FORTY-FOUR

Monitoring Salamander Populations in Great Smoky Mountains National Park

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Recent evidence of worldwide amphibian population declines has highlighted the need for a better understanding of both species-specific habitat associations and methodologies for monitoring long-term population trends (Barinaga, 1990; Blaustein and Wake, 1990; Wake, 1991; Lannoo, 1998b). For decades, studies have relied on relative abundance indices to evaluate salamander populations across space and time. However, little effort has been made to evaluate the underlying assumptions of these indices or their relationship to the true population. Heatwole (1962) has shown that eastern red-backed salamanders *(Plethodon cinereus)* change their microhabitat use in response to precipitation events, differentially using cover objects and leaf litter refugia in response to changing humidity levels. This behavior may suggest that eastern red-backed salamanders are not equally detectable at different moisture levels. Because salamander surface activity is likely to vary with topography, season, humidity, climate, or other landscape variables, the ability to detect animals may also vary across space or time.

Comparing two populations over time or space requires that $n1/n2 = [C_1/b_1]/[C_2/b_2] = C_1/C_2$, where n = population size, C = number of individuals counted, and b = the ability of individuals to be detected. To compare two count indices we assume that $b_1 = b_2$. Finally, we must assume a linear relationship between salamander counts (C) and population size (n), $E(C) = bN$ (Lancia et al., 1994).

Great Smoky Mountains National Park (GRSM) is committed to incorporating salamander population monitoring into the park's long-term inventory and monitoring program because of the large number of unique species in the park, as well as evidence that salamanders are finely tuned indicators of environmental quality (Duellman and Trueb, 1986; Corn and Bury, 1989a; Dodd, 2003). Data from ongoing research in GRSM designed to assess spatial and temporal patterns in salamander diversity and abundance are being used to evaluate sampling effectiveness and bias across a variety of habitat types. Here we present evidence that some common salamander sampling techniques may not be appropriate indices for salamander abundance and, therefore, may not be suitable methodologies for use in long-term monitoring programs in the southern Appalachians and perhaps elsewhere.

Study Area and Methods

Great Smoky Mountains National Park is an internationally recognized refugia of temperate forest biodiversity. Geography and geology, combined with steep, complex topography, promote extreme gradients of temperature and moisture across the park's environments. In many groups, including salamanders (Jackson, 1989), these gradients produce levels of species diversity that are unmatched elsewhere in North America. Perhaps as many as 10% of the world's salamander species are found in the region (Petranka, 1998).

As part of a larger study designed to assess the distribution, abundance, and habitat associations of salamanders in GRSM (Simons and Johnson, 1999; Hyde, 2000), 111 terrestrial sampling sites were established within the Mount LeConte USGS quadrangle. Sampling sites were stratified by elevation, land use history, and plant community type. Because salamander life histories are variable, we employed four different sampling methods: searches of natural cover objects along transects (Jaeger, 1970, 1994), opportunistic nighttime surveys along transects (Ash and Bruce, 1994), artificial cover boards (Fellers and Drost, 1994; Jung et al., 1997), and leaf litter searches (Pauley, 1995c). Prior to this study, we did not know the relationship between species abundance estimates obtained by these sampling methodologies.

The sampling framework at each site was comprised of up to four (approximately parallel) 50 m transects, one transect for each sampling method (Fig. 44-1). Where possible, each site included all three diurnal transects. However, impassable terrain and safety concerns prohibited the inclusion of all transects at some sites. Transects for nighttime surface counts were included at a subset of sites and were opportunistically sampled on warm rainy nights when temperature and humidity conditions favored surface activity by terrestrial salamanders. For a detailed description of our site design or sampling techniques see Hyde (2000).

Results

All sites were sampled a minimum of three times between 27 May and 5 August 1998, and five times between 5 April and 27

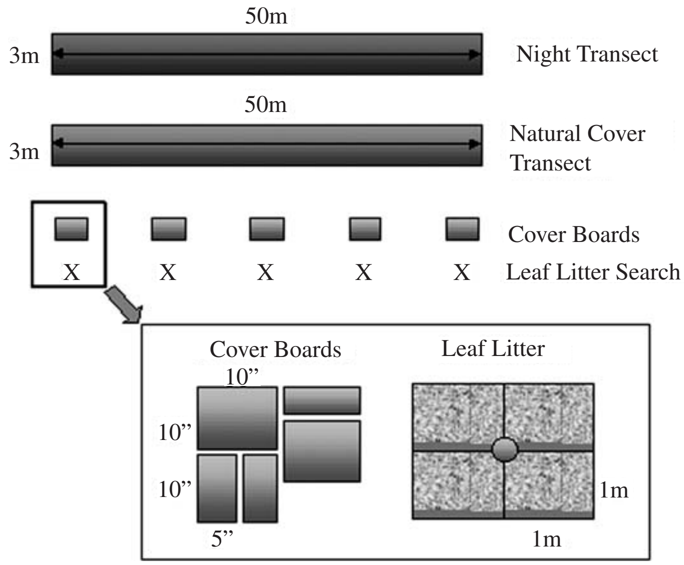

FIGURE 44-1 The sampling framework consisted of four transects: night, natural cover, artificial cover board, and leaf litter. The cover board transect contained five cover board stations, each 10 m apart. Each station contained two large boards and three small boards. Leaf litter stations were 1–2 m from each cover board station.

TABLE 44-1
Relative Efficiency of Salamander Sampling by Four Methods

	Number of:			*Salamanders per Transect:*	
	Transects	Samples	Salamanders	Undisturbed	Disturbed
Cover boards	101	837	1,224	1.9	1.1
Natural cover	92	700	2,651	7.0	2.0
Leaf litter	97	731	566	1.4	0.4
Night	26	97	1,669	25.2	8.5

NOTE: Salamander captures were higher on undisturbed sites than on sites with a history of disturbance prior to the formation of the park 65 years ago.

June 1999. During the 1998 and 1999 field seasons, 98 opportunistic night transect samples were recorded at 39 different sites. In addition to regular sampling, three sites were sampled every 7 to 10 days during the 1998 and 1999 field seasons as part of a separate study and to determine within site variation in salamander abundance.

The distribution of salamander catches in 1998 and 1999 was non-normal for all sampling methods. Because we were unable to satisfy the requirements of parametric statistics even after transforming the data, hypothesis testing was conducted by non-parametric statistics.

An analysis of salamanders captured per unit effort (as measured by the number of transect samples) suggests that night surveys and natural cover transects are more efficient for capturing salamanders than are artificial cover boards or leaf litter counts (Table 44-1). However, this measure of catch per unit effort does not account for the variability of counts, expense, effort required per sample, practicality, or disturbance caused by sampling, all of which must be considered when choosing a sampling method.

Species Specific Bias

Our data indicate that sampling techniques may have species-specific biases (Fig. 44-2; Table 44-2). For example, Jordan's salamanders (also termed red-cheeked salamanders, *P. jordani*) were 20–30% more likely to be captured on night transects than with any other method. In contrast, pigmy salamanders *(Desmognathus wrighti)* were more likely to be detected on leaf litter searches (43% of all salamander captures) than under cover boards (15% of captures) or on natural cover transects (25% of captures). These variations in measures of species composition probably reflect differences in the microhabitat used by different species. Although Huhey and Stupka (1967) state that pigmy salamanders are relatively rare in GRSM, we found pigmy salamanders to be the second most abundant species on our undisturbed sites. Because this species spends most of its time in leaf litter, it may be underrepresented by traditional search techniques that target natural cover. Therefore, methods that target specific microhabitats may produce misleading

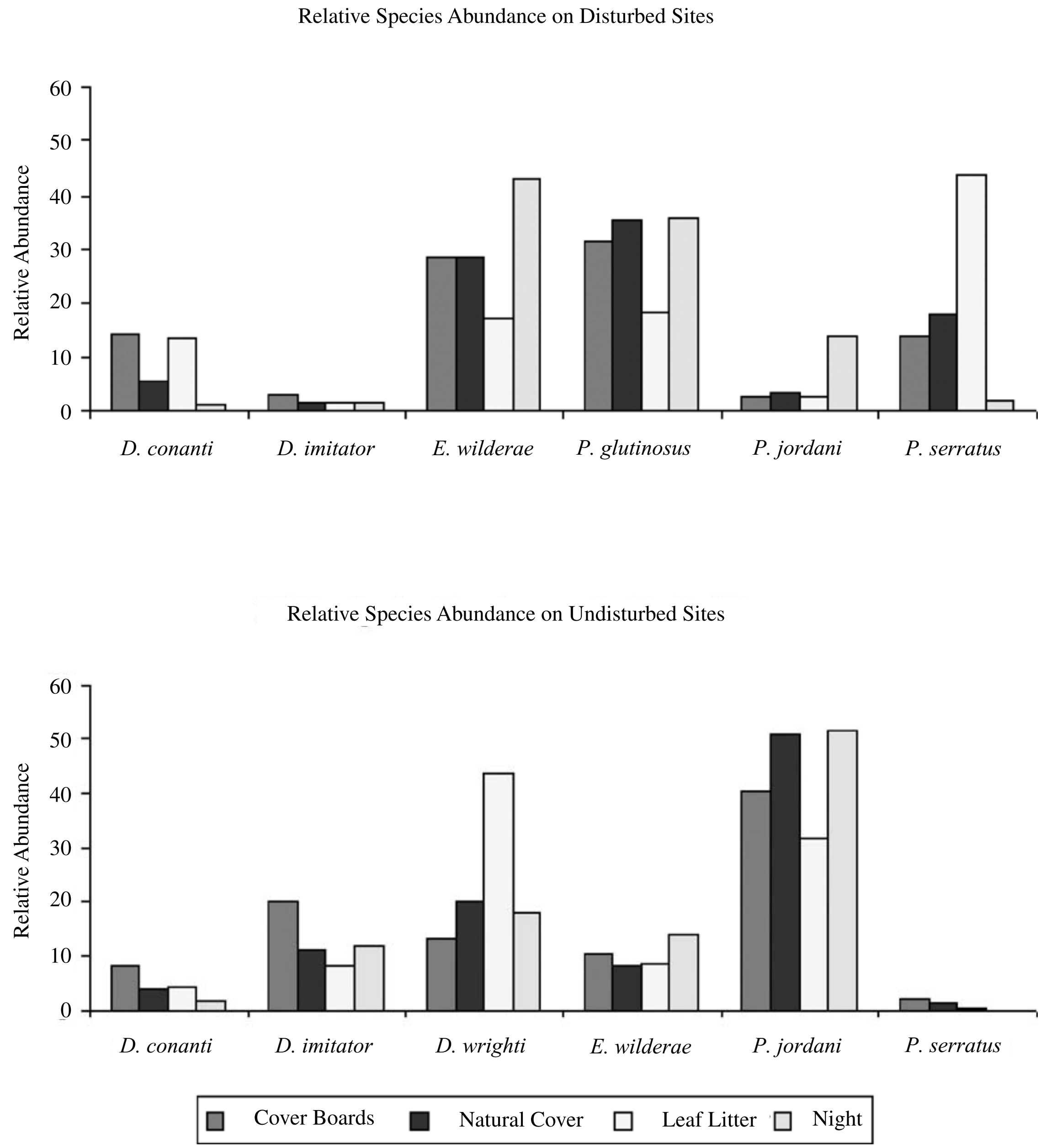

FIGURE 44-2 The estimated relative abundance of species in the salamander community depends on the sampling method employed. If species were represented equally by all sampling methods, relative abundance (% of total captures) would be equal across methods.

conclusions about the distribution and abundance of salamanders across larger areas. We do not currently know the relationship between relative abundance measures obtained by these methods and the true relative abundance of salamanders.

Lack of Conformity Among Methods

Relatively large sample sizes (2,400 samples of 320 transects) permit us to explore relationships among several sampling methods. Because measures of relative abundance should reflect characteristics of the true population, we expect a positive relationship between any two methods that sample the same population. In other words, an increase in one method (theoretically reflecting a larger population) should correspond to an increase in another method. Our data show a poor correlation between cover board samples and samples on adjacent natural cover transects ($r^2 = 0.11$; Fig. 44-3). Equally weak relationships exist between abundance indices obtained with other sampling methods (Fig. 44-3).

Effect of Natural Ground Cover on Salamander Abundance Indices

Because natural ground cover provides habitat for many salamanders, the quantity of natural cover on a study site may bias sampling results. Differences in natural ground cover

TABLE 44-2
Salamander Composition at Disturbed and Undisturbed Sites Differs According to the Method Used for Sampling

Cover Boards	*Natural Cover*	*Leaf Litter*	*Night*
Disturbed Sites			
Northern slimy salamanders *(Plethodon glutinosus)*	Northern slimy salamanders *(Plethodon glutinosus)*	Southern red-backed salamanders *(Plethodon serratus)*	Blue Ridge two-lined salamanders *(Eurycea wilderae)*
Southern red-backed salamanders *(Plethodon serratus)*	Southern red-backed salamanders *(Plethodon serratus)*	Northern slimy salamanders *(Plethodon glutinosus)*	Northern slimy salamanders *(Plethodon glutinosus)*
Blue Ridge two-lined salamanders *(Eurycea wilderae)*	Blue Ridge two-lined salamanders *(Eurycea wilderae)*	Blue Ridge two-lined salamanders *(Eurycea wilderae)*	Southern red-backed salamanders *(Plethodon serratus)*
Dusky salamander complex (*Desmognathus* sp.)	Dusky salamander complex (*Desmognathus* sp.)	Dusky salamander complex (*Desmognathus* sp.)	Red-cheeked salamanders *(Plethodon jordani)*
Undisturbed Sites			
Red-cheeked salamanders *(Plethodon jordani)*	Red-cheeked salamanders *(Plethodon jordani)*	Pigmy salamanders *(Desmognathus wrighti)*	Red-cheeked salamanders *(Plethodon jordani)*
Imitator salamanders *(Desmognathus imitator)*	Blue Ridge two-lined salamanders *(Eurycea wilderae)*	Red-cheeked salamanders *(Plethodon jordani)*	Pigmy salamanders *(Desmognathus wrighti)*
Pigmy salamanders *(Desmognathus wrighti)*	Southern red-backed salamanders *(Plethodon serratus)*	Blue Ridge two-lined salamanders *(Eurycea wilderae)*	Blue Ridge two-lined salamanders *(Eurycea wilderae)*
Southern red-backed salamanders *(Plethodon serratus)*	Pigmy salamanders *(Desmognathus wrighti)*	Imitator salamanders *(Desmognathus imitator)*	Imitator salamanders *(Desmognathus imitator)*

NOTE: Species listed in order of decreasing abundance.

densities across time or space may alter the effectiveness of sampling methods, thereby violating the assumption of equal detectability required for comparing indices. We found a poor relationship between the quantity of natural cover and the number of salamanders under cover boards ($r^2 = 0.11$; Fig. 44-4). Only 40% of the variation in natural cover transect counts could be attributed to variations in the density of natural cover (Fig. 44-5). Additional research is needed to clarify the relationship between natural ground cover and relative abundance indices.

Effect of Land Use History on Salamander Sampling Success

Salamander diversity and abundance in GRSM were significantly higher in undisturbed areas than in areas with a history of disturbance prior to the establishment of the park 65 years ago. The relationship between abundance and disturbance history was unaffected by the sampling method used (Fig. 44-6).

Measures of salamander abundance were more variable on disturbed sites for all three diurnal sampling methods (Fig. 44-7). This result may reflect differences in soil and leaf litter moisture at disturbed and undisturbed sites. We currently are analyzing soil moisture data to test this hypothesis. Because increased sampling variability decreases our ability to detect population trends, salamander population declines may be most difficult to detect on disturbed habitats, the very regions that are most likely to suffer declines in salamander diversity or abundance.

All sampling methods show high within and across site variability. Total variation (coefficient of variation [CV] across time and space) for salamander samples ranged from 90–205% depending on the sampling method used (Fig. 44-8). Total variation for individual species counts were much higher. Locally rare species or species that are poorly sampled by a given sampling method regularly experienced CVs as high as 300–900%. Such high variability reduces the power to detect population trends without very large sample sizes. Decreasing the inherent variability of salamander sampling techniques will be critical to developing efficient and reliable methods for monitoring terrestrial salamander populations. Although all our sampling techniques showed high variation, we found lower variability with natural cover transects ($n = 89$) and cover board transects ($n = 88$) than with leaf litter transects ($n = 80$; 8 samples per transect; Fig. 44-8). Frequent sampling ($n = 14$) on three sites shows that natural cover transects have lower variability than other methods.

Summary

Data collected over two years in GRSM suggest that salamander sampling techniques may violate assumptions required

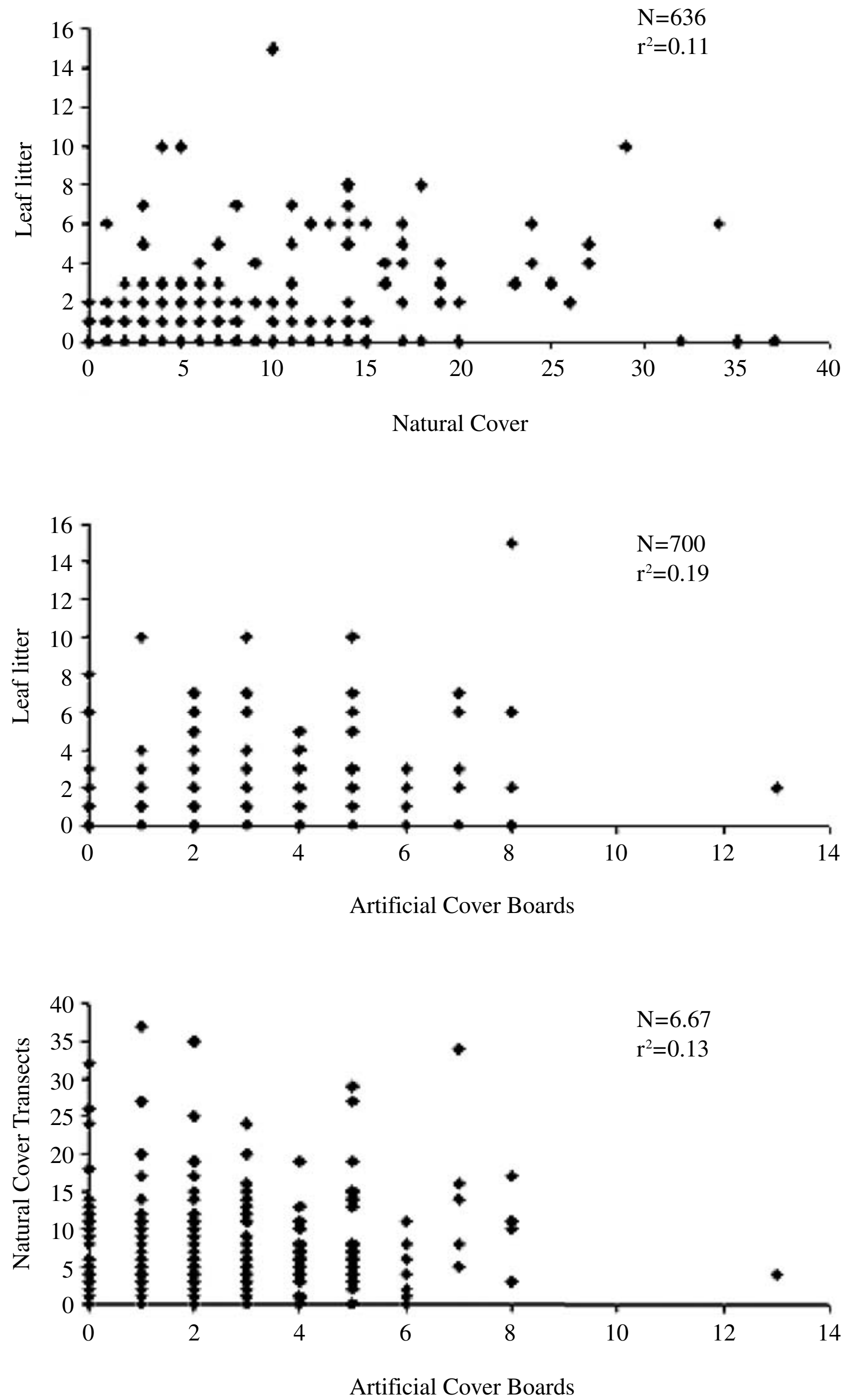

FIGURE 44-3 Abundance indices by various methods are poorly related.

to make valid comparisons of population indices over space or time. Land use history and temporal changes in habitat characteristics may affect the abundance or surface activity of salamanders. During drought years, salamanders may spend less time actively feeding at the surface and more time in underground refugia where they would not be detected by our sampling methods. Such a change in detection probability (b) violates one assumption required for comparing relative abundance indices. Changes in microhabitat use may also affect the probability of detecting a salamander with a given sampling method. Additional research is necessary to clarify how salamander detectability changes over space and time.

We have shown that detectability (b) varies across species according to the sampling method used. Differences in the ability to detect salamanders may result from species-specific microhabitat use that is unequally represented by sampling methods. Therefore, a single method may not be reliable for comparing relative abundance.

We have shown that salamander counts in GRSM are not normally distributed, exhibit enormous variation, and display unequal variances across habitat types. Our findings suggest

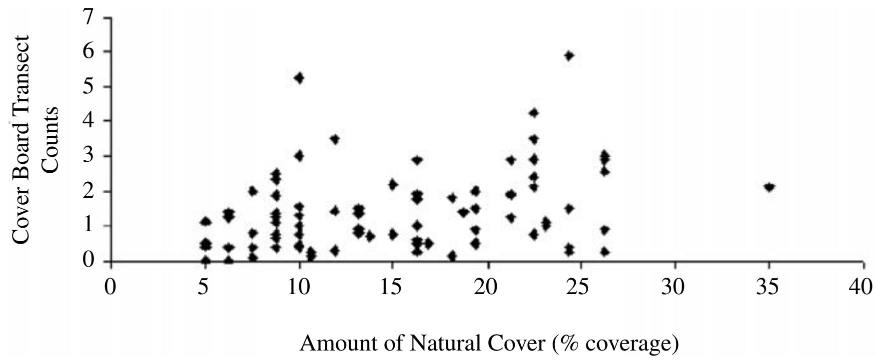

FIGURE 44-4 Salamander abundance under cover boards is poorly related to the abundance of natural cover ($r^2 = 0.11$).

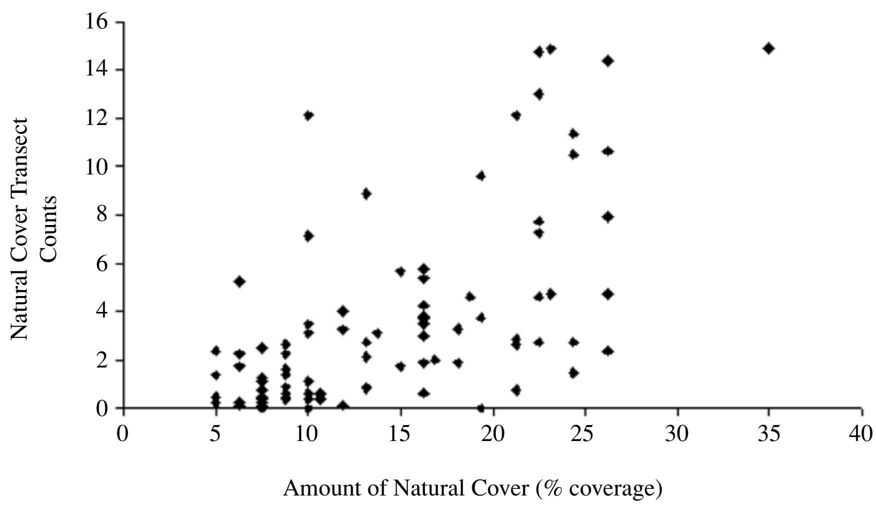

FIGURE 44-5 Only 40% of the variation in salamander abundance on natural cover transects is explained by the density of natural cover ($r^2 = 0.40$).

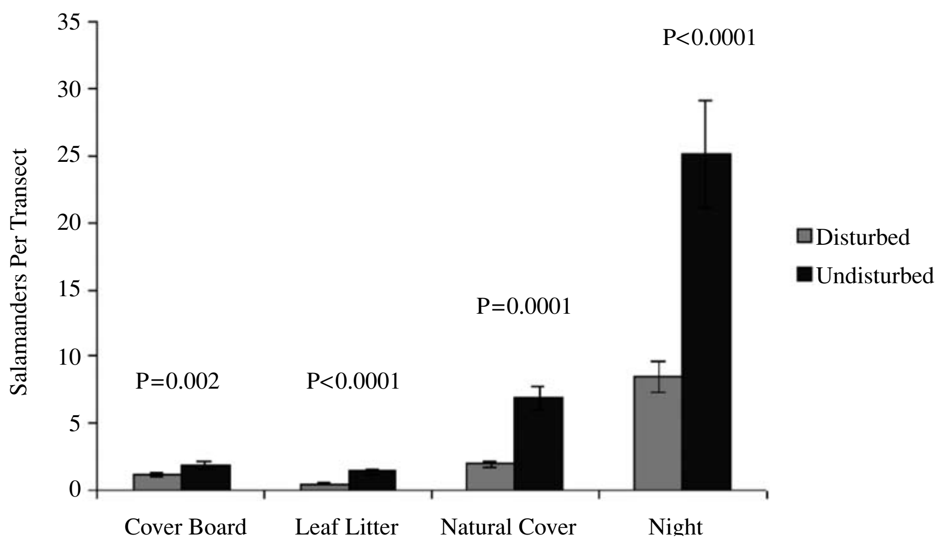

FIGURE 44-6 Variation in salamander counts was significantly higher on undisturbed sites than on disturbed sites. This relationship was consistent for all four sampling methods.

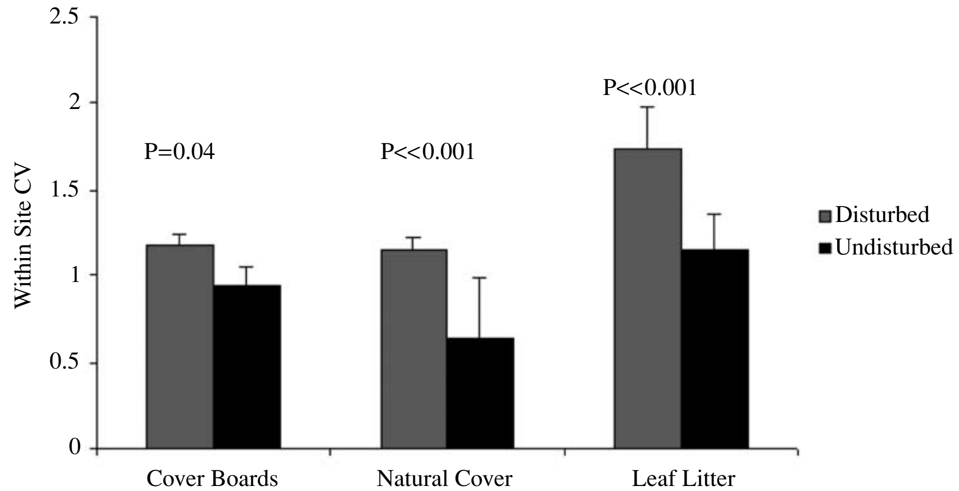

FIGURE 44-7 Within-site variation in salamander counts was significantly higher on disturbed sites than on undisturbed sites. This relationship was consistent for all sampling methods.

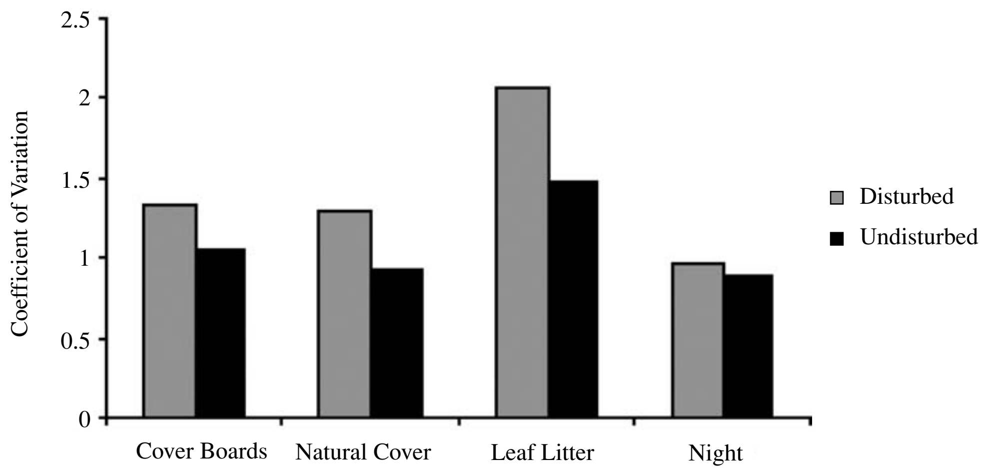

FIGURE 44-8 The high total variation in salamander samples (CV across time) will limit power for detecting population trends.

that different sampling methods are sampling different "populations." These characteristics reduce our ability to detect long-term population trends and limit the use of parametric statistics. It is important to understand the biases of the sampling methods used before substantial investments are made to inventory or monitor salamander populations. Additional research is necessary to design salamander monitoring methods that reduce variation, adequately sample important microhabitats, and meet necessary assumptions about detectability.

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