26056 (lot of tadpoles), 27333 (tadpole). *Megaelosia bocainensis*: São Paulo, São José do Barreiro, Serra da Bocaina: MNRJ 15900 (holotype). *Megaelosia boticariana*: São Paulo, Atibaia, Parque Florestal do Itapetinga: ZUEC 9561 (holotype), ZUEC 9562, 9563 (juvenile) (paratopotypes). *Megaelosia goeldii*: Rio de Janeiro, Nova Friburgo: AL-MN 2865, 3579, 3580, MNRJ 3683, MZUSP 0895, 2149; Petrópolis: MNRJ 27322, 27336 (tadpole); Teresópolis: AL-MN 1959–960, MNRJ 13677, 13684, 27318, 27319–321, 27323, 27324, 27325–326, 27327, 27328–329, 27330–331, MZUSP 1009, 53330–34 (topotypes); São Paulo, Serra da Bocaina: AL-MN 2306. *Megaelosia lutzae*: Rio de Janeiro, Itatiaia, PARNA Itatiaia: MNRJ 4181 (paratopotype), MNRJ 15464 (topotype). *Megaelosia massarti*: São Paulo, Salesópolis, Boracéia: MZUSP 2347; Santo André, Paranapiacaba: CFBH 02058, MNRJ 15463, ZUEC 8849–50 (juveniles), 8516, 9176, 11395, 11396 (juvenile), 11397, 11427 (juvenile), 11553 (topotypes). *Megaelosia* sp.: Espírito Santo, Santa Teresa: MZUSP 27717.

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Monitoring Terrestrial Salamanders: Biases Caused by Intense Sampling and Choice of Cover Objects

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ABSTRACT.—**Arrays of wood cover boards are useful tools for studying and monitoring plethodontid salamander populations. However, little is known about the biases inherent in monitoring data collected from such arrays. We used Red-Backed Salamanders, *Plethodon cinereus*, to test for two potential biases associated with use of wood cover board arrays. First, we tested whether frequent sampling of arrays can cause reduced counts of salamanders, resulting in the appearance of population declines where none exist. Second, we tested whether salamanders found under wood cover boards differed from salamanders found under natural cover objects in terms of sex ratios, stage class ratios, and snout–vent length. We found that sampling cover boards daily substantially reduced salamander counts under cover objects and that this result was pronounced for adults but not for juveniles. We found no decrease in counts with sampling cover boards weekly as compared to sampling every three weeks. With respect to differences between salamanders found underneath cover boards versus natural cover objects, we found that samples from under cover boards contained higher proportions of adults and lower proportions of juveniles and hatchlings than did natural cover objects. This was true in both the spring and fall. There were no differences in sex ratios or in snout–vent length within stage classes for salamanders in cover boards versus natural cover objects. These results suggest that cover boards used for monitoring or for studies of ecology and behavior should be sampled no more than once per week if natural levels of movement and territoriality are desired. Additionally, although cover board arrays may be suitable for tracking relative changes in overall population size, bias among size classes may make cover boards less than ideal tools for studies of salamander demography.**

Long-term monitoring data are critical for assessing the status of populations and the causes of population declines. For birds, more than 35 years of data from the Breeding Bird Survey have produced extensive analyses of patterns of decline and responses to habitat changes (e.g., Sauer and Droege, 1990; James et al., 1996; Villard and Maurer, 1996). For taxa such as amphibians, fewer such datasets are available, and establishing long-term population monitoring programs has become a priority. In North America, programs have been established to monitor populations of aquatic-breeding amphibians using calling surveys (Bishop, 1996; Mossman et al., 1998; Sargent, 2000) and populations of terrestrial salamanders using arrays of artificial cover objects (Droege et al., 1997; Jung et al., 2000). Similar efforts to monitor amphibians are underway in other parts of the world (Young et al., 2001).

Although monitoring data are extremely valuable, reliable data are often difficult to collect. To be useful, monitoring data must be relatively consistent among observers and habitat types, sufficiently powerful to show population

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changes, and unbiased towards indicating false increases or decreases in population size (Gibbs et al., 1998). Several aspects of amphibian behavior may make these criteria difficult to satisfy. For example, some aquatic breeding amphibians may only breed several nights each year (Wells, 1977) and may skip years entirely when conditions are unfavorable (Twitty, 1966; Semlitsch et al., 1996). Other species may reproduce with great success in rare years but generally decline in between. In these species, data gathered over short intervals may show population declines that are simply a natural aspect of population dynamics (Alford and Richards, 1999). High population variability also makes detecting trends in aquatic-breeding species particularly difficult (Pechmann et al., 1991; Marsh, 2001).

Terrestrial-breeding amphibians, such as plethodontid salamanders, generally exhibit smaller population fluctuations than do aquatic breeding species (Welsh and Droege, 2001), which could make population trends easier to detect. Because of this, plethodontid salamanders have been proposed as good indicator species for monitoring environmental change (Welsh and Droege, 2001). However, there are also difficulties with monitoring terrestrial salamanders. One major problem is variability among observers. Terrestrial salamanders are small, inconspicuous, and spend most of their time hiding underneath rocks and logs or underground. As a result, counts of salamanders under natural cover objects may vary two- to fivefold among observers (D. Marsh, unpubl.). Use of artificial cover objects, such as wood boards, may help circumvent this problem. The principle advantages of cover boards are that salamanders are generally more visible beneath them, and that total search effort can be strictly controlled by restricting searches to these objects (Fellers and Drost, 1994). Because of these advantages, cover boards are increasingly used as tools for salamander monitoring, as well as basic studies of salamander behavior and ecology (Monti et al., 2000; Hyde and Simons, 2001; Houze and Chandler, 2002).

Other difficulties with monitoring terrestrial salamanders may not be ameliorated with use of artificial cover objects. First, in many populations, most individuals are underground at any given time, even during periods of high surface activity (Test and Bingham, 1948; Fraser, 1976). The relationship between surface density and the actual population density is unknown, although comparisons of surface abundance to mark-recapture estimates do suggest a direct correlation (Smith and Petranka, 2000). Second, territorial behavior, common among terrestrial salamanders (Mathis, 1989; Jaeger and Forester, 1993), could also present problems if territorial individuals prevent others from being detected (but see Monti et al., 2000). Third, salamanders generally prefer moist microhabitats (Wyman, 1988), and turning cover objects could cause these habitats to dry out. If salamanders abandon these cover objects, monitored populations may appear to decline, when in fact salamanders are simply moving to unmonitored cover objects. Finally, salamanders prefer some cover objects to others (Mathis, 1990), and larger salamanders may be tend to be found under larger cover objects (Mathis, 1990; Hyde and Simons, 2001). Thus, it is possible that animals found underneath artificial cover objects may not accurately reflect the population underneath natural cover objects.

We tested for the presence of these last two biases in Red-Backed Salamanders, *Plethodon cinereus*. To test whether frequent monitoring of cover boards causes salamanders to abandon these sites, we randomly assigned artificial cover objects to one of three sampling regimes: daily sampling, weekly sampling, or sampling every three weeks. We then compared the abundance of salamanders under these board types. To test whether salamander under artificial cover objects differ from salamanders under natural cover objects, we compared size, sex, and stage class of salamanders collected under artificial cover objects and salamanders collected under natural cover objects at the same site in the spring and fall of 2001.

MATERIALS AND METHODS

Species and Study Site.—Red-Backed Salamanders, *Plethodon cinereus*, are found in woodland habitats from North Carolina north to Quebec and west to Minnesota. In Virginia, they may reach densities above 2 per m^2 (Mathis, 1991), and they are commonly found beneath rocks and coarse woody debris. Red-Backed Salamanders rapidly colonize artificial cover objects, particularly wood boards (Monti et al., 2000; Houze and Chandler, 2002; see below). Both males and females may defend cover objects (Mathis, 1991), though juveniles are not thought to be territorial (Jaeger et al., 1995). Red-Backed Salamanders in Virginia breed in the fall, and females lay and brood eggs from the spring to the early summer. We studied Red-Backed Salamanders in a 35-ha woodlot on the property of Washington and Lee University in Rockbridge County, Virginia. The study site consisted of mature deciduous forest composed mostly of *Acer saccharum*, *Liriodendron tulipifera*, *Quercus rubra*, *Quercus alba*, and *Carya cordiformes*.

Sampling Intensity Experiment.—From 10–12 February 2001, we established an array of 169 artificial cover objects at the study site. Cover objects were 30 × 30 × 2 cm white oak boards. We placed cover boards at least 5 m apart along a 500 × 50 m segment of the woodlot. Most boards were 6–10 m from the next closest board. We cleared any leaf litter from beneath the boards and then pushed down on the boards to make them flush with the ground. Each board was numbered and marked with a flag for identification.

We randomly assigned the 169 cover objects to one of three treatments: daily sampling, weekly sampling, or sampling every three weeks. Sampling consisted of carefully turning over each cover board and noting the number and stage class of any salamanders underneath. To avoid harming salamanders when cover objects were replaced, we replaced the cover boards first and then put any captured salamanders next to the cover object, as recommended by the Terrestrial Salamander Monitoring Program (Droege et al., 1997). Most salamanders immediately crawled back underneath the cover object.

From 24 April to 6 June 2001, we searched cover boards according to their sampling treatment. Searches were always performed during the day, although actual times of the searches varied. On four dates, daily boards could not be searched because no investigator was available. Daily boards were searched a total of 38 times, weekly boards were searched seven times, and three-week boards were searched three times. For each board, we calculated total number of salamanders found on dates of interest over the course of the experiment, and we considered a cover board as the experimental unit.

We used generalized linear models to determine whether total number of salamanders found under each board differed among sampling intensity treatments. We performed two separate tests. First, we compared number of salamanders found underneath daily boards and weekly boards summed over the seven dates on which all these boards were checked. Because the three-week boards were only checked three times, we then separately compared number of salamanders underneath weekly boards to three-week boards summed over the three dates on which both types were checked. Some data for the weekly boards were used in both of these comparisons, so these were not strictly independent analyses. To be conservative, we used an alpha of 0.025 for statistical significance. We performed each of these analyses for total salamanders, for adults only and for juveniles only. Stage classes were not recorded on the first survey date, so our measure of the total number of salamanders exceeds the sum of recorded juveniles and adults. Total number of salamanders, adults, or juveniles per board was modeled as a Poisson variable, based on initial analysis of frequencies. Significance of sampling intensity was determined with a likelihood ratio test for each response variable. Analyses were performed using PROC GENMOD in SAS 8.2.

For these analyses, we assumed that the total number of salamanders found under each board was independent of the number under other cover boards. This assumption would be violated if salamanders regularly moved between cover boards. We expect that this type of movement occurred infrequently if at all. Red-Backed Salamander home ranges are generally from 10–30 m^2 (Kleeberger and Werner, 1982). Because most cover boards were 6–10 m apart, few home ranges would have contained multiple cover boards. Second, we estimate that there were approximately 7.5 natural cover objects within a 5 m radius of each experimental cover board. Thus, most salamanders that left cover boards likely moved to natural cover objects rather than other cover boards.

Cover Object Comparison.—On 14 March, 28 March, 14 April, 27 September, and 4 October 2001, we collected salamanders underneath cover boards. At these same times, we collected a similar number of salamanders from underneath rocks and logs between the cover boards. All salamanders were brought to the lab where we determined sex, weight, snout–vent length and tail length. Salamanders were also classified by stage class. For the spring surveys (March and April), we classified salamanders as juveniles or adults based on size and the presence/absence of mature gonads. Juveniles in these surveys were most likely hatched the previous summer. For the fall surveys (September and October), we classified salamanders as hatchlings, juveniles, or adults. Hatchlings were hatched the previous summer, and juveniles were most likely hatched one year before.

There were no significant size differences among salamanders found on the different dates, so we pooled all data from the three spring surveys. We separately pooled the data from the two fall surveys. For each set of surveys, we asked whether salamanders under artificial cover objects differed from salamanders under natural cover objects in sex ratio, stage class ratio, and size. We used G-tests to determine whether the frequency of each sex differed between artificial and natural cover objects. We also used G-tests to determine whether the frequency of the different stage classes (juveniles vs. adults in the spring; hatchlings vs. juveniles vs. adults in the fall) differed between artificial and natural cover objects. Finally, we used two-way ANOVA to test whether snout–vent length differed between artificial and natural cover objects for salamanders within the same stage class. For this analysis, we used stage class and cover object type as fixed effects, and used snout–vent length

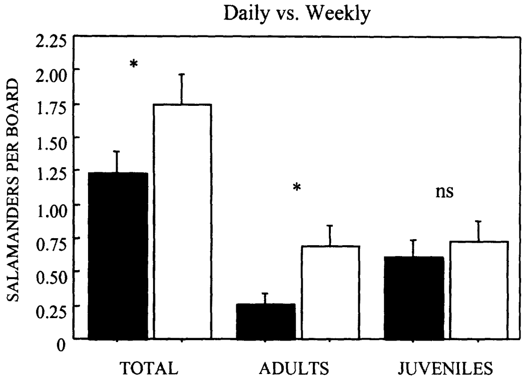

FIG. 1. Percentage of time tadpoles of *Pseudacris triseriata* spent swimming and feeding in the absence and presence of predatory newts (*Notophthalmus viridescens*). Bars represent means ± 1 SE.

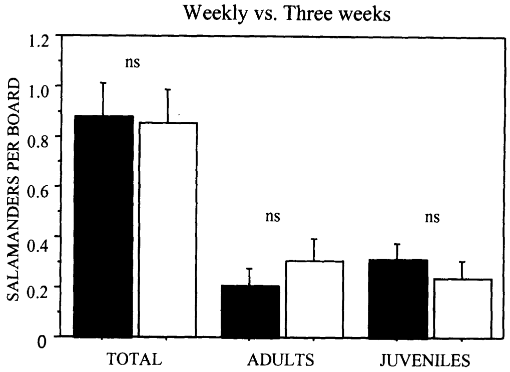

FIG. 2. Percentage of time fed and hungry tadpoles of *Pseudacris triseriata* spend near the edge of the testing chamber in the presence and absence of predatory newts (*Notophthalmus viridescens*). Bars represent means ± 1 SE.

as our response variable. We were not interested in the significance of the stage class effect because it is assumed that adults will be larger than juveniles. Rather, we used this factor to account for variation in size based on stage class and then asked whether there was additional variation in size that was caused by cover object type.

RESULTS

Sampling Intensity Experiment.—For the seven dates on which both the daily and weekly boards were checked, 76 of the 115 boards had at least one salamander, and the mean number of salamanders found per board was 1.49. Boards checked daily had significantly fewer total salamanders than boards checked weekly (mean = 1.78 for weekly boards vs. 1.29 for daily boards, $\chi^2 = 5.12$, $P = 0.024$, Fig. 1). This result was strong for adults (mean = 0.69 for weekly boards vs. 0.26 for daily boards, $\chi^2 = 11.36$, $P = 0.0008$, Fig. 1) but did not approach significance for juveniles (mean = 0.72 for weekly boards vs. 0.66 for daily boards, $\chi^2 = 0.52$, $P = 0.47$, Fig. 1).

For the three dates on which both the weekly and three-week boards were checked, 58 of the 113 boards had at least one salamander, and the mean number of salamanders per board was 0.87. There were no significant differences in total salamanders found underneath boards surveyed weekly versus boards surveyed every three weeks (mean = 0.88 for weekly boards vs. 0.85 for three week boards, $\chi^2 = 0.02$, $P = 0.89$, Fig. 2). This pattern held for both adults (mean = 0.21 for weekly boards vs. 0.31 for three-week boards, Fig. 2) and juveniles (mean = 0.31 for weekly boards vs. 0.24 for three-week boards, Fig. 2).

Cover Object Comparison.—In the spring 2001 surveys, we captured 19 females and 12 males underneath cover boards and 14 females and 12 males under natural cover objects. There was no significant difference in sex ratio among cover object types ($G^2 = 0.32$, $P = 0.57$). With respect to stage classes, we captured 31 adults and 27 juveniles under cover boards and 26 adults and 58 juveniles underneath natural cover objects. Stage class distributions were significantly different among cover object types ($G^2 = 7.22$, $P = 0.007$). There was no effect of cover object category on snout–vent length once stage class was accounted for ($F_{1,130} = 0.744$, $P = 0.39$). That is, salamanders within stage classes were not significantly larger or smaller in cover boards versus natural cover objects.

Results were similar in the fall 2001 survey. We captured 28 females and 13 males under cover boards and 17 females and 11 males underneath natural cover objects. There was no significant difference in sex ratio among cover object types ($G^2 = 0.42$, $P = 0.52$). For the three stage classes, we captured 45 adults, 22 juveniles, and 10 hatchlings underneath cover boards and 32 adults, 11 juveniles, and 27 hatchlings under natural cover objects. These stage class distributions were significantly different ($G^2 = 13.72$, $P = 0.001$), again with a bias toward greater proportions of younger salamanders among natural cover objects. As in the previous spring, there was no difference in size of salamanders within stage classes in artificial versus natural cover objects ($F_{2,135} = 0.018$, $P = 0.89$).

DISCUSSION

Red-Backed Salamanders had significantly higher counts underneath cover boards sampled weekly than underneath boards sampled daily, although this result applied only for adults. Effects of sampling intensity disappeared at lower intensities, and salamanders were counted in similar numbers underneath boards sampled weekly and boards sampled every three weeks. Additionally, salamanders underneath cover boards differed from salamanders found underneath natural cover objects. Samples of salamanders underneath cover boards were biased toward adults as compared to samples from underneath natural cover objects. There were no differences in sex ratio or size within stage class between the cover object types.

The results of the sampling intensity experiment are largely favorable for using cover board arrays to monitor salamanders. Although daily sampling substantially reduced salamander counts, few monitoring programs would need to sample more often than once per week, and we found no significant differences in counts under boards sampled weekly versus boards sampled every three weeks. It is unlikely that the lack of a difference between weekly and three-week sampling is an artifact of reduced statistical power resulting from the use of only three dates for comparison. The difference in salamander counts between these two sampling intensity treatments was only 4%, whereas the difference between weekly and daily sampling was 41%.

Although relatively unimportant for population monitoring, the negative effects of frequent sampling on abundance may be quite relevant to studies of salamander ecology and behavior. Studies of salamander movement and territoriality may require frequent sampling of cover objects. Although these studies have traditionally been conducted with natural cover objects rather than cover boards (e.g., Keen and Reed, 1985; Mathis, 1990; Jaeger et al., 1995; Marvin, 1998), our findings may still be relevant. Because natural cover objects are more difficult than cover boards to reposition flush with the ground (D. Marsh, pers. obs.), soil underneath natural cover objects may dry out quickly when objects are frequently sampled. Thus, our data suggest that to be conservative, cover objects (natural or artificial) should not be sampled more often than once per week if natural rates of movement and site fidelity are desired.

It is interesting that lower counts under frequently sampled cover objects were observed only for adult salamanders. This result is consistent with studies observing territoriality in Red-Backed Salamander adults but not in juveniles (Jaeger et al., 1995). If adults are using cover objects as territories or parts of territories then adults should be more sensitive to changes in cover object quality. In contrast, if juveniles are using cover objects only opportunistically, they may be affected less by frequent disturbance of cover objects.

Our second principle result was that samples of salamanders underneath wood boards contained higher proportions of adults and lower proportions of hatchlings and juveniles as compared to samples from underneath natural cover objects. This result differs from those of Monti et al. (2000) and Houze and Chandler (2002), who found no differences in sizes of salamanders between natural cover objects and cover boards. There were several methodological differences between our study and these previous studies. For example, Monti et al. (2000) used cover boards that were only 10 cm in width, whereas we used boards that were 30 cm wide. Monti et al. also used cedar shingles as cover boards, Houze and Chandler (2000) used plywood, and we used white oak boards. Cedar boards are recommended as "moderately suitable" by the terrestrial amphibian monitoring program (Droege et al., 1997) based on water retention characteristics, plywood is not currently recommended, and white oak is recommended as "highly suitable." Cedar contains compounds that may be avoided by arthropod prey (Anderson et al., 2002), whereas plywood may tend to dry out soil (Droege et al., 1997). Thus, differences in the overall suitability of cover boards could explain the difference in patterns of use between these studies. Similarly, it is almost certain that natural cover objects differed between the study sites, and this difference may also have contributed to the variation in results. These complications highlight the critical importance to monitoring programs of understanding how salamanders use both artificial and natural cover objects in a variety of habitats (e.g., Hyde and Simons, 2001).

Strictly speaking, differences in salamander samples among cover object types do not necessarily mean that samples from underneath cover boards are biased samples of the overall population. Because most salamanders are underground at any given time (Test and Bingham, 1948; Taub, 1961; Petranka and Murray, 2001), samples from underneath natural cover objects may not be representative of the population as a whole. Nevertheless, for anyone using cover boards to study demography or population structure, it is worrisome that cover boards had different stage class distributions than natural cover objects. One solution might be to create cover boards of varying sizes and thicknesses in frequencies that generally match the sizes of natural cover objects within a site. This could also reduce the high fluctuations we observed between sample dates in counts underneath cover boards (see also Hyde and Simons, 2001; Houze and Chandler, 2002).

The difference in salamander stage classes among cover object types is unlikely to result from simple sampling bias. One of the main advantages of cover boards is that salamanders are more visible under cover boards than are salamanders under natural cover objects. Under natural cover objects, salamanders are often missed when they hide within holes in the cover objects or in rock crevices below the surface. Because salamanders are easier to see under cover boards, and because young salamanders are less conspicuous, we would expect any observation bias to be toward seeing more young salamanders underneath artificial cover boards. Instead, our results show the opposite pattern of greater proportions of adults underneath cover boards.

There are several potential explanations for this result. First, adults may generally prefer wood boards to many natural cover objects and defend them against intruders. Adult Red-Backed Salamanders generally prefer wider cover objects (Mathis, 1990), and the boards we used (30 × 30 cm) were wider than the majority of natural cover objects available. Studies from natural cover objects also show an association between the size of Red-Backed Salamanders and the size of their cover objects (Mathis, 1990), and the same may be true for artificial cover (Hyde and Simons, 2001). Second, it is possible that adults are simply better dispersers than juveniles; hence they move into these new habitats more quickly. However, this hypothesis is not supported by the fact that the bias toward adults was just as strong after eight months (the fall surveys) as it was after two months (the spring surveys). Finally, it is possible that reproductive success is low underneath cover boards as compared to natural cover objects and the paucity of hatchlings in the fall surveys reflected poor recruitment. This explanation is possible because wood boards do not contain as many microhabitats as downed wood and, thus, could be less suitable for eggs and/or hatchlings. However, it is inconsistent with the difference we observed in the original spring surveys, when reproduction had not yet occurred.

Whatever the mechanism, it is clear that data on salamander stage structure and/or demography collected from wood cover boards must be treated with caution. It is unfortunate that accurate demographic data are not easier to collect for plethodontid salamanders, because there are major gaps in our understanding of the population dynamics of these organisms. In addition, accurate data on stage class distributions could be used to project population responses to environmental change (Caswell, 2001). Furthermore, effective monitoring of hatchlings and juveniles may be particularly useful for detecting early effects of environmental change, given the long life span of adults. Thus, determining how to best collect accurate demographic data from natural populations should be a priority. Until then, data from cover board arrays may be most reliably used only for the purpose of detecting relative changes in population density within a site.

Several problems remain in the establishment of effective salamanders monitoring programs based on arrays of cover boards. As mentioned above, salamander use of cover boards may depend on the density and range of natural cover objects available (Hyde and Simons, 2001). Thus, changes in forest characteristics that affect coarse woody debris may alter detection rates under cover boards. This could either create the appearance of declines where none exist or could mask real declines. Second, little is known about how counts underneath cover boards relate to actual population status. Smith and Petranka (2000) found high correlations between surface counts and mark-recapture population estimates across sites. However, within sites, the effects of population decline on counts under cover boards may be less predictable. Because most terrestrial salamanders are probably underground at any given time, salamanders moving into cover objects on the forest floor could potential fill desirable cover objects and make declines more difficult to detect. This scenario is speculative, but these issues do warrant further investigation.

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