Conservation and the botanist effect

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ABSTRACT

Over the last few decades, resources for descriptive taxonomy and biodiversity inventories have substantially declined, and they are also globally unequally distributed. This could result in an overall decline in the quality of biodiversity data as well as geographic biases, reducing the utility and reliability of inventories. We tested this hypothesis with tropical tree records ($n = 24{,}024$) collected from the Eastern Arc Mountains, Tanzania, between 1980 and 2007 by 13 botanists, whose collections represent 80% of the total plant records for this region. Our results show that botanists with practical training in tropical plant identification record both more species and more species of conservation concern (20 more species, two more endemic and one more threatened species per 250 specimens) than untrained botanists. Training and the number of person-days in the field explained 96% of the variation in the numbers of species found, and training was the most important predictor for explaining recorded numbers of threatened and endemic species. Data quality was related to available facilities, with good herbarium access significantly reducing the proportions of misidentifications and misspellings. Our analysis suggests that it may be necessary to account for recorder training when comparing diversity across sites, particularly when assessing numbers of rare and endemic species, and for global data portals to provide such information. We also suggest that greater investment in the training of botanists and in the provisioning of good facilities would substantially increase recording efficiency and data reliability, thereby improving conservation planning and implementation on the ground.

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1. Introduction

Species losses are occurring at unprecedented levels (Novacek and Cleland, 2001; Wilson, 2000) and anthropogenic pressures have been identified as the major cause (Vitousek et al., 1997). The rate at which we are losing biodiversity is projected to increase in the face of global environmental change (Brook et al., 2008; Stork, 2010). In order to conserve species and ecosystems effectively we need reliable information on the distribution of biodiversity (Pimm and Lawton, 1998), particularly because limited resources (James et al., 1999) force us to focus conservation efforts on the most important areas in greatest need (Margules and Pressey, 2000).

At the same time, resources for descriptive taxonomy, collections and biodiversity inventories are declining (Disney, 1989; Ehrenfeld, 1989; Gaston and May, 1992; Gee, 1992; Wheeler et al., 2004; Whitehead, 1990), and they are also globally unequally distributed. Higher education institutions often do not replace retiring taxonomists (Feldmann and Manning, 1992), and while university ecology and conservation curricula increasingly emphasize statistics and the use of Geographical Information Systems, the number of courses offered in systematic biology or practical field skills has been widely reduced (Muir and Schwartz, 2009; Noss, 1996). These trends and the fact that measures for academic performance such as the citation index do not favor basic taxonomic work (Samyn and Massin, 2002; Valdecasas et al., 2000) decrease the incentive for students to enter a career in systematic biology. Today, natural history is often thought of as a hobby (Rivas, 1997) and there is an increasing reliance on amateur taxonomists (Hopkins and Freckleton, 2002), volunteer labor (Brandon et al., 2003; Brightsmith, 2008; Darwall and Dulvy, 1996; Haag, 2005; Lovell et al., 2009; Schmeller et al., 2009), and 'parataxonomists' (Basset et al., 2004). Declining support for basic biodiversity inventories hits the tropics particularly hard because their biodiversity remains severely understudied (Prance et al., 2000) and resources for training and employing biodiversity recorders are chronically inadequate.

Declining resources for taxonomy and training may mean that the quality of collected biodiversity data decreases, and varies from area to area depending on the available resources for taxonomic identification. For example, almost two thirds of a sample of 80 recent ecological papers did not state how correct identifications were verified, suggesting that neither expert taxonomists' knowledge nor identification literature were used (Bortolus, 2008). Random observer effects, introducing noise in reported species richness and numbers of species of conservation concern, present a widely acknowledged problem (Archaux, 2009; Leps and Hadincova, 1992). Systematic effects have been documented less frequently, but understanding and accounting for such effects is extremely important as they may introduce directional biases into census estimates. It is conceivable that a field botanist with less training and fewer resources may be more prone to misidentifications (Scott and Hallam, 2003) and identify fewer species and rarities. Such an effect would severely hamper our ability to pinpoint areas of conservation priority because we would be unsure whether the data collected were a reliable reflection of the actual species pool or strongly biased due to the limited taxonomic resources.

In this paper we collated an extensive database of plant records from the Eastern Arc Mountains (EAM), a series of mountain ranges within the Eastern Afromontane biodiversity hotspot (Mittermeier et al., 2005), and examined the potential effects of the level of the botanists' training and the resources available to them on biodiversity assessments. Tanzania provides a good case study because there, as in many other tropical countries, professional botanists are becoming rare, the herbaria are under-funded and understaffed, and yet Tanzania has a relatively well-documented flora (Beentje and Smith, 2001) and probably the largest number of vascular plant species of any country in tropical Africa (Roy E. Gereau, Missouri Botanical Garden, pers. comm.).

In our analysis we focused on three questions:

(1) Are the training of botanists and the resources available to them better predictors of the documented numbers of species and threatened or endemic species than: (a) actual differences in plant diversity, (b) sampling intensity, and (c) the range and number of sample locations?
(2) Is data quality related to available identification resources, e.g. do projects that provide their botanists with access to good herbarium facilities generate fewer misidentified records?

(3) Are the perceived plant diversity patterns across the EAM (and associated conservation priorities) biased by a 'botanist effect' (the spatial distribution botanic training and resources)?

Addressing these questions is an important first step towards understanding the influence of biodiversity inventory training and resources on conservation planning. While the loss of taxonomic expertise is not a novel phenomenon, to our knowledge its consequences on biodiversity assessments particularly in the notoriously understudied tropical forests have not been systematically analyzed. An understanding of this is essential in the face of rapid biodiversity loss and continued financial cuts to herbaria and museums.

2. Material and methods

2.1. Study area

The EAM (Fig. 1) are a chain of 13 ancient crystalline mountain blocs composed of heavily metamorphosed Precambrian basement rock and estimated to have been uplifted in the Miocene 30 million years ago (Schlüter, 1997). The mountains stretch from south-east Kenya to south-central Tanzania and are under the direct climatic influence of the Indian Ocean. Today, they support ~3300–5100 km^2 of tropical forest (Burgess et al., 2007; Platts et al., 2010), which may be less than 30% of the original forested area (Burgess et al., 2007).

2.2. Data

2.2.1. Species records

We collated vegetation plot assessments for the region (n = 1909), totaling 56,515 records (49,032 identified to species) collected by 13 (leading) field botanists. All records were taxonomically standardized to the African Flowering Plants Database (2008), and further updated by reference to taxonomic revisions and monographs by Roy E. Gereau, Missouri Botanical Garden. In the analysis only trees with a diameter at reference height (DRH; 1.3 m up the stem or above buttresses) greater than or equal to 200 mm (n = 24,024 identified to species; in 1863 plots) were considered, the minimum DRH that had been sampled by all botanists. Because the number of trees assessed by the botanists differed (371–4594), we randomly sampled 250 individuals out of all the trees assessed by each respective botanist, and recorded the number of species found, also noting the numbers of threatened (Gereau et al., 2010) and endemic species (Roy E. Gereau, unpublished data) reported. The results were averaged over 1000 repetitions.

2.2.2. Botanist data

The botanists' training and resources were scored in eight categories (Table 1). We derived the scoring system through discussion with three active field botanists, focusing on factors that are both important for accurate botanical work and objectively measurable. The scores were kept as general as possible, typically only differentiating three categories, in order to minimize errors resulting from subjective decisions near boundary placements. We were able to score all categories with a high level of confidence for 13 botanists (many of whom are authors on this paper) for the final analysis. Data quality was measured in six categories: percentage of: (1) unidentified species, (2) species with uncertain identification, (3) almost certainly misidentified species (species recorded way outside their recognized distribution area (different continent or part of Africa) and which are not known to have been introduced), (4)
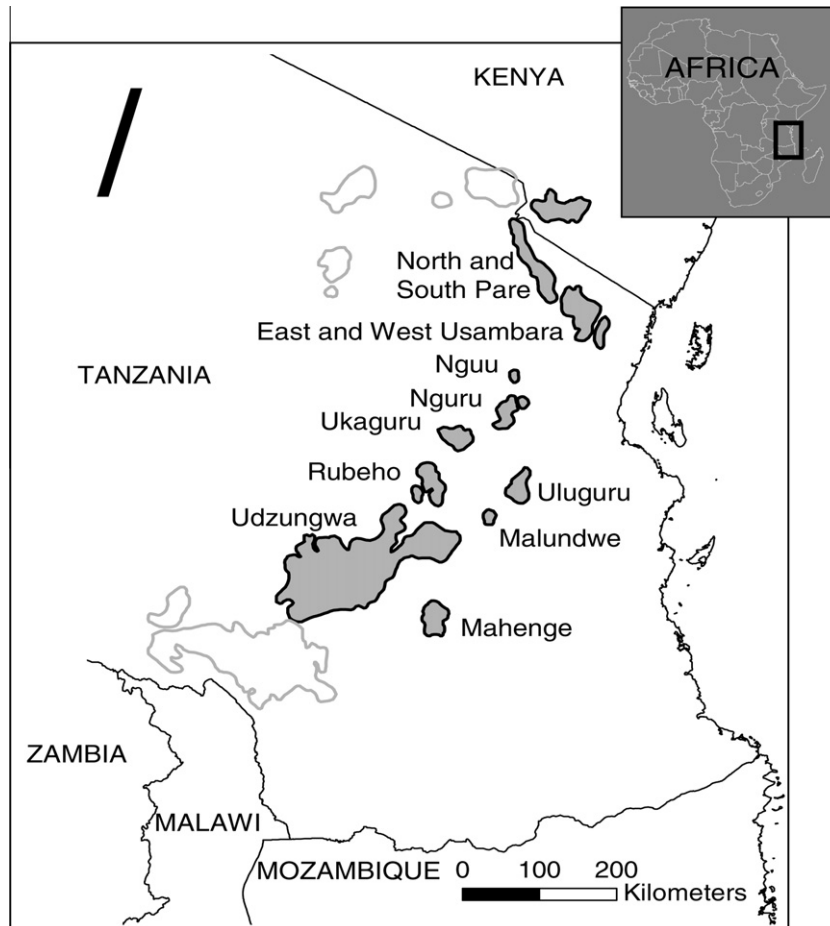
Fig. 1. Map of the Eastern Arc Mountains, projected to UTM S37 with datum WGS84.

misspelled species, (5) species with uncertain identification due to spelling errors and (6) unrecognizable species due to spelling errors (see Table S1 in Appendix A, Supplementary material).

2.2.3. Other predictor variables

In addition to the levels of the botanists' training and available resources we considered nine other candidate predictors, which would be expected to drive the dependent variables (numbers of species, threatened and endemic species recorded) in the absence of a botanist effect: minimum altitude sampled, altitude range sampled, number of vegetation plots sampled, number of mountain blocs sampled, number of assessed trees ⩾200 mm DRH, number of days spent in the field, and number of days spent in the field multiplied by number of field staff on those days (person-days), predictive estimates of species richness in the sampled mountain blocs, and predictive estimates of species richness in the sampled mountain blocs scaled by the numbers of species modeled per mountain bloc (two types of scaling: predicted richness/number of species modeled, and predicted richness/log (number of species modeled)). The reason for scaling the predictive estimates of species richness in the sampled mountain blocs by the number of species per mountain bloc was to account for potential biases in the modeled predictions as it is possible that more intensively sampled mountain blocs are predicted to be more species rich only because their climate space has been sampled more intensively. For threatened and endemic species we also included their relative richness (ratio of the number of these species to the total species richness in the sampled mountain blocs). Pre-

dicted numbers of species in the sampling areas were based on regional-scale climatically driven species distribution models (Platts et al., 2010). Uncertainties associated with these variables are noted; for example, the botanists may have sampled only a small area of the entire bloc and the model predictions themselves are prone to biases; however, they are a best possible approximation. There is also a risk of circularity in that data collected by the botanists were used to develop the species distribution models. However, as this is likely to increase the probability of committing a Type II error (increased chance of accepting the null hypothesis that there is no botanist effect when it is untrue), it makes our tests for a botanist effect more conservative, i.e. we can have more confidence in any significant botanist effect found.

2.3. Analysis

2.3.1. Species diversity recorded by botanists

We established significant predictors for the dependent variables: (1) species richness, (2) numbers of threatened species and (3) numbers of endemic species found by the botanists using a linear regression approach with the following general procedure: Firstly, to avoid inflated standard errors, we tested for collinearity between predictor variables (Zuur et al., 2007). The total set of candidate predictors was reduced to the strongest uncorrelated set (Pearson's $r < 0.7$) according to the predictive power of variables in univariate tests (Quinn and Keough, 2002). There is a risk of this procedure resulting in the exclusion of driving variables, and we therefore present all collinear variables in Table S2 (Appendix A).

Table 1
The scoring system used to measure the training and resources available to the botanists, on the basis of the expert opinion of three leading botanists.

Category	Score	Explanation
Regional experience	0	Less than 5 years (sum of actual time spent in the field and in the herbarium) of experience in identifying plants from tropical East Africa
	0.5	Five years or more of experience in identifying plants from tropical East Africa but less than 5 years of experience in the Eastern Arc Mountains
	1	Five years or more of experience in identifying plants from the Eastern Arc Mountains
MSc	0	No botany related MSc
	0.5	Partly botany related MSc
	1	Botany related MSc
PhD	0	No botany related PhD
	0.5	Partly botany related PhD
	1	Botany related PhD
Training	0	No formal training in tropical plant identification
	0.5	Less than 6 months of formal training in tropical plant identification
	1	Six months or more of formal training in tropical plant identification
Herbarium access	0	No access to a worldwide leading herbarium for East Africa with good facilities and extensive collections (East African Herbarium, Kew, Missouri) for specimen identification
	1	Access to a worldwide leading herbarium for East Africa for specimen identification
Herbarium staff	0	Never worked as herbarium staff
	0.5	Worked as herbarium staff for part of the career
	1	Career as herbarium staff
Access to identification literature	0	No access to identification literature
	0.5	Occasional access to the complete Flora of Tropical East Africa and other identification literature (e.g. upon visiting a herbarium)
	1	Full access to the complete Flora of Tropical East Africa and other identification literature
Collaboration with taxonomic experts	0	Never collaborated with expert taxonomists
	0.5	Occasional collaboration with expert taxonomists
	1	Regular collaboration with expert taxonomists

The elimination procedure left us with over 10 candidate predictors in all three analyses (Appendix A, Table S3). Because this set was still impractically large, in each case we used hierarchical partitioning (Chevan and Sutherland, 1991) to identify a small subset of the predictors most likely to play a critical role in determining the value of the dependent variable. The hierarchical partitioning function implemented in the R library *hier.part* (Walsh and Mac Nally, 2008) currently only allows for the simultaneous analysis of 12 predictors. Where more candidate predictors were selected for the analysis (Appendix A, Table S3), we randomly selected 12 predictors for the hierarchical partitioning and averaged the results for each predictor over 100 repetitions. Using the reduced set of predictors (Appendix A, Table S3) we then fitted a multiple additive linear regression model. Validation procedures, following Zuur et al. (2009), indicated no problems associated with assumptions of normality and heterogeneity of variance. To find the minimum adequate model in each case, we applied a backward stepwise selection on the basis of the partial *F*-statistic. Where model validation revealed a Cook's distance greater than one for one or several of the data points, the analysis was undertaken both with and without these observations in order to assess if they had any significant impact on the structure of the minimum adequate model. The respective contribution of each variable towards explaining the variation in reported species richness and numbers of threatened and endemic species was established by decomposing the variance in a partial regression (Zuur et al., 2007).

2.3.2. Data quality

We employed a multivariate approach to establish whether particular aspects of the resources available to the botanists were significantly associated with the quality of the generated plant record data (for measures see Appendix A, Table S1). The analysis consisted of two steps – ordination and vector fitting. The use of Non-metric Multidimensional Scaling (NMDS), one of the most robust ordination methods (Minchin, 1987), allowed us to account for non-normality in our data. We based dissimilarity on Gower distance (Gower, 1971), and used 20 iterations with random starts to seek the most stable solution (minimum stress). Subsequent to the ordination we fitted predictors representative of the botanists' resources (Table 1) as vectors onto the ordination. We calculated squared correlation coefficients (R^2) for each predictor and established their significance in 1000 random permutations.

2.3.3. Relationship between inventory funding, botanist training and perceived conservation importance

Previous analyses suggest that perceived patterns of plant diversity in the EAM are better explained by the total funding invested in botanical inventories per mountain bloc between 1980 and 2007 than by environmental conditions or sampling intensity (Ahrends, unpublished results; see Appendix A, Table S4 for all candidate environmental predictors tested in this analysis). We tested whether this may partly be due to funding influencing the skill levels of employed botanists, which may in turn impact the number of species found. Firstly, we analyzed correlations between funding and botanic training, and subsequently tested for a botanist effect on perceived biodiversity by modeling plant recording efficiency on the predicting variables botanist training and number of field days. We also included an interaction term between these two predictors because recording efficiency is likely to vary with the number of available field days (a minimum number of field days are needed to collect efficiently). A botanist training score for each individual mountain bloc was derived as follows

$$\sum_{b=1}^{B}((r_b/R) \times t_b)$$

where b is an individual botanists, rb is the number of records made by them, t_b is their training score, and B and R are the total number of botanists and records, respectively. In total, we developed three models (for species richness, the number of threatened species

and the number of endemic species). Recording efficiency was measured as the number of recorded species divided by the logarithm of the number of records. This type of transformation was chosen based on Mosteller and Turkey's bulging rule from the Box-Cox family of transformations (Zuur et al., 2007).

The plant species data were based on a recent compilation of all available plant records for the area, a dataset totaling 75,631 records of specimen label data from the Missouri Botanical Garden's TROPICOS database (http://www.tropicos.org/), with specimen collections for the EAM from a wide range of herbarium and literature sources, and from 2216 vegetation plot assessments (including those used in this paper). These data were recorded by over 500 collectors; detailed information was available for only 13 of these individuals. The botanist variable is, however, representative in our view because the 13 botanists participating in this study have made major contributions to the assessment of the regional flora: they have collected 80% ($n = 60,193$) of the currently available (i.e. digitized) plant records for the EAM, and over 90% in four of the 12 mountain blocs (East Usambara, Nguru, Nguu, Ukaguru). The botanists also spanned a range of training and other taxonomic resource levels. Model selection, validation, search for the minimum adequate model and procedures for dealing with extreme observations were as outlined above.

All statistical analyses were performed in the "R" statistical and programming environment version 2.9.2 (R Development Core Team, 2009) and its libraries hier.part (Walsh and Mac Nally, 2008), nlme (Pinheiro et al., 2009) and vegan (Oksanen et al., 2009).

3. Results

3.1. Species diversity recorded by botanists

The botanists' training in tropical plant identification was a highly significant predictor for reported species richness, with training and the number of person-days explaining 96% of the variation in the number of species documented (Table 2). Other candidate predictors, such as overall species richness in the collection areas and predictors representative of the heterogeneity of the sampled locations (altitude range, number of plots, and number of mountains) were not found to be significant. The selection of significant predictors was consistent across the analyses with and without a single observation with a Cook's distance greater than one. The coefficients show that, on average, a trained botanist found ~20 more species for every 250 individuals recorded than an untrained botanist, whereby it did not make a difference whether the botanist had received more or less than 6 months of training on tropical plant identification. The overall model fit dropped by 14% when the botanists' training was removed as an explanatory variable, and by 33% when person-days was removed (Fig. 2), suggesting that survey intensity in the field is more important than training in determining species richness.

Models for reported numbers of threatened and endemic species showed that trained botanists found more threatened and endemic species, but contrary to species richness, training of more than 6 months had significant impact relative to the effect of training for less than 6 months. Botanists who had received more than 6 months training found ~1 more threatened and ~2 more endemic species for every 250 individuals recorded than an untrained botanist (Table 2), and the overall model fit dropped by 20% and 30% when the botanists' training was removed as an explanatory variable for recorded numbers of threatened respectively endemic species (Fig. 2).

It is necessary to exclude the possibility that better trained botanists simply visited more diverse areas. Correlations between the level of training and the modeled total plant diversity of the areas visited were insignificant (Pearson's r [training, total species richness] = 0.136, $P > 0.1$; Pearson's r [training, total number of threatened species] = 0.039, $P > 0.1$; Pearson's r [training, total number of endemic species] = -0.122, $P > 0.1$).

3.2. Data quality

Out of 70,081 records, 7857 (11%) were not identified, 36 (<1%) almost certainly misidentified, 4158 (6%) were misspelled and 7% of the misspelled records were entirely unrecognizable. Had the original data been used without checking and corrections being made, overall species richness would have appeared to be nearly twice as high (1806 species instead of 925) due to spelling errors, use of synonyms and misidentifications. Multivariate analysis showed that the most significant predictors for data quality were access to herbaria and academic training (Fig. 3). Projects that provided botanists with access to one of the worldwide leading herbaria for East Africa tended to produce more thoroughly checked data (no species almost certainly misidentified versus 0.3% misidentifications for data where no access to such a herbarium was provided, and 6% of recorded species misspelled versus 24% (difference significant: $t = -4.41$, d.f. = 6, $P \leqslant 0.01$)). Botanists with better herbarium access seldom provided records that were unrecognizable due to spelling mistakes and more frequently marked identifications as uncertain. Overall, data quality was highest in the 1980s and since then has declined whilst collection rates have increased slightly (see Appendix A, Fig. S1). Average available funds per survey were highest in the 1990s (see Appendix A, Fig. S1), but so was the proportion of misidentifications, indicating that projects may have inadequately invested in herbarium identification and botanic resources.

Table 2
Model results for species richness and numbers of threatened and endemic species found by the botanists.

| Variable	Predictor	Coefficient	P	F	d.f.	R^2 (adj.)
Species richness	General model		$\leqslant 0.001$	57.38	8	0.96 (0.94)
	Intercept	9.59	$\leqslant 0.05$			
	Training < 6 months (score = 0.5)	22.28	$\leqslant 0.01$			
	Training > 6 months (score = 1.0)	19.34	$\leqslant 0.01$			
	Person-days	0.12	$\leqslant 0.001$			
Number of threatened species	General model		$\leqslant 0.01$	9.64	9	0.76 (0.68)
	Intercept	−0.35	>0.05			
	Training < 6 months (score = 0.5)	−0.03	>0.05			
	Training > 6 months (score = 1.0)	1.24	$\leqslant 0.05$			
	Number trees sampled	3.73×10^{-4}	$\leqslant 0.05$			
Number of endemic species	General model		$\leqslant 0.001$	13.24	9	0.82 (0.75)
	Intercept	−0.31	>0.05			
	Training < 6 months (score = 0.5)	0.33	>0.05			
	Training > 6 months (score = 1.0)	1.93	$\leqslant 0.01$			
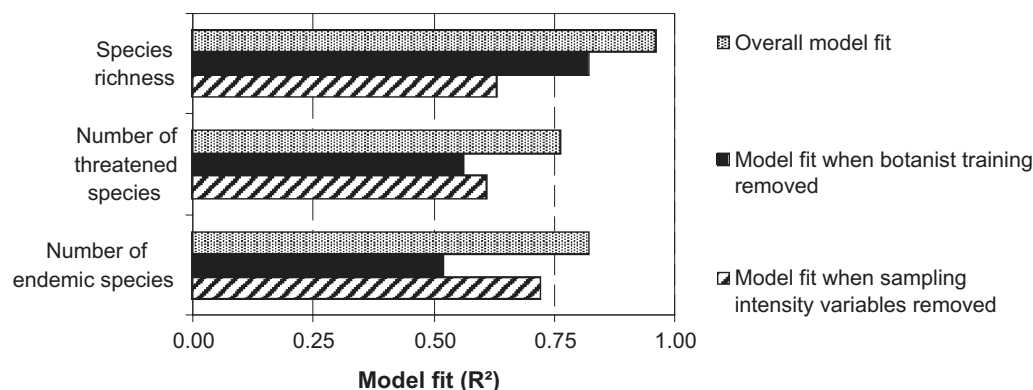
Fig. 2. Relative importance of the predictors in explaining the number of species, the number of threatened species, and the number of endemic species found by the botanists. (For more explanation on the variables see Table 1, and for the associated model coefficients see Table 2.)
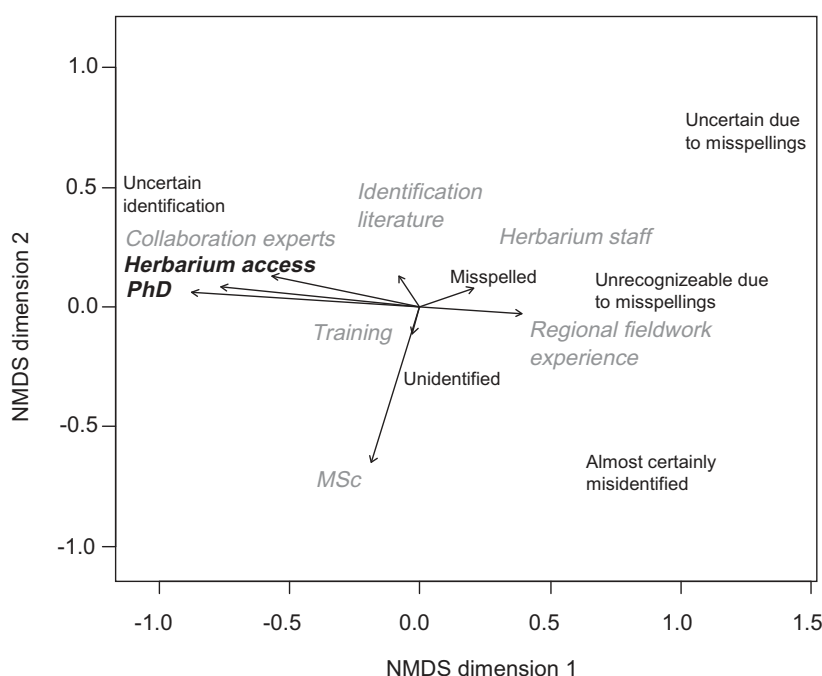
	NMDS dimension 1	NMDS dimension 2	R^2	P
Regional fieldwork experience	1.00	-0.07	0.11	>0.1
MSc	-0.28	-0.96	0.33	>1.0
PhD	-00.1	0.07	0.56	<0.01
Training	-0.26	-0.97	0.01	>0.1
Herbarium access	-0.99	0.11	0.43	<0.05
Herbarium staff	0.93	0.36	0.04	>0.1
Access to identification literature	-0.54	0.84	0.02	>0.1
Collaboration with taxonomic experts	-0.97	0.23	0.25	>0.1

Fig. 3. Ordination (NMDS) graph of the quality of the collected data and predictors. The predictors are fitted as vectors, pointing in the direction of the most rapid change in the particular predictor. The length of a vector is proportional to the predictor's correlation with the ordination. All predictor names are in italics; significant predictors are highlighted in bold; all others are in grey.

3.3. Relationship between inventory funding, botanist training and perceived conservation importance

There were significant positive correlations between the available funds for surveys, the number of records collected, the training score of the employed botanists multiplied by their time in the field, and the perceived plant diversity of the respective mountain blocs (Fig. 4). These correlations suggest that funding influences both sampling intensity and botanist quality, which in turn influence perceived biodiversity. It is also likely that there is positive circular reinforcement between perceived biodiversity and funding (Ahrends, unpublished results). In order to test for a botanist effect inde-
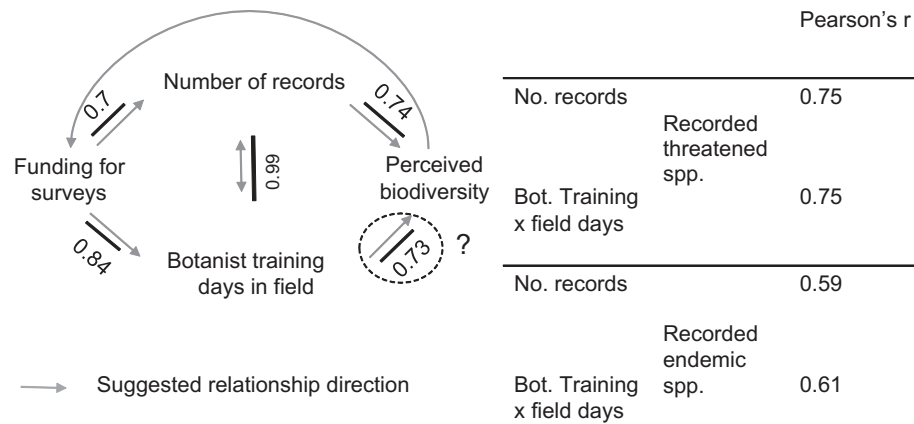
Fig. 4. Relationships between funding, sampling intensity, botanist training and perceived biodiversity patterns in the EAM. Numbers represent Pearson correlation coefficients (for species richness; correlations for threatened and endemic species are given in the table to the right). The arrows show the suggested direction of the relationship. While it has previously been suggested that funding and the number of records influence perceived biodiversity which in turn influences funding (Ahrends, unpublished results), this paper's analysis focuses on the encircled relationship between botanist resources and perceived biodiversity.

pendent of the number of records that have been collected we modeled recording efficiency (number of species found over number of records collected) on the standardized botanist training score and the number of field days. The interaction between these two explanatory variables was significant for all three models (Table 3).

In terms of cost per recorded species, botanists with little training were least efficient, and botanists with an intermediate level of training (6 months or less) were most efficient: the average cost to projects that employed botanists trained to an intermediate level (mean training score of 0.5) were US$ 538, US$ 3843 and US$ 4798 per reported species, endemic and threatened species respectively; projects that employed intensively trained botanists (average training score >0.5) invested US$ 1559, US$ 11,959 and US$ 18,764; and projects that employed poorly trained botanists (average training score <0.5) invested US$ 762, US$ 9311, and US$ 10,119 (all US$ values standardized to the year 2007 with a GDP deflator; www.measuringworth.com). This is before accounting for the financial cost of correcting identification and entry mistakes. However, botanists with training of 6 months or more made a greater overall contribution to reported floristic diversity in the EAM: they documented 296 species (46 threatened and 57 endemic) not reported by botanists with less training. Botanists with training of less than 6 months reported only 57 species (seven threatened and eight endemic) that had not been collected by more intensively trained botanists. This is not due to differences in recording intensity: botanists with less than 6 months training provided almost 50% of the plant records for the study area.

4. Discussion

Concerned about the decline of support for taxonomy and field biology, we analyzed whether this may mean that the quality of

collected biodiversity data decreases overall, and non-uniformly from area to area, depending on the resources available for species identification. Our findings suggest that better trained botanists record both more species and more species of conservation concern.

Our analysis was speculative in nature, due to the inherent subjectivity involved in designing a scoring system, and because we had data from only 13 botanists, who sampled in different areas for which true species richness and levels of endemism and threat are unknown. Having more data points would have meant greater statistical power and would have allowed us to include more predictors into the modeling process; i.e. reduced the risk that real predictors have been excluded during the initial predictor selection process. However, the information collected for each of these botanists and their records were detailed and extensive, and the emerging pattern was strong and consistent across all analyses, increasing our confidence in the results.

Despite the above caveats it is striking that the number of person-days and level of training almost entirely explained spatial variations in the numbers of species the botanists found. Whilst for species richness person-days had greater explanatory power than training, for numbers of threatened and endemic species found, training was the most influential predictor variable, explaining up to 30% of the variation on its own. Access to good herbarium facilities had a strong effect on the quality of the data generated. Our results show that projects can underestimate time and budget needed for herbarium identification, and, alarmingly, the quality of the plant data collected in the EAM has declined since the 1980s. Qualitatively poor data can lead to cascades of errors in ecological research (Bortolus, 2008), and the analyses of the unchecked EAM dataset would have operated with nearly as many imaginary species as actual species.

Table 3
Models for recording efficiency. Irrespective of the number of number of records made, better trained botanists and/or those that have more time in the field find more species.

Variable	Predictor	Coefficient	P	F	d.f.	R^2 (adj.)
Species richness recording efficiency	General model		⩽0.05	7.61	7	0.77 (0.66)
	Intercept	−39.7	>0.1			
	Training score: field days	−2.21	⩽0.05			
Threatened species recording efficiency	General model		⩽0.001	20.28	7	0.9 (0.85)
	Intercept	−5.74	>0.1			
	Training score: field days	−0.37	⩽0.01			
Endemic species recording efficiency	General model		⩽0.05	6.23	7	0.73 (0.61)
	Intercept	−3.17	>0.1			
	Training score: field days	−0.23	⩽0.05			

Perceived plant diversity patterns across the EAM (and associated conservation priorities) are largely driven by funding invested for biodiversity inventories (Ahrends, unpublished results). This may be because better funded inventory projects facilitate more time in the field and employ better trained botanists. Further research into these biases in other areas, taxonomic groups and at different scales is necessary. It is possible that this study's findings cannot be generalized across all tropical countries as the influence of data generated by untrained recorders on conservation assessments varies. However, the finding that funding, botanical training and survey intensity effects almost entirely explain the variation in the perceived plant diversity patterns in the EAM is alarming, and stresses the importance of greater transparency of data that underpin conservation decisions. We recommend that schemes using survey data to prioritize areas for conservation collect comprehensive metadata about the origins of the data, and test and potentially account for biases. Furthermore, potential data quality issues should be documented by massive scale data portals such as GBIF (http://www.gbif.org/). Finally, where possible, primary data collectors should be involved in analyses and publications of their data to ensure that their first-hand understanding of potential biases and problems informs these processes.

The importance of practical training in identification and recording accuracy has previously been documented, e.g. for invertebrates (Lovell et al., 2009), coral reef fish (Darwall and Dulvy, 1996), and lichens (McCune et al., 1997), and a wide range of predominantly faunal studies have shown that observer skills can affect detection probability (Evans et al., 2009; Fitzpatrick et al., 2009; Jiguet, 2009; Lindenmayer et al., 2009; Pierce and Gutzwiller, 2007). In our case study, the detection probability was theoretically equal to one (large trees in a vegetation plot), but in practice was lower for untrained observers. Vascular plant studies may be affected by recorder skill effects for a number of reasons. Firstly, a less-well trained botanist may collect insufficient voucher material and/or field notes. Secondly, they may mistake a new species in the field for a species already collected, or may be more hesitant to identify a specimen as a new species (to science or to the region) or rarity – this requires a high level of taxonomic expertise and associated confidence. Thirdly, the identification of sterile specimens is often not possible with conventional keys and instead requires a high level of familiarity with the regional flora. Having revised morphology based identifications for the tropical tree genus *Inga* (Leguminosae) made during an ecological survey where many individuals were sterile, Dexter et al. (2010) found error rates between 6.8% and 7.6% of all individuals, and these errors had a measurable impact on ecological analyses. Finally, declining resources for herbaria mean that the time spent by professional taxonomists helping with the identifications is limited. Consequently, mathematical frameworks that account for heterogeneous detection probabilities in surveys (e.g. Etterson et al., 2009; Garrard et al., 2008; Zuur et al., 2009), mainly developed for fauna surveys, are also highly relevant to vascular plants (Chen et al., 2009; Garrard et al., 2008).

Good field data, particularly for the tropics, are limited in spatial coverage. Regionally focused distribution models can provide surrogates for full-coverage biodiversity inventories; however such estimates remain biased by the underlying species data (e.g. Platts et al., 2010). In this respect, botanists with an intermediate level of training can make extremely useful contributions by increasing data volumes and mitigating geographic biases (Abadie et al., 2008; Basset et al., 2004; Hopkins and Freckleton, 2002). Our analyses suggest that they find more species and species of conservation concern per funding and time unit than experts. In the EAM and also elsewhere (e.g. Lovell et al., 2009; Schmeller et al., 2009), intermediately trained recorders contribute high volumes of data and cover a large number of sites, because employment costs are lower and professionals frequently collect for herbaria

which have limited cupboard space and more focused 'interests', with common and widespread species tending to not be collected, and often not even recorded. For example, only 12 out of the 3450 species recorded in the Missouri Botanical Garden's database TROPICOS for the EAM have 50 or more records, the minimum number generally considered necessary for deriving species distribution models (Coudun and Gegout, 2006). The increasing number of ecotourism holidays (Cousins, 2007) can thus make valuable contributions to research and conservation of particular sites (Haag, 2005). However, the results also show that rare species are most reliably assessed with a high level of training, and this is where collaborations between volunteer-based/semi-professional and professional collections may be particularly fruitful: while volunteer or semi-professional collectors could be tasked with rapid assessments that aim to increase the data volume on readily identifiable species, experts could focus on assessments used for conservation planning and the supervision of the less-well trained botanists. (In this manuscript, the words 'experts' and 'professionals' denote intensively trained botanists with no reference to their employment status.)

Finally, the increasing pressure to define species' ranges accurately and to predict their future distribution in the face of rapid global environmental change (Parmesan and Yohe, 2003) calls for thorough biodiversity inventories and an understanding of the biases. Museums and botanical gardens have a major role to play in this endeavor (Primack and Miller-Rushing, 2009) and in the training of field biologists. Greater investment in the training of botanists and their provisioning with better facilities, we think, would pay significant dividends due to increased recording efficiency and reliability of data for conservation assessments, and reduced time for data cleaning. Greater data accuracy could also be achieved by combining morphological with molecular approaches such as DNA barcoding (Dexter et al., 2010; Hollingsworth et al., 2009). Reducing support for taxonomy and field biology means that we risk losing species and misdirecting generally scarce conservation resources simply because our data are not good enough.

5. Conclusions

Our study indicates that declining resources for field botany and taxonomy may result in reduced biodiversity data quality. This in turn could mean that chronically short biodiversity survey and conservation funds are inefficiently spent. Further study is needed to test whether these results hold true for other regions and taxonomic groups, where there may be a less strong reliance on volunteer and semi-professional labor for biodiversity assessments. We suggest that greater investments in museums and herbaria and the training of field biologists would pay dividends in terms of less effort needed for data cleaning and greater data reliability, thereby improving conservation planning and implementation on the ground.

6. Glossary

Parataxonomist: Coined as a parallel to 'paramedic', parataxonomists are (generally local) assistants to taxonomists. They have no scientific education in the research subject but have been trained in for example the collection and preparation of specimens and their sorting to morphospecies. The first parataxonomy course was held in Costa Rica in 1989 (Basset et al., 2004).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.08.008.

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