmeat hunting catch and effort	Status
Rist L et al. 2010	India	16 villages around a sanctuary	Interviews	47	Mistletoe (*Taxillus tomentosus*) infection	Status
Oldekop et al. 2011	Ecuador	9 communities	Counts	20	Species richness of ferns	Status
Nagendra et al. 2011	Several countries	53 forests	Interviews	–	Densities of trees and shrubs and saplings	Trend[a]

Note: The dashes denote that no data were available. [a]Retrospectively. [b]In two communities, static findings over several years.

scientists and the representatives of the local communities. A *study site* was defined as a specific area of discernible forest or woodland with a size ranging from a few hundred hectares to several thousand hectares and, furthermore, that was important in terms of both its biological resources and its value to local livelihoods.

Representatives of the local communities in the study areas helped us select community participants on the basis of their interest in and experience with forest resources. The community participants included some of the most experienced collectors of forest products in each study site. Most of the community participants had attended only primary school and had a limited ability to read and write; however, in each study site, there was at least one literate participant.

The community participants received training from an intermediary organization once, for 2–3 days per study site, in the recording of forest resources and resource use during forest patrols. In Nicaragua, this training was provided at the beginning of the present study, whereas in the other three countries, this training was provided several years ahead of the study, when the schemes were established (in the Philippines, 9 years earlier; in Tanzania, 5 years earlier; in Madagascar, 3 years earlier). In all of the study sites, however, during the time of the present study, training follow up was performed during visits of 2–3 hours per study site each year, during which the researchers assisted the community participants and obtained copies of the field forms.

The scientists had academic degrees at the master's level or the equivalent in a natural science. They all had at least 10 years of prior field experience in tropical forest surveys.

The community participants obtained no payment for their work, but they were provided meals and snacks, except in three study sites in Tanzania, where they were paid for their labor by the village (the equivalent of US$1– US$2 per day, with funds generated from local user fees) as part of the existing monitoring schemes. The idea was that the time and effort provided by the community members for monitoring should match those that they were already providing in the existing locally based monitoring schemes, which are being sustained with no or very limited external funding because of their utility for local communities' decisionmaking (Danielsen et al. 2010a).

Table 2. Results of published comparisons of the accuracy of community member– and trained scientist–executed natural resource monitoring in developing countries.

Study	Biome	Attribute	Matched time and area[a]	Agreement of community member– with trained scientist–executed surveys
Hellier et al. 1999	Terrestrial	Forest cover and harvested species	No[b]	There was some contradiction with scientist-derived data on vegetation change.
Noss 1999	Terrestrial	Abundance and density of game species	No[c]	For two out of four species, a hunter-based method generated only abundance indices, not density estimates.
Gavin and Anderson 2005	Terrestrial	Plants and animals harvested	No[d]	There was agreement on species harvested but contradiction on quantities.
Uychiaoco et al. 2005	Marine	Reef benthic cover and fish abundance	Partially[e]	One of four community measures of reef benthic cover and fish abundance correlated with the scientists' reports.
Lunn and Dearden 2006	Marine	Fish catch and effort	No[f]	Fishermen reported larger catches and greater effort than the scientists observed.
Halme and Bodmer 2007	Terrestrial	Forest types	Yes	There was close correspondence between forest type classification by communities and floristic classification by botanists.
Holck 2008	Terrestrial	Forest disturbance	Yes	After a few days' training, the local people produced data that matched scientists'.
Jones et al. 2008	Terrestrial and freshwater	Crayfish (*Astacoides*) and firewood collection	Yes	Local reports of quantities, effort, and spatial pattern of harvesting were comparable with the scientists'.
Léopold et al. 2009	Marine	Reef fish abundance	Yes	The local people overestimated fish abundance and provided more variable results than did the scientists.
Acharya et al. 2009	Terrestrial	Bird species richness	Yes	There were strong similarities in bird species recorded.
Yasué et al. 2010	Marine	Reef fish abundance	No[b]	There was a gap between community perceptions and biological survey results on changes in fish abundance, size, and diversity.
Mueller et al. 2010	Terrestrial	Species richness, diversity and height of grasses and trees	No[d]	The community members and the scientists agreed on height and density measures for grasses and trees and on tree species richness but not on herb species richness.
Rist J et al. 2010	Terrestrial	Bushmeat hunting catch and effort	Yes	Community and scientist data matched on catch and effort and the locations of hunting trips.
Rist L et al. 2010	Terrestrial	Mistletoe (*Taxillus tomentosus*)	Yes	Harvesters provided accurate information on infection characteristics and primary host species but were less accurate for secondary host species.
Oldekop et al. 2011	Terrestrial	Species richness of ferns	Yes	There was a strong correlation of species richness estimates between the community members and the scientists.
Nagendra et al. 2011	Terrestrial	Densities of trees and shrubs and saplings	Partially[g]	Qualitative community assessments of changes in tree density were correlated with change determined by the scientists from randomly distributed forest plots.

[a]Surveys undertaken at the same temporal and spatial scales, at the same time (within the same 3-month period) and in the same geographical area. [b]Different scales and different time and area. [c]Different time and area. [d]Different temporal scale and different time. [e]Almost the same area; same scales and same time. [f]Different time. [g]Almost the same temporal scale, different spatial scale, same area.

Prior to the fieldwork, we had asked the community participants to select natural resources and resource-use events that they would like to monitor. We proposed a minimal list: a species of large mammal (more than 5 kilograms [kg]), a species of small mammal (less than 5 kg), a species of bird (figure 5), a type of resource use of animals (figure 6), and a type of resource use of plants (figure 7). On the basis of these criteria, the community members decided on 68 targets to be monitored (tables 4 and 5), which were divided into three classes: birds (39 taxa), mammals (24 taxa), and resource use (e.g., cut bamboo; there were five types of resource use). Most of these resources were of value to the local people.

The community members recorded sightings and signs of natural resources and fire, snares, and other resource use during regular foot patrols in the forest. In Madagascar and Tanzania, at each study site, the community participants carried out patrols two to three times per month; the duration of each patrol was typically 3–6 hours, and they were sometimes up to 14 kilometers long. In Nicaragua and the Philippines, the community members carried out patrols one time during each 3-month period; each patrol had a duration of 2 hours and a length of 2000–2500 meters (m). For safety reasons, the community participants always worked in pairs.

Figure 2. Dry deciduous forest in central western Madagascar. Photograph: Anselme Toto Volahy.

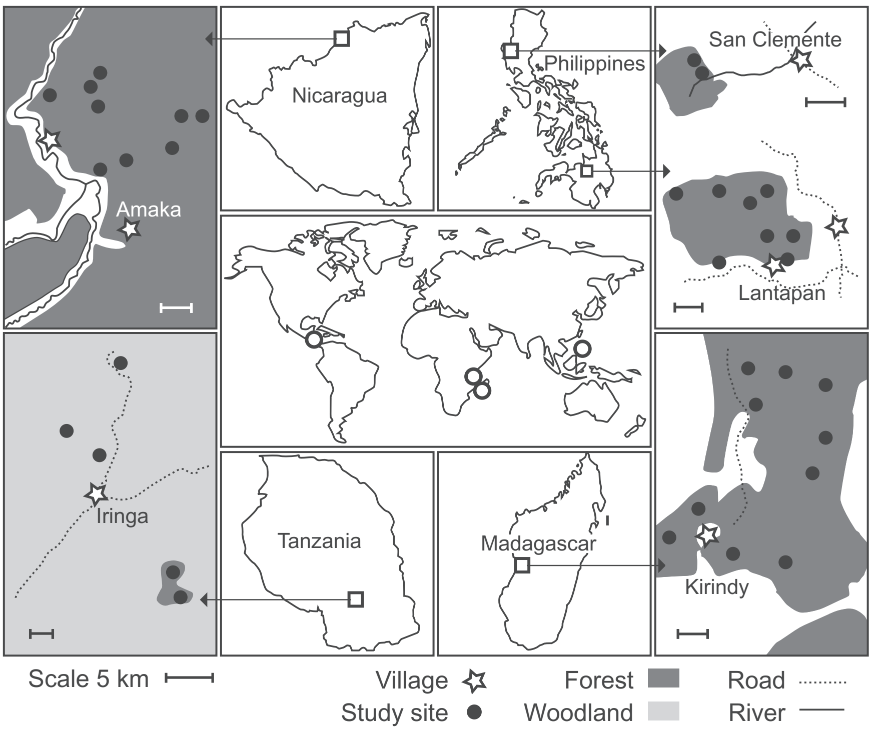


Figure 3. The locations of the 34 tropical forest study sites in Madagascar, Nicaragua, the Philippines, and Tanzania. Abbreviation: km, kilometers.

In all four countries, the scientists carried out surveys of natural resources and resource use along fixed routes within the same forest or woodland study sites, using a variable-distance line-transect method (adapted from Buckland et al. 1993). One or two transect routes were surveyed by each scientist once during each 3-month period in each study site. The length of the transect routes was 2000–2500 m. The speed of walking was kept constant at about 1 kilometer per hour. This speed allowed brief stops when animal vocalizations and signs of resource use were detected. For each resource or resource-use contact, the scientists sought to record the name of the species or resource-use event and the number of individuals or resource-use events. The scientists attempted to avoid counting the same individual twice. In order to minimize biases caused by differing detectability, all of their surveys were made during optimal conditions (i.e., between 6:00 and 9:00 a.m., during clear, dry weather). All surveys of a study site were undertaken by the same scientist working alone.

Both the community participants and the scientists recorded all of their observations, independent of the distance from the survey routes. Likewise, both direct sightings and indirect evidence (e.g., calls, tracks, scat, burrows) were recorded. For resources that occurred in clusters (groups), the cluster size was estimated. Moving resources (e.g., birds in flight) were also recorded.

We did not standardize the shape, length, or location of the community member survey routes among the countries, because all of the local schemes, except in Nicaragua, were based on community monitoring systems that existed prior to this study. In the Philippines and Nicaragua, fixed routes were surveyed inside the forest (along existing narrow forest trails), and the scientists surveyed the same routes but on separate days. In Tanzania, the existing community patrol routes varied from survey to survey, dependent on where the monitors expected to find cut trees or illegal uses of forest resources. In Madagascar, the existing patrol routes were located along the forest boundary. In these countries, the scientists established survey routes independent of the existing system of trails inside the woodland or forest. These survey routes were meant to include representative habitats for the study sites and were cut in a straight line in each study site, regardless of logging roads, light gaps, and so on. We did not force the scientists to survey the same routes as those of the community members in the two countries with more variable routes (Tanzania and Madagascar), because we sought a more realistic comparison between the scientists' standardized, fixed-route surveys and

*Figure 4. Community members monitoring miombo (*Brachystegia*-dominated) woodland resources in Tanzania. Photograph: Michael K. Poulsen.*

is unlikely that either measurement of abundance is without error. Given the variation inherent in sampling natural resource abundance, we chose an analytical approach designed to effectively test the hypothesis that community members and trained scientists are equally good monitors. Specifically, we organized the observations in paired time series, excluded time series for rare resources detected inconsistently, and used a generalized linear model that is particularly sensitive to differences between scientists and community members.

Our time series consisted of the number of counted individuals of particular natural resources and events of resource use per hour of effort in each 3-month period (a quarter of a year) within a specific site. When the locals sampled several times within a given quarter, the sum of individuals recorded for all surveys within the quarter divided by the number of hours of effort was used as an observation for the given quarter. Quarterly sample units were chosen because the records include one trained scientists' survey at each site in each 3-month period.

We excluded time series for rare resources that were reported by only one of the observer groups. We considered these resources to occur below a detection threshold for reliable reporting, given the level of survey effort typical of the monitoring schemes. Counts of such rare resources tend to have a high standard error relative to the mean, which increases the noise:effect ratio and thereby decreases the probability of rejecting the null hypothesis (i.e., increases the probability of a type II error). Furthermore, agreement on the absence of very rare species could lead to an artificially high correlation between the two groups of monitors.

the different, country-specific approaches to locally based natural resource monitoring.

In Nicaragua and Tanzania, the community member and scientist surveys were a few days apart (Nicaragua, mean [M] = 11.1 days, standard error [SE] = 1.2; Tanzania, M = 6.32 days, SE = 8.9), whereas in the Philippines and Madagascar, there were longer gaps in time between the surveys (Philippines, M = 13.5 days, SE = 15.9; Madagascar, M = 47.5 days, SE = 8.7).

How did we undertake the analysis?

Our study was essentially a double-observation test, which did not include controls or other experimental interventions. It was not known whether the trained scientists or the community members recorded true abundance; indeed, it

Table 3. Study areas, their levels of disturbance, and the type of vegetation studied.

Country	Location	Number of study sites	Vegetation	Altitude (in meters above sea level)	Disturbance level
Madagascar	Menabe Antimena protected area	10	Dry, deciduous forest	25–100	Most of the area is only marginally disturbed, but the periphery of the reserve is moderately to severely degraded
Nicaragua	Bosawas Biosphere Reserve	9	Wet, dipterocarp forest	180–360	Moderately degraded
Philippines	Mount Kitanglad Range Natural Park, Bukidnon, Mindanao	8	Wet, dipterocarp forest	850–1700	Two sites largely undisturbed, six sites moderately to severely degraded
Philippines	Mount Manleluag, Pangasinan, Luzon	2	Wet, dipterocarp forest	200–350	Moderately to severely degraded
Tanzania	Forest reserves in Iringa and Kilolo Districts	3	Miombo woodland	1050–1750	Largely sustainably used or moderately to severely degraded from unsustainable cutting of wood for charcoal
Tanzania	Forest reserves in Iringa and Kilolo Districts	2	Montane evergreen forest	1750–2100	Marginally disturbed except for game poaching

*Figure 5. Scale-feathered malkoha (*Dasylophus cumingi*) in the Philippines. Photograph: Martin Lindop.*

*Figure 6. A hunter disentangling a snared blue duiker (*Philantomba monticola*) in Tanzania. Photograph: Michael K. Poulsen.*

Finally, we felt that including rare species could bias the results simply because the community members had spent more survey effort in our comparisons, not because they were (necessarily) more adept at detecting rare species than were the trained scientists (see the supplemental material).

Records of natural resources occurring at multiple sites were considered independent observations, even if it could be expected that the given individual resource may have belonged to the same population. Our unit of observation was quarterly summed counts per hour of effort, and one observation was composed of a series of quarterly effort-adjusted counts of a specific resource at a specific site. This condensation of the data generated 600 time series (300 each from the community members and the trained scientists) spanning 3–10 quarters (i.e., 9–30 months; M = 7.13 quarters, SE = 0.10). A total of 55 time series originated from Nicaragua, 85 were from Madagascar, 125 were from the Philippines, and 35 were from Tanzania.

From each time series, we calculated the mean, the standard deviation, and the coefficient of variation from effort-adjusted counts across quarterly time series (see table 6 for an example). Trends in the abundance of resources or resource use over time were assessed by linear regression to provide a conservative estimate of the trends. Relative trends were calculated by dividing the trends by the mean count across quarters (i.e., the mean number of individuals recorded per hour) for the given resource or resource-use event. Finally, Pearson's correlation coefficient was calculated for each paired time series. The data are provided in supplemental data set S1 for the purpose of replicating and building on this work.

The observations were analyzed as paired data, because analyzing paired data increases the chances of detecting systematic differences among the observers. For example, if the community members recorded counts per hour of 1, 2, 3, 4, and 5 and the trained scientists recorded 2, 3, 4, 5, and 6, the derived means would be 3 and 4 (SEs = 0.7), these would not be significantly different when they were assessed as independent samples, but by pairing the data, it would be found that the trained scientists systematically found higher counts per hour than did the community members (exactly one more in each pair). When pairing was noted as significant, it means that the community members' and the trained scientists' counts per hour were highly and positively correlated.

The paired records were evaluated in a generalized linear model, which—in a single model—was able to assess both the correlation between the observers and whether their observations were significantly different. When no significant differences were found between the two types of observers, we assumed that the community members' and the trained scientists' methods were equally effective within the limitations

Figure 7. Trees cut with axes for charcoal production in Tanzania. Photograph: Michael K. Poulsen.

imposed by transect observations (e.g., Plumptre 2000). For further details, see the supplemental material.

We performed analyses of variance (ANOVAs) to determine main effects and Bonferroni-corrected *t*-tests for *post hoc* comparisons ($\alpha = .05$). We checked all of the model fits graphically by means of residual plots and Q–Q plots. The estimated changes are presented with 95% confidence intervals, and the estimated relative changes are presented as percentages accompanied by 95% confidence intervals (95% CI) calculated on a log scale and back transformed. All analyses were made using SAS (version 9.1, SAS institute, Cary, North Carolina).

What did we find?

A total of 24,881 hours of monitoring by the community members (19,183 hours) and the trained scientists (5698 hours) yielded 5804 paired records between the two groups for the same natural resource or resource-use activity at the same site during the same 3-month period.

Assessment of natural resource status. Paired mean counts per hour by the community members and the trained scientists differed significantly (test for heterogeneity between pairs, $p < .001$). There was also a highly significant effect of the type of observer on the mean count per hour ($p < .001$), with the community members producing a 53% (95% CI = 43–62) lower count per hour than did the scientists. When the scientists surveyed the same fixed routes inside the forest as did the community members (i.e., in Nicaragua and the Philippines), the two groups of observers obtained comparable mean counts per hour (figure 8a, table 7a, 7b; the differences were 4.8% for Nicaragua and 29.8% for the Philippines). When the scientists surveyed fixed routes inside the forest and the community members surveyed along the forest boundary (i.e., in Madagascar) or when the community members surveyed along existing trails and varied their survey routes over time, dependent on where they expected to find resources (i.e., in Tanzania), the scientists' mean counts per hour were 358% (Madagascar) and 452% (Tanzania) higher than those of the community members (figure 8a, table 7a, 7b).

In terms of the precision of the observed indices of abundance of natural resources, we analyzed the absolute precision (i.e., the standard deviation) and the relative precision (i.e., the coefficient of variation). With the present effort, the standard deviation of the counts per hour (figure 8b) showed no significant effect of observer ($p = .22$). Within a given pair of observers, the standard deviation for the community members was 12% (95% CI = –8 to 28) lower than that for the trained scientist observers. In addition, there was a highly significant effect of pairing (test for heterogeneity between pairs, $p < .001$) that could not be explained by differences in country and class, which suggests that, in cases in which the scientists provided highly variable counts per hour, so did the community members. In terms of coefficients of variation, as a further measure of precision, there was no significant difference in the mean counts per hour between groups ($p = .14$). Within a given pair of observers, the expected coefficient of variation was estimated to be 7% (95% CI = –2 to 18) higher among the community members than that among the scientist observers. As was expected, there was a significant effect of pairing (test for heterogeneity between pairs, $p < .001$). Therefore, the variation in the observations of the pairs of community members and scientists was substantial—or, equivalently, the observations within pairs of community members and scientists were positively correlated.

Assessment of trends in natural resources. Our comparison of trends in the counts per hour by the community members and by the trained scientists revealed that variation in the trends over time was associated with the observer type ($p = .02$). Regarding the differences between observers, the scientists recorded, on average, 11% (95% CI = 5–18) greater rates of decline than did the community members.

Large differences in relative trends were observed between classes of resources (table 8a, 8b). The community members found mean relative changes in indices of resource abundance that closely matched those found by the trained scientists (figure 9). Moreover, considerable differences in relative trends were observed among countries. The community members and the trained scientists reported comparable mean relative changes in natural resources in Madagascar, Nicaragua, and the Philippines, whereas their results were less comparable in Tanzania (table 7a, 7b).

Table 4. Birds recorded by the community members and trained scientists between 2007 and 2009 and the number of paired observations of each species (180 total).

Country	Taxon	Common name	*n*
Madagascar	*Coua coquereli*	Coquerel's coua	10
	Coua cristata	Crested coua	10
	Coua gigas	Giant coua	10
	Lophotibis cristata	Madagascar crested ibis	2
	Mesitornis variegatus	White-breasted mesite	8
Nicaragua	*Ara ambiguus*	Great green macaw	9
	Crax rubra	Great curassow	4
	Pteroglossus torquatus	Collared aracari	8
	Ramphastos sulfuratus	Keel-billed toucan	9
	Ramphastos swainsonii	Chestnut-mandibled toucan	9
Philippines	*Accipitridae* spp.	Raptor spp.	2
	Basilornis mirandus	Apo myna	1
	Buceros hydrocorax, Aceros leucocephalus	Rufous hornbill, writhed hornbill	3
	Centropus viridis	Philippine coucal	1
	Chrysocolaptes lucidus	Greater flameback	1
	Dasylophus cumingi	Scale-feathered malkoha	1
	Dasylophus superciliosus	Rough-crested malkoha	1
	Dicrurus balicassius	Balicassiao	2
	Dryocopus javensis	White-bellied woodpecker	5
	Ducula spp.	Imperial pigeon spp.	4
	Gallus gallus	Red junglefowl	8
	Haliastur indus	Brahminy kite	3
	Loriculus philippensis, Bolbopsittacus lunulatus	Philippine hanging parrot, guaiabero	7
	Macropygia tenuirostris	Philippine cuckoo-dove	8
	Mulleripicus funebris	Sooty woodpecker	1
	Oriolus chinensis	Black-naped oriole	1
	Other *Columbidae* spp.	Other pigeons or doves	10
	Penelopides affinis	Mindanao tarictic hornbill	5
	Penelopides manillae	Luzon tarictic hornbill	2
	Phapitreron leucotis, Phapitreron amethystinus	White-eared brown dove, amethyst brown dove	10
	Picidae spp.	Woodpecker spp.	2
	Prioniturus spp.	Racket-tail spp.	7
	Sarcops calvus	Coleto	1
	Scolopax bukidnonensis	Bukidnon woodcock	2
	Spilornis holospilus	Philippine serpent eagle	4
	Trichoglossus johnstoniae	Mindanao lorikeet	1
Tanzania	*Numida meleagris*	Helmeted guineafowl	3
	Pternistis afer	Red-necked spurfowl	3
	Tauraco livingstonii	Livingstone's turaco	2

Note: Each paired observation represents a time series of parallel records encompassing at least three sequential quarterly registrations of one resource or resource-use event at one site by community members and trained scientists.

The results show that the relative change in mean counts per hour between pairs varied significantly (test for heterogeneity between pairs, $p < .001$), which may again be thought of as a positive correlation between observations from within pairs of community members and scientists. There was also a significant effect of the type of observer ($p = .02$). Within a given pair of observers, the difference was 6% (95% CI = 1–11). When we omitted the data from Tanzania, where the community members varied their survey route from patrol to patrol, the effect of observer was no

Table 5. Mammal species and resource-use events recorded by community members and trained scientists between 2007 and 2009 and the number of paired observations of each.

Country	Species or resource use	Common species name	Number of observations
Madagascar	*Eulemur rufus*	Red-fronted lemur	6
	Hypogeomys antimena	Giant jumping rat (votsovotsa)	5
	Lepilemur ruficaudatus	Red-tailed sportive lemur	7
	Microcebus murinus	Gray mouse lemur	3
	Mungotictis decemlineata	Narrow-striped mongoose	7
	Propithecus verreauxi	Verreaux's sifaka	9
	Cut trees		5
	New active path		3
Nicaragua	*Cuniculus paca*	Lowland paca	4
	Dasypus novemcinctus	Nine-banded armadillo	5
	Mazama temama	Central American red brocket	4
	Odocoileus virginianus	White-tailed deer	3
Philippines	*Macaca fascicularis*	Crab-eating macaque	3
	Paradoxurus hermaphroditus, Viverra tangalunga	Asian palm civet, Malayan civet	6
	Podogymnura truei	Mindanao gymnure	3
	Rusa marianna	Philippine deer	3
	Sus philippensis	Philippine warty pig	7
	Cut bamboo		1
	Cut trees		5
	Fire		2
	Hunting		2
Tanzania	*Cephalophus natalensis harveyi*	Harvey's duiker	2
	Colobus spp.	Udzungwa red colobus, Angola colobus	2
	Dendrohyrax spp. *and Heterohyrax brucei*	Tree and rock hyrax spp.	1
	Loxodonta africana	African bush elephant	1
	Madoqua kirkii	Kirk's dikdik	3
	Philantomba monticola, Neotragus moschatus	Blue duiker, Suni	1
	Potamochoerus larvatus	Bushpig	3
	Sylvicapra grimmia	Bush duiker	3
	Tragelaphus strepsiceros	Greater kudu	2
	Cut trees		3
	Fire		3
	Hunting		3
Total	Species		93
	Resource use		27

Note: Each paired observation represents a time series of parallel records encompassing at least three sequential quarterly registrations of one resource or resource-use event at one site by community members and trained scientists.

longer significant ($p = .06$). A linear regression of each natural resource in those countries in which fixed survey routes were used (i.e., Madagascar, Nicaragua, the Philippines) suggests that the trained scientist trends could be accurately predicted from the community member trends, such that the community member trend was the trained scientists trend multiplied by 0.82 (± 0.15) minus 0.01 (± 0.02) ($R^2 = .81$, $p = .002$, $n = 8$). The relationship was therefore close to a one-to-one correlation for all natural resources in the three countries (figure 10).

In natural ecosystems, resource abundance may not show simple linear declines or increases but, rather, is more likely to fluctuate over time. We therefore also evaluated the Pearson correlation coefficient for paired time series on the quarterly counts per hour to assess the correlation of relative variation in resource abundance indices over time. The variation over time detected by the community members and the trained scientists was generally positively correlated (table 8b), both for the individual classes of birds, mammals, and resource use types and for the overall data set.

Table 6. Example of calculations based on a hypothetical time series of parallel records of sequential quarterly registrations of one resource or resource-use event at one site.

		Number of individuals per hour				Independent variable for statistical analysis					
Paired set of records	Observer	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Mean number of individuals per hour	Standard deviation	Absolute trend in relative abundance	Coefficient of variation	Relative trend in abundance index	Pearson's correlation coefficient
1	Community member	15	7	9	4	8.75	4.65	–3.10	0.53	–0.35	.80
	Trained scientist	12	5	6	7	7.50	3.11	–1.40	0.41	–0.19	
2	Community member	2	0	4	0	1.50	1.91	–0.20	1.28	–0.13	.00
	Trained scientist	9	1	0	2	3.00	4.08	–2.20	1.36	–0.73	

The within-pair Pearson correlation was significantly affected by both country (p = .005) and class (p = .02). The highest positive average Pearson correlation was found for resource use (r = .27, SE = 0.10), and the lowest was for birds (r = .07, SE = 0.03), whereas that for mammals was in between (r = .17, SE = 0.05; table 8b).

In terms of countries (table 7b), the highest correlation in relative changes in resource abundance indices over time was found for Nicaragua and Tanzania, where the community members' and the scientists' surveys were only a few days apart. The lowest correlation was found for Madagascar, where there was more than a month between the community members' and the scientists' surveys. In between were the Philippines, where the community members' and the scientists' surveys were almost 2 weeks apart.

What do our findings mean?

Our findings suggest that, in tropical forest habitats in developing countries, community members with little or no formal scientific education, who have decided which natural resources should be monitored, can generate records of abundance estimates, relative trends, and the variation over time of natural resources and resource uses that are very similar to those of trained scientists. We found the greatest match in results between the two groups of observers when they surveyed the same route (i.e., Nicaragua, the Philippines) with short time intervals between their surveys (i.e., Nicaragua). We found the least correspondence in results when the community members varied their survey routes among patrols (i.e., Tanzania). We also found matches in relative trends over time but no match in static abundance estimates when the scientists surveyed forest routes and the community members surveyed forest-boundary routes and when there were long time gaps separating the scientist and the community member surveys (i.e., Madagascar). When there were only small differences in the route, area, and time of the surveys by the community members and the trained scientists, the groups produced similar estimates.

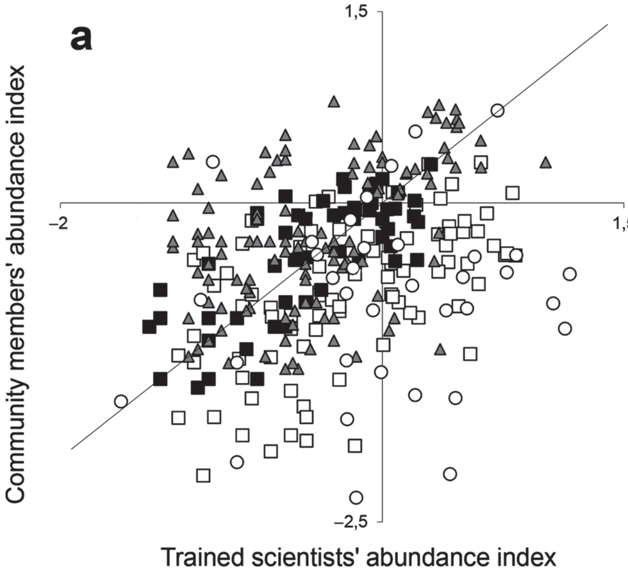
The large reduction in resource use recorded during our study (a 22%–30% decline recorded by both the community members and the trained scientists over 1.5 years; figure 9, table 8a, 8b) might be due to a patrol effect of the monitoring: This is either a real reduction in resource use in the study sites or a relocation of resource extraction away from the areas monitored by the communities and scientists as resource users sought to avoid the surveyors.

Our findings on the consistency of the community member counts of resource abundance and trends relative to those of the trained scientists concur with previous studies in the forested habitats of developing countries in which there were no differences in scale, place, or the time of the survey effort between the community members and the scientists (n = 7 studies; tables 1 and 2). Terrestrial studies in which contradictions were reported between community members and scientists had mismatches between the temporal (three studies) and spatial (one study) scales, the timing (four studies), or the geographical area (two studies), which might have influenced these comparisons.

Several factors probably contributed to the correspondence of observations between the community members and the trained scientists in our study. The community members know their forests intimately from years of experience as forest users. Except in Nicaragua, the community members had recorded data regularly over several years, so there would be no learning curve, which accounts for much of the variability in volunteer-based monitoring in industrialized countries (Dickinson et al. 2010). Since the community members' role was to make direct counts, the scheme is not susceptible to changing human perceptions of trends. The patrol records approach is simple and compatible with community members' daily routines for collecting forest products.

How representative are our findings?

We looked at resources of interest to local people. The community members who performed the surveys used forest resources on a weekly basis, and they decided which resources



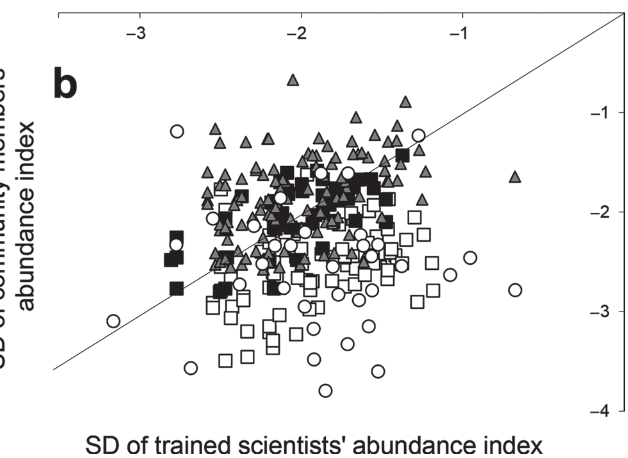


Figure 8. Relationship between the community members' and scientists' (a) indexes of abundance of 68 forest resources and forest uses and (b) the standard deviations (SD) of those measures recorded between 2007 and 2009 at 34 sites in Madagascar (the white squares), Nicaragua (the black squares), the Philippines (the triangles), and Tanzania (the circles) (N = 300 pairs of observations) Note the $\log_{10}$ scales. Each point in the graphs represents a time series of records based on the means of effort-corrected quarterly registrations of one resource or resource-use event at one site by community members (y-axis) and trained scientists (x-axis). The diagonal line represents y = x.

to monitor (figure 11). We do not know whether the results would be the same if the scientists had chosen the resources to be monitored. For instance, dung beetles (Coleoptera: Scarabaeinae), which have been shown in empirical studies (Gardner et al. 2008) to be a high-performance indicator for the quality of a tropical forest, may mobilize less enthusiasm among village recorders, but, given our encouraging results across varying biological and socioeconomic contexts across the globe, we believe that these findings are representative for community-based patrol record sampling in tropical forests and savanna woodlands. This is particularly true when the community members are motivated by some training and by clear links to their livelihoods.

Our main comparison was between community members' patrol records and trained scientists' line transects. The line-transect method is recognized to have weaknesses (e.g., Gale et al. 2009) for capturing true resource abundance density and trends. Moreover, other factors, such as the selection of the survey routes, the probability of the detection of resources, and the ease of observing different taxa, may affect our ability to assess trends (Yoccoz et al. 2001).

Our goal was to test whether community members and trained scientists would record similar resource trends, and line transects are the scientific method closest to the community members' patrol system. Moreover, the line-transect method is fairly simple, inexpensive, and widely used by scientists for monitoring natural resources in tropical forests (Peres 1999, Luzar et al. 2011). Other scientific methods (e.g., mark and recapture, point–count methods, territory mapping, camera trapping; Bibby et al. 2000, Burton 2012) would have introduced additional biases and would probably have resulted in a mismatch between the taxa that could be recorded by the scientists and those recorded by the community members.

What is the societal relevance?

Our findings are relevant to ongoing debates on the best ways to monitor natural resources and the potential role of local communities in such monitoring (Chhatre and Agrawal 2009). Across the developing world, decisionmaking has been decentralized to operational levels of management, including to local communities (Agrawal et al. 2008). Therefore, monitoring management outcomes at the local level becomes vital. Moreover, involving community members in resource monitoring helps link that resource monitoring to decisionmaking at the operational level of resource management (Danielsen et al. 2010b) and, therefore, has the potential to become a major contributor to global conservation strategies. This is particularly relevant as the world struggles with linking environmental performance to payment schemes, bringing indigenous and local knowledge systems into the science–policy interface (UNEP 2012), and monitoring basic issues of natural resource change.

Locally based natural resource monitoring has been demonstrated to be suitable for monitoring organisms or phenomena that are meaningful for community members—for example, as a source of food or income or with cultural or spiritual value. However, if the aim is to monitor attributes that are not relevant from the local perspective, locally based natural resource monitoring may not be suitable. This is important to consider for any locally based monitoring scheme.

In the present study, there was no conflict over resources in any of the areas studied. In situations in which an abundance of resources may condition quotas or financial payments

Table 7a. Measures of relative abundance and trends recorded by community members and trained scientists between 2007 and 2009 (N = 300 pairs of observations).

	Madagascar (n = 85)				Nicaragua (n = 55)				Philippines (n = 125)				Tanzania (n = 35)			
	Community members		Trained scientists		Community members		Trained scientists		Community members		Trained scientists		Community members		Trained scientists	
Measure	**Mean (M)**	**Standard error (SE)**	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**	**M**	**SE**
Number of individuals per hour	0.38	0.05	1.36	0.18	0.63	0.06	0.60	0.07	1.14	0.12	0.80	0.11	0.58	0.19	2.62	0.63
Absolute trend in relative abundance	–0.02	0.01	–0.02	0.03	–0.05	0.02	–0.09	0.02	–0.01	0.03	–0.01	0.03	–0.05	0.05	–0.46	0.18
R^2 of absolute trend	.29	.02	.16	.02	.31	.03	.27	.03	.17	.01	.17	.02	.42	.06	.61	.06
Relative trend in abundance index	–0.06	0.03	–0.02	0.03	–0.12	0.04	–0.14	0.05	–0.03	0.03	–0.07	0.03	0.07	0.10	–0.19	0.09
Standard deviation	4.2×10^{-3}	4.4×10^{-4}	0.02	1.7×10^{-3}	0.01	9.9×10^{-4}	0.01	1.2×10^{-3}	0.02	2.3×10^{-3}	0.01	1.9×10^{-3}	0.01	2.5×10^{-3}	0.03	0.01
Coefficient of variation	1.12	0.09	1.48	0.09	1.40	0.08	1.62	0.09	1.68	0.07	1.67	0.07	1.05	0.09	0.84	0.07

Table 7b. Mean Pearson correlations for paired time series of data and the number of observations in each paired series of observations in each country.

	Madagascar		Nicaragua		Philippines		Tanzania	
Measure	**Mean (M)**	**Standard error (SE)**	**M**	**SE**	**M**	**SE**	**M**	**SE**
Pearson's correlation coefficient	.06	0.05	.30	0.07	.07	0.04	.13	0.12
Number of observations per series	7.95	0.12	6.18	0.07	7.96	0.15	3.71	0.08

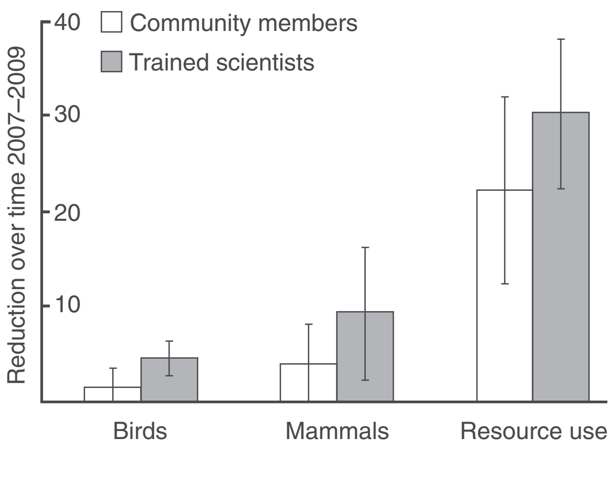


Figure 9. Relative abundance (as the reduction percentage) of 68 forest resources and forest uses recorded by community members (white) and trained scientists (gray) between 2007 and 2009 at 34 sites in Madagascar, Nicaragua, the Philippines, and Tanzania. All of the trends are negative, and the y-axis is therefore inverted (N = 300 pairs of observations; each paired observation represents a time series of parallel records of sequential quarterly registrations of one resource or resource-use event at one site by community members and trained scientists). The error bars represent the standard error.

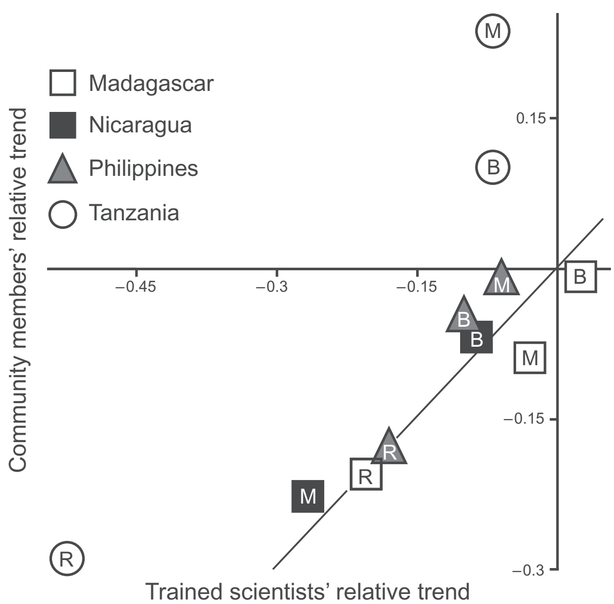


Figure 10. Relative abundance of 68 forest resources and forest uses recorded by community members and trained scientists between 2007 and 2009 at 34 sites in Madagascar, Nicaragua, the Philippines, and Tanzania (N = 300 pairs of observations). The diagonal line represents y = x. Abbreviations: B, birds; M, mammals; R, resource use.

Table 8a. Measures of relative abundance and trend for birds, mammals, and resource uses recorded by community members and trained scientists between 2007 and 2009 (N = 300 pairs of observations).

	Birds (n = 180)				Mammals (n = 93)				Resource use (n = 27)			
	Community members		Trained scientists		Community members		Trained scientists		Community members		Trained scientists	
Measure	Mean (M)	Standard error (SE)	M	SE	M	SE	M	SE	M	SE	M	SE
Number of individuals per hour	0.98	0.09	0.99	0.09	0.42	0.07	1.54	0.28	0.54	0.23	0.72	0.20
Absolute trend in relative abundance	–0.02	0.02	–0.04	0.02	0.01	0.01	–0.09	0.07	–0.10	0.05	–0.29	0.11
R^2 of absolute trend	.22	.02	.20	.02	.32	.03	.25	.03	.31	.05	.43	.06
Relative trend in abundance index	–0.01	0.02	–0.05	0.02	–0.04	0.04	–0.09	0.04	–0.22	0.10	–0.30	0.08
Standard deviation	0.02	1.7×10^{-3}	0.02	9.5×10^{-4}	0.01	9.4×10^{-4}	0.02	3.5×10^{-3}	0.01	2.4×10^{-3}	0.01	2.8×10^{-3}
Coefficient of variation	1.31	0.06	1.47	0.06	1.41	0.08	1.58	0.09	1.89	0.16	1.53	0.14

Table 8b. Mean Pearson correlations for paired time series of data and the number of observations in each paired series of observations for each observation type.

	Birds		Mammals		Resource use	
Measure	Mean (M)	Standard error (SE)	M	SE	M	SE
Pearson's correlation coefficient	.07	0.03	.17	0.05	.27	0.10
Number of observations per series	7.42	0.13	6.89	0.21	6.07	0.38

Figure 11. Miskito community members in Nicaragua selecting the mammal species they would like to monitor. Photograph: Sune Holt.

to communities, the local communities may have an incentive to report false positive trends in those natural resources so that they can continue to harvest the resources or to be paid, even though the resources may actually be declining. Periodic triangulation of the monitoring results will therefore be required, but this is not different from any well-designed natural resource management initiative, whether the monitoring is implemented by communities, the government, or the private sector (Danielsen et al. 2011). Triangulation could be based on random spot checks in which a subset of the area is resampled using other monitors or other field methods (e.g., remote sensing of forest cover). It could also be combined with a statistical analysis of the community-based data to search for anomalies or trends that are beyond the normal or expected range.

Here, we have shown that local people and trained scientists can be equally good at collecting data and, therefore, that local communities can play this role in monitoring if schemes are organized to facilitate their engagement.

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Supplemental material

The supplemental material is available online at *http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biu001/-/DC1*.

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