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Repeatability of Community Data: Species Richness Versus Gradient Scores in Large-scale Lichen Studies

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Abstract. *Repeated ecological assessments based on permanent plot data require sufficient data quality to detect a signal of change against a background of noise (sampling error of various kinds). We analyzed several components of error in the time-constrained method for sampling lichen communities used by the Forest Health Monitoring program: between-crew (Technicians), crew-to-expert, between-expert, and seasonal variation. Data were from the southeastern United States and Oregon. Two types of dependent variables were used: species richness and scores on lichen community gradients (responses to climatic and air quality gradients). Gradient scores were repeatable to within 2–10% for experts and technicians alike and did not differ between those groups. Species richness is much more difficult to estimate reliably. Despite relatively low species capture by technicians, the high repeatability in gradient scores demonstrates the statistical redundancy in information provided by various lichen species. These results imply that repeated assessments of species richness will contain considerable observer error, but that shifts in community composition may nevertheless be detected reliably.*

Many conservation organizations and government agencies have recently embraced large-scale acquisition of ecological and species inventory data. In so doing, much of the task of collecting biological data necessarily shifts from professionals trained in a narrow discipline to field technicians who may have little or no formal training in biology (e.g., Oliver & Beattie 1993). This same shift is also occurring in lichenology, as lichen communities become accepted as indicators of air quality, biodiversity, and climate change. Lichens are included in the Forest Health Monitoring program (FHM; Lewis & Conkling 1996), designed to monitor forest condition at a regional scale.

Effective monitoring based on permanent plot data requires the ability to detect a signal of change against a background of noise (sampling error of various kinds). We analyzed several components of error in the method for sampling lichen communities used by FHM: between-crew, crew-to-expert, expert-to-expert, and seasonal variation. Although lichen communities show little or no seasonal variation, it is possible that observer error changes through a season with improvement in skills or changes in motivation.

This paper reports these components of sampling error and evaluates the repeatability of estimates of species richness and scores on gradients in community composition. We did this in two regions of the country with very high lichen diversity. Repeatability of community sampling is rarely documented and we know of no other attempts to compare the repeatability of various community parameters. The rationale for including lichens in Forest

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Health Monitoring and the biological results from the first years of the project are presented elsewhere (McCune et al. 1996).

METHODS

Several classes of data were analyzed here. The "reference-plot study" consisted of several "reference plots" repeatedly sampled by several crews and by an expert during each of three weeks, at the beginning, middle, and end of the field season. "Multiple-expert trials" were single plots sampled by as many as 11 different observers, including multiple lichenologists, in a single season. An "on-frame audit" consists of independent samples of the same plot by an expert and a field crew member. "On-frame" refers to samples taken on the formal sampling framework. This is a "quarter-interpenetrating" design, whereby the whole region is sampled every year and an individual plot is resampled every fourth year (Messer et al. 1991). The basic lichen community method is first summarized, then each of these special data quality studies is described in detail below.

FHM lichen community method.—Lichen communities are assessed in FHM by determining the presence and abundance of macrolichen species on trees in 0.378 ha circular plots. Because the FHM program is designed to track regional changes, the lichen method was designed to maximize regional representativeness of a single plot. This is achieved by maximizing species "capture" at the expense of quantitative accuracy for individual species (McCune & Lesica 1992). The lichen plot is a circular area with 36.6 m (120 ft.) radius excluding four circular subplots used for measurements on the vascular vegetation. Where subplots have not been set up, an equal area is sampled by using a 34.7 m (114 ft.) radius circular plot, sampling the whole area within that radius. The field crew collects samples for mailing to lichen experts. The field methods are described in detail in the FHM Field Methods Guide (Tallent-Halsell 1994).

The method has two parts that are performed simultaneously. 1) In each plot, the field crew collects specimens for identification by a specialist, the collection representing the species diversity of macrolichens in the plot as fully as possible. The statistical population being sampled consists of all macrolichens on woody plants, excluding the 0.5 m basal portions of trees and shrubs. Living and dead trees as well as fallen branches are included in the sampling. 2) The field crew estimates the abundance of each species using a four-step scale: 1 = rare (< 3 individuals in plot); 2 = uncommon (4–10 individuals in plot); 3 = common (> 10 individuals in plot but less than half of the boles and branches have that species present); and 4 = abundant (more than half of boles and branches in the plot have the subject species present).

The sampling is time constrained to help standardize effort across crews and to facilitate scheduling crew activities (many other kinds of data are collected by the crew during the same visit to a plot). Sampling time is constrained by the following two rules: 1) Sampling continues for a maximum of two hours or until 10 minutes elapse with no additional species recorded. 2) At least 45 minutes in the eastern U.S. and 30 minutes in the western U.S. must be spent searching the plot, even if very few lichens are present.

Reference-plot study.—The reference-plot study was designed to measure several components of error: between crews, between crews and expert, and seasonal fluctuations. We used a balanced incomplete block design consisting of 4 observers (3 crews and 1 expert), 3 dates (beginning, middle, and end of field season), and 3 plots (blocks) representing a variety of forests in the vicinity of Asheville, North Carolina. Interactions between plots and the other factors were weak and nonsignificant and were therefore omitted from the final model.

Signal-to-noise ratio can be calculated explicitly as a ratio of the variance in on-frame scores (outside the reference-plot study) to the pooled within-plot variances from repeated observation. The noise term includes differences between observers and seasonal differences.

Multiple-expert trials.—We conducted two multiple-expert trials, one near Asheville, North Carolina and one near Portland, Oregon. The purposes of these trials were 1) to estimate the proportion of the total number of species on a plot that is obtained by experts and crews, 2) evaluate the influence of degree of training on "species capture," and 3) evaluate the extent to which expert skills are transferable between regions. In each case, a single plot was sampled a single time by multiple observers. In North Carolina, the plot was sampled by four experts and three trainees. The trainees had just completed the first three days of the one-week lichen training, but had no prior experience with lichens. In Oregon, the plot was sampled by ten experienced observers and one trainee, all on the same day. In both cases, the experts varied considerably in their degree of experience with that region's lichen flora. A total species list for each plot was constructed by combining the seven and eleven species lists, respectively. A single regional expert was responsible for assigning names to all samples in a given region. Observer experience was scored in two parts: overall experience with lichen floristics and experience with the flora of a particular region. Overall experience was rated on a three-step scale. "Experienced" observers had two or more peer-reviewed publications including or devoted to lichen floristics. "Intermediate" observers had a combination of formal and informal training giving a ready working knowledge of most common lichen genera and many species. "Beginner" observers knew only a small number of genera.

On-frame audits.—An on-frame audit consists of two independent samples of a plot, one by a regular field crew member and one by an expert (usually a professional lichenologist). They are "on-frame" in that the samples are taken as part of the regular data collection on the sampling framework, i.e., the hexagonal EMAP grid. The purpose of an audit is to conduct routine evaluations of performance by field crews, such that information on data quality is a regular part of the flow of data from the permanent plots. We report on the total of 15 audits taken in 1993 and 1994 from Colorado, northeastern U.S., southeastern U.S., and the Pacific Northwest.

Gradient analysis.—Raw data on species abundances are summarized into several plot-level indices: an air quality index, a regional climatic index, and species richness. The first two indices are extracted from the data by multivariate gradient modeling (McCune et al. 1996) using non-metric multidimensional scaling (NMS; Kruskal 1964, Mather 1976, McCune & Mefford 1995). The air quality index and regional climatic index have so far only been developed for the Southeast. We used NMS with the quantitative version of the Sørensen distance measure. The dimensionality of the data set was first determined by plotting a measure of fit ("stress") to the number of dimensions. A two-dimensional solution was requested of NMS since additional dimensions provided only slight improvement in fit. One hundred iterations were used for each NMS run, using random starting coordinates. Several NMS runs were used for each analysis to ensure the likelihood that the solution was stable and represented a con-

TABLE 1. Analysis of variance for the reference-plot study in North Carolina. An ANOVA table is given for each of three dependent variables: species richness, score on climatic gradient, and score on air quality gradient.

Source of variation	Sum of squares	DF	Mean square	F	p
Species richness					
Plot	934	2	467	28.6	0.000
Crew	1454	3	485	29.7	0.000
Date	4	2	2	0.1	0.890
Crew by date	52	6	9	0.5	0.774
Residual	212	13	16		
Score on climatic gradient					
Plot	567	2	284	2.5	0.116
Crew	1295	3	432	3.9	0.035
Date	641	2	320	2.9	0.092
Crew by date	933	6	155	1.4	0.287
Residual	1447	13	111		
Score on air quality gradient					
Plot	3132	2	1566	5.2	0.022
Crew	3569	3	1190	3.9	0.034
Date	837	2	419	1.4	0.286
Crew by date	2197	6	366	1.2	0.363
Residual	3945	13	303		

figuration with the best possible fit. Plots not in the data set used to calibrate the gradient models were assigned index values using an iterative prediction algorithm based on NMS (program NMSCORE, McCune, unpubl.).

Criteria for assessing data quality.—Data quality was assessed for each plot-level summary statistic (air quality index, climatic index, and species richness) with several criteria: species capture, bias, and accuracy. "Species capture" is the proportion of the total number of species in a plot (as determined from data collected by experts) that was captured in the sampling. Percent deviation in gradient score is calculated as: 100% × (observer's score − expert's score)/length of the gradient. Accuracy is 100% minus the absolute value of the percent percent deviation from "true" gradient scores, as determined from expert data. Bias is the signed deviation from "true" gradient scores, as determined from expert data. Both accuracy and bias are reported because inaccurate estimates are not necessarily biased. An expert is considered to be a person with extensive experience with the local lichen flora, in most cases with two or more peer-reviewed publications in which the person contributed floristic knowledge of lichens.

RESULTS

Reference-plot study.—As expected, plots (blocks) differed in species richness and scores on the two gradients (Table 1). Although species richness differed strongly among crews (particularly between the expert and the other three crews; Table 2), the gradient scores showed only minor differences among crews. All three community measures were seasonally stable. Effectiveness of the crews did not consistently change through the season as indicated by the nonsignificant date and interaction (crew × date) terms.

We found two data points representing minimal efforts by one crew member, when that crew member substituted for the regular person collecting the lichen data. In one case, only four species were collected (versus an average of about 20 species in that plot). The analysis was rerun with this crew removed. We found that this single person had inflated the between-crew variance and the residual variances for the score on the air quality gradient. Removal of this crew rendered the differences in gradient scores between the remaining crews and experts nonsignificant.

Signal-to-noise was high for all three community parameters for the expert in the reference plot study (3 for species richness and over 25 for the two gradient scores; Table 3). Signal-to-noise ratios were much lower for the crews; however, two crews performed notably better than the other crew' (Table 3). Across both experts and crews, the climatic gradient had the strongest signal-to-noise ratio.

Another issue addressed by the reference-plot study was whether the repeated sampling will deplete the number of species in the plots. Even though each reference plot was sampled nine times

TABLE 2. Average accuracy and bias of estimates of species richness and gradient scores in the southeastern United States. Results are given separately for experts and trainees in the multiple-expert trials. Activities are described under "Methods." Accuracy and bias are both measured as percentages, relative to expert data (see text).

		Species richness		Score on climatic gradient		Score on air quality gradient	
	N[1]	% of expert	Bias	Acc.	Bias	Acc.	Bias
Reference plots[2]	16	61	−39	95.6	+2.4	88.9	−10.5
Multiple-expert trials, experts	3	95	−5	96.4	+3.6	95.3	−4.7
Multiple-expert trials, trainees (beginners)	3	54	−46	92.0	+8.0	95.0	−5.0
Certifications	7	74	−26	97.3	+2.4	97.9	−2.1
Audits	3	50	−50	89.7	+3.7	94.0	+2.7

[1] N = sample size.

[2] Excludes two minimal-effort outliers (see text).

TABLE 3. Signal-to-noise ratios in three lichen community indices, the "signal" being the between-plot variance from the on-frame plots and the "noise" being between-observer and between-date variance from the reference plot study.

	Lichen Community Index		
	Species richness	Climatic gradient	Air-quality gradient
Between-plot variance, 1993 on-frame	35.8	606.45	622.87
Signal:noise ratio			
Expert only	3.0	60.0	25.5
Crew 1	4.6	2.1	1.4
Crew 2	4.6	38.9	2.0
Crew 3	4.2	10.0	6.0
All 3 crews	2.6	2.6	1.4
Crews + expert	0.5	3.5	1.4

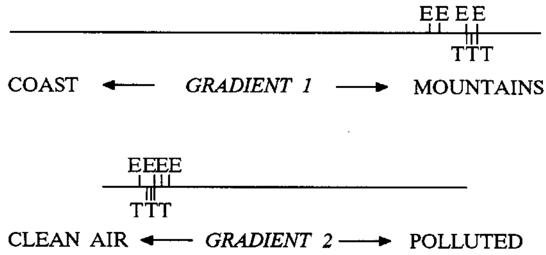

FIGURE 1. Replicate observations on a single plot in North Carolina by four experts ("E") and three trainees ("T"), scored on two multivariate community gradients in the southeast United States. Gradient 1 is a regional climatic gradient. Gradient 2 is an air quality gradient.

during one season, we found no indication of a decline in species richness through the season. Sampling once every four years according to the formal sampling design should not deplete species richness on the plot. This is another advantage of using a large plot. Nevertheless, conspicuous species with only one or two occurrences in a plot might be lost from the plot by sampling.

Multiple-expert trials.—When many observers collect data on the same plot a very complete species list results. In both cases reported here the plots were rich in species, containing at least 46 species of epiphytic macrolichens in Oregon and 56 in North Carolina (Table 4; Fig. 1). In North Carolina, observers used from 1–2 hours, while in Oregon, observers used from 1.5–2 hours.

No single observer exceeded 63% and 67% of the total species list in North Carolina and Oregon, respectively. Six of seven observers (including two trainees) in North Carolina found one or more species not found by any other observers (Table 4). The three trainees found between 38 and 66% of the expert's total (we used 65% as a criterion for passing training and audits for field crews).

Despite the relatively low species capture rates by both experts and beginners, scores on the gradients were relatively consistent, both among trainees and between trainees and experts (Fig. 1; Table 4). The percent deviation of trainees' scores from experts ranged from 7–9% for the climatic gradient and from 4–6% for the air quality gradient. In practice, obtaining 65% or more of the expert's species yielded index scores with acceptable repeatability (bias $< 10\%$ and accuracy $> 90\%$) for index scores. Using the combined species list as the minimum "true" species richness, none of the observers achieved accuracy and bias for species richness that were as good as those for the gradient scores.

The broad range of expertise in the multiple-expert plot in Oregon allowed us to evaluate the dependence of species capture rates on observer experience with lichen floristics. Both general experience and regional experience (i.e., experience with the local species) improved species capture rates (Fig. 2). In general, experienced observers found more species than intermediate and beginning observers. Exceptions to this trend are at least partly explained by familiarity with the regional flora. For example, some intermediate observers with local experience found more species than observers whose experience was concentrated in a different region.

TABLE 4. Repeated lichen community measurements from a single plot in North Carolina by seven observers, including 4 experts ("E") and three trainees ("T").

	Observer						
	E1	E2	E3	E4	T1	T2	T3
Number of species found	32	35	30	26	12	19	21
% of total species list	57	63	54	46	21	34	38
% of expert	100	109	94	81	38	59	66
Score on climatic gradient	77	84	85	79	85	85	84
Deviation from expert, %	0	7	9	2	9	8	7
Score on air quality gradient	30	27	25	28	26	27	27
Deviation from expert, %	0	−4	−8	−2	−6	−5	−4
Number of unique species	2	5	5	3	0	3	1

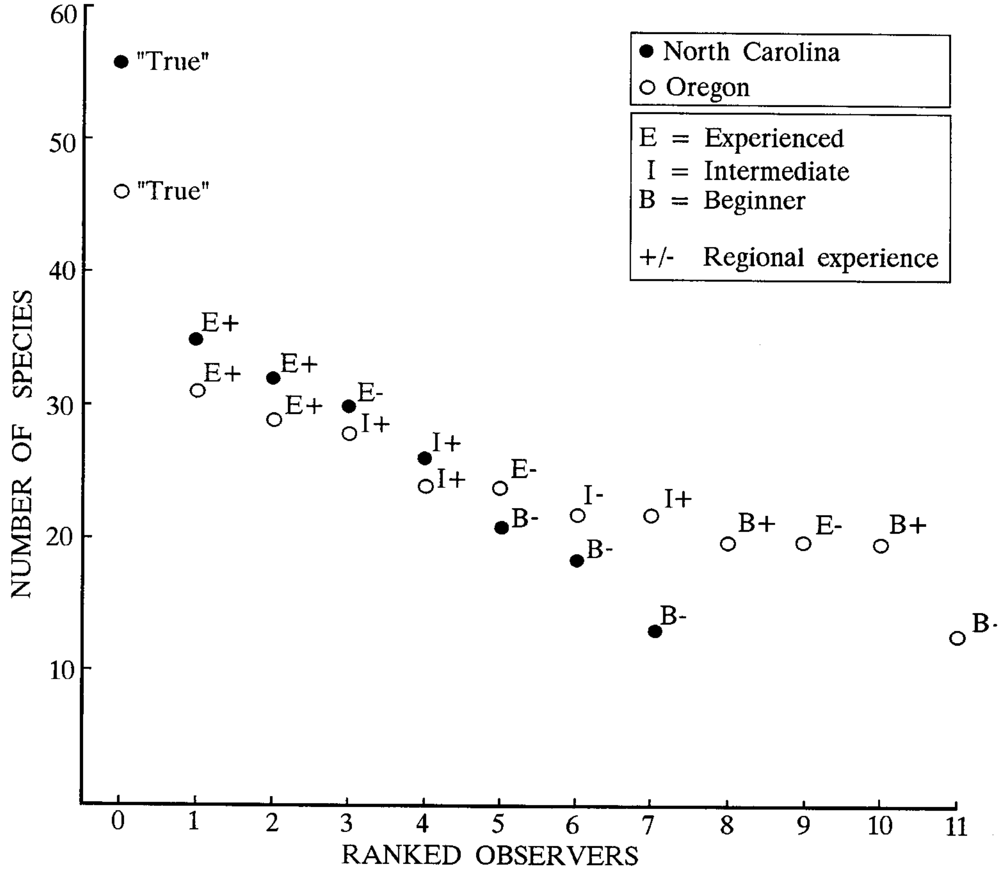

FIGURE 2. Dependence of species capture on degree of training and experience, based on multiple observers in a single plot in western Oregon and North Carolina. Each point represents an observer. The "true" values are the minimum number of species actually on the plot, based on the combined species lists for each plot.

On-frame audits.—Audits of field crews during the regular season indicate the quality of lichen data flowing out of the program. Each audit includes an independent data collection from a given plot by an expert and a field crew member. The number of species collected by the crew member relative to the expert is used as a rapid method of checking data quality and providing feedback to the crews. For 15 audits distributed among four regions, there is considerable variation in the species capture rate by the crew (Table 5). The most difficult area was the southeastern United States, where lichen diversity is typically high, many of the distinctions among species are subtle (particularly in the parmelioid genera), and crews had less prior botanical experience and training. Sample sizes were too small to compare with other regions.

TABLE 5. Species capture of lichen community data collected by technicians in "on-frame" sampling in various regions of the United States.

Region	Number of audits	Average species capture, %	Average species richness, expert
Colorado	2	83	11
Northeast	6	77	17
Southeast	5	56	29
Pacific NW	2	90	17

DISCUSSION

Two results of this study seem most important. First, species richness is very difficult to estimate, depending strongly on the skill, experience, and training of the observer. Second, scores on compositional gradients are relatively consistent across observers, even in cases where there is considerable variation in species capture by different observers. Each of these points is discussed further below.

With the concept of "biodiversity" becoming deeply entrenched in the management plans of government agencies and conservation organizations, there comes a great need to inventory, monitor, and understand underlying factors controlling diversity.

Perhaps the simplest and most readily communicated descriptor of diversity is species richness (Whittaker 1972). Some sampling characteristics of species richness, in particular species-area relationships have been studied in detail (Arrhenius 1921; Connor & McCoy 1979; MacArthur & Wilson 1967; Palmer 1995) and are widely applied to determine the number of subsample units needed to adequately characterize an area. Although many people are aware that different investigators can have different species capture rates, this apparently has not been quantified or published. It has, however, been noted that changes of investigators in long-term monitoring of permanent plots can produce spurious apparent changes (Ketchledge & Leonard 1984; McCune & Menges 1986).

It is arguable that the low species capture rates in this study, even by experts, reflects the very large single plot, and that use of very small subplots would improve the repeatability of the species richness estimates. While the many-and-small sampling strategy (many small subsample units) results in more accurate estimates of abundance for the common species, this strategy also results in much lower species capture rates (McCune & Lesica 1992). So while it is possible that the many-and-small strategy would result in more consistent data on species richness than our very large single plots, the species list would be much shorter and represent a smaller area. We chose ocular survey of a large single plot 1) to maximize the regional representativeness of the sample unit and 2) to maximize the information obtained on the highest number of species in the shortest amount of time. It is well known that in data sets with high beta diversity, such as we expect from a large-scale regional random sample, most of the useful information in the data is carried in the presence and absence of species, rather than in small quantitative differences (Greig-Smith 1983).

Although small sample units may deliver more repeatable results, many of the problems of accurately estimating species richness apply to virtually any sampling method and group of organisms. Taxonomic skills have a large bearing on estimates of species richness. For example, forest ecologists will often disagree on the number and names of the oak and hickory species present in midwestern oak-hickory forests. Perception depends on preconception, such that we tend to see the species that we expect to see. Unfortunately these biases against recognizing certain species are often repeated over and over by an observer.

Given the difficulties we encountered with producing species lists that were consistent between experts and crews, particularly in the southeastern U.S., it may seem remarkable that the gradient scores produced by experts and technicians were so consistent. The explanation for this lies in the redundancy of information provided by different species. (Note: "redundancy" is used here in a statistical sense without any inferred redundancy in ecosystem function or genetic information.) Redundancy in species means that different subsamples of the species may lead to the same conclusion about the ecological state of the community. This is not surprising if one considers the following example. If ten lichen species were chosen at random from a forest in the Appalachian Mountains, a specialist familiar with the southeastern U.S. would have no difficulty informing you that the group of specimens came from the mountains rather than the coastal plain or piedmont. Because multivariate methods of data reduction seize upon this redundancy and exclude unrelated noise (Gauch 1982), these methods can produce scores for a sample unit that are fairly consistent across observers.

A thorough analysis of redundancy in community data examined different partitions of a large data set from Australia (Webb et al. 1967). Random subsamples of species tended to produce the same patterns as the complete data set. If, however, groups of species are defined by their growth forms or position in the forest, then different patterns of diversity and compositional gradients will result (McCune & Antos 1981*a,b*).

We conclude that the gradient scores produced by the FHM lichen community methodology will be useful indicators of change if implemented over a long period of time. In the case of the southeastern United States, the lichen community gradients related to climate and air quality should be responsive to regional changes in climate and air quality. Species richness, on the other hand, is likely to be more volatile in response to changes in hiring practices (education and experience required for field crews), amount of preseason training in lichenology, and attitudes of the field crews. Although these factors decrease the utility of lichen species richness as an indicator of forest condition, species richness will continue to be a useful comparator for more substantial changes. For example, much of Europe has far lower richness of epiphytic macrolichens than eastern North America, owing to a longer history of air pollution in Europe. As air quality improves in Europe, we should see a rebound in lichen species richness that would be readily detectable with the FHM methodology.

The problems inherent in estimating species richness have no easy solution, nor can they ever be eliminated. It is obvious, however, that improving the taxonomic training of field observers can significantly reduce, although never eliminate, the negative bias in estimating species richness. Given this need, it is important that more emphasis be placed on basic taxonomic training of field ecologists.

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