Forestry Operations and Terrestrial Salamanders: Techniques in a Study of the Cow Knob Salamander, *Plethodon punctatus*[1]

Abstract.—The status and ecology of *Plethodon punctatus* was investigated in George Washington National Forest, Virginia to determine potential effects of logging. Pitfall traps and mark-recapture supplemented searching by hand. Elevation, aspect, soil characteristics, and number of cover objects (rocks) are the most important features that identify *P. punctatus* habitat. Intensive logging operations appear to be detrimental to this species.

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Increasing emphasis is being placed on conservation and preservation of biological diversity worldwide (Norse et al., 1986; Wilson, 1988). U.S. federal and state agencies have become concerned about the biodiversity of their managed lands and are directing efforts towards preserving natural biota. From a management perspective, research on amphibians and reptiles lags behind that devoted to game animals, such as some mammals, birds, and fish (Bury et al., 1980). This is partly due to a previous lack of interest in these groups, but also because some species can be more difficult to observe or investigate.

The Cow Knob salamander, *Plethodon punctatus*, is a dark, moderately large (to 74 mm snout-vent length), woodland, fossorial amphibian (Martof et al., 1982) found only on Shenandoah and North Mountain of western Virginia and eastern West Virginia (Highton, 1972, Tobey, 1985). Most of the known range of this recently described species (Highton, 1972) is in the George Washington National Forest. Fraser (1976) compared some aspects of the ecology of this species with a sympatric congener, *Plethodon hoffmani*. Little else is known of the ecology of this salamander. Because of its relatively small range and unknown status, *P. punctatus* was added to the U.S. Fish and Wildlife Service's Category 2 list (U.S. Fish and Wildlife Service, 1985). Potential timber harvesting within the range of this species (USDA Forest Service, 1986) prompted us to examine its status in forest stands of various ages. In this paper we report the following aspects of this study: techniques of capture and data collection, salamander habitat characteristics, and potential effects of logging operations. Our objective in this paper is to make other researchers aware of the techniques we used and the problems we encountered in developing useful management recommendations for the protection of an apparently rare terrestrial salamander.

Materials and Methods

We conducted this study on Shenandoah Mountain, Augusta and Rockingham Counties, George Washington National Forest, Virginia. Before its purchase, between 1911 and 1940, by the U.S. government, this area was repeatedly logged and burned (Leichter, 1987; original land deed documents). Few virgin stands of forest remain, and regrowth and logging operations has resulted in a mosaic of mixed hardwoods of various ages.

We selected five sites of different aged forest to determine the relative abundance of *Plethodon punctatus* (fig. 1) to see if its presence was affected by logging. All sites selected had similar aspects (S-SE) and elevation (914- 1127 m) (table 1). We used USDA Forest Service compartment descriptions and maps to aid in selection of sites and to obtain information on the history, physical and biological descriptions, and future management goals for each site. A compartment is divided into a series of stands, each of which defines a forested area of similar tree species by composition, age, and stand condition. Stand age is defined by the age of dominant canopy trees. Final choices of sites were made only after each was checked in the field and tree age was verified by tree ring analysis.

In each site we erected drift fence arrays (Campbell and Christman, 1982) consisting of four 60 cm x 7.5 m sections of aluminum flashing arranged in a cross pattern. Opposite arms of the cross were separated by 15 m and all sections were sunk in

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the ground approximately 10 cm. A 5-gal plastic bucket was placed in the center of each arm and #10 cans were placed in the ground on either side of the ends of each arm so that the tops of the pitfalls were flush with the ground surface. Sites A and C contained two drift fence arrays, and the remaining three sites had one array each. In each pitfall we put 4-10 cm of 10% formal-dehyde solution to insure adequate preservation of the salamanders. We selected this method to obtain samples of all the terrestrial fauna for a range of studies on reproductive cycles and ecology. Pitfalls were checked and all captures (including other vertebrates and all invertebrates) were collected weekly May 5 - June 18, 1987, bi-weekly July 7 - November 22, 1987 and monthly December 1987 and January 1988. Samples were sorted in the laboratory and the vertebrates stored in 10% neutral buffered formaldehyde. Invertebrates were stored in 70% isopropanol.

Hand-collecting supplemented drift fence collection and was used to determine the elevational range of *P. punctatus* and to obtain information on range and habitat characteristics. Results from timed collecting periods allowed comparison among sites and dates of collection. Between April 20 and June 2, 1987, we collected data on eleven microhabitat variables at 67 sites to evaluate those most important in predicting the presence of this salamander. These variables were elevation, aspect, slope, soil temperature under cover object, soil moisture, soil pH, soil description, canopy cover, number of cover objects available within a 2 m circle, type of cover object (e.g., rock, log), and forest type.

One site >1 km away from any of the collection sites was selected for estimation of population size and data on individual movements. We searched for salamanders in daylight by turning and replacing all surface objects and at night while they were active on the surface (i.e., during conditions of near 100% relative humidity [sensu Heatwole, 1960; Jaeger 1978]). Each individual was measured (snout-vent length, tail length to nearest mm), weighed (nearest 0.1 g), the sex determined, assigned to adult or juvenile age-classes, marked by toe-clipping, and released at its capture site. We marked each capture site with survey flags on which the salamander's number and capture

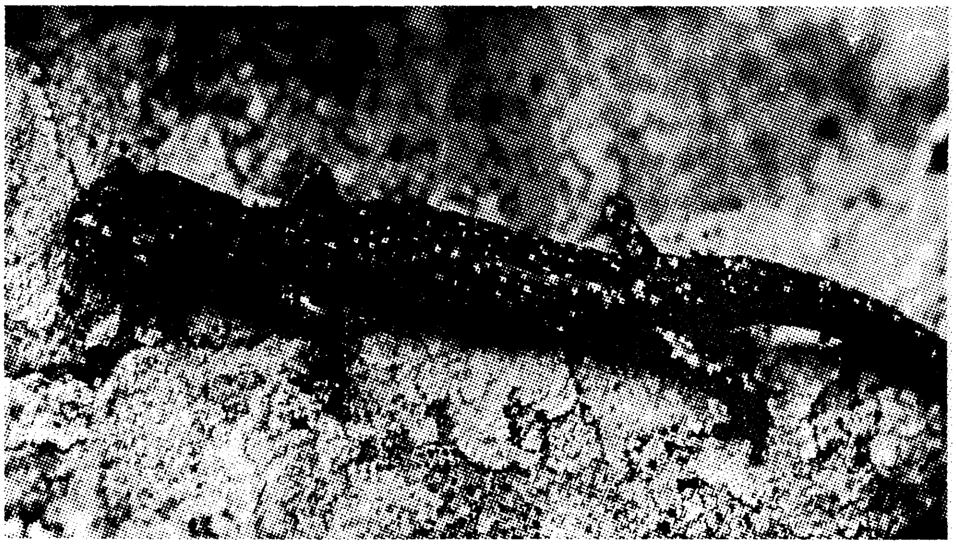

Figure 1.—*Plethodon punctatus*, the Cow Knob salamander, from Shenandoah Mountain, Augusta County, Virginia. Photograph by Kurt A. Buhlmann.

Table 1.—Descriptions of drift fence study sites for *Plethodon punctatus* on Shenandoah Mountain, Virginia. Slope angle is in degrees and site age is in years since last logging activity.

Site	Timber descrip.	Slope	Manag. type	Site age	Stand condition	Past logging history
A	1 yr old white pine several hardwood seed trees	30	white pine	2	seedling/ sapling	90% clearcut few hardwood trees
B	white oak/ red oak/hickory	45	oak/hickory	8	sparse saw timber	thinned due to ice damage, 1979
C	white pine/mixed hardwoods	25	white pine	30	immature pole timber	cut in 1956, planted in white pine, some hardwood seed trees
D	white oak/hickory	30	oak/hickory	60-100	mature saw timber	no recent management
E	white oak/ red oak/ hickory	5	none	virgin?	low quality saw timber	none known

date were written. We noted all recaptures and measured movements in linear fashion (0.1 m) between capture points.

Results and Discussion

Capture Techniques

Nineteen *P. punctatus* were caught in the pitfall traps, 2.0% of the total number of salamanders. Of the 17 recorded, 12 were caught in 5-gal. buckets and 5 in #10 cans. Eleven *P. punctatus* were caught in Site E, six in Site B, and two Site D. None were caught in Site A or the Site C. In contrast, by hand collecting in areas adjacent to Site E, we found 38 *P. punctatus* in 7.7 man hours of searching. The drift fence method appears only moderately effective in sampling this salamander. It is feasible that *P. punctatus* is less likely to fall into the pitfalls than other salamander species. We observed several individuals climbing rocks and tree trunks during nocturnal surface activity. This suggests that this salamander is able to detect precipices and avoid falling into pitfalls. Also, this species may be active on the horizontal surface only for limited periods of time and under specific environmental conditions. Thus, the drift fence technique, which depends on horizontal activity, may not be an effective sampling method for this salamander (R.D. Semlitsch, pers. comm.).

Data from pitfall traps, combined with data from hand collecting, can provide information for management decisions. For instance, seasonal trends in surface activity were similarly indicated by both drift fence results (fig. 2) and captures based on hand collection (fig. 3). Comparison of *P. punctatus* with that of its sympatric congener *P. cinereus* (fig. 3) reveals concordance in seasonal activity and suggests similar responses to surface environmental conditions. This information could be used to determine the times logging opera-

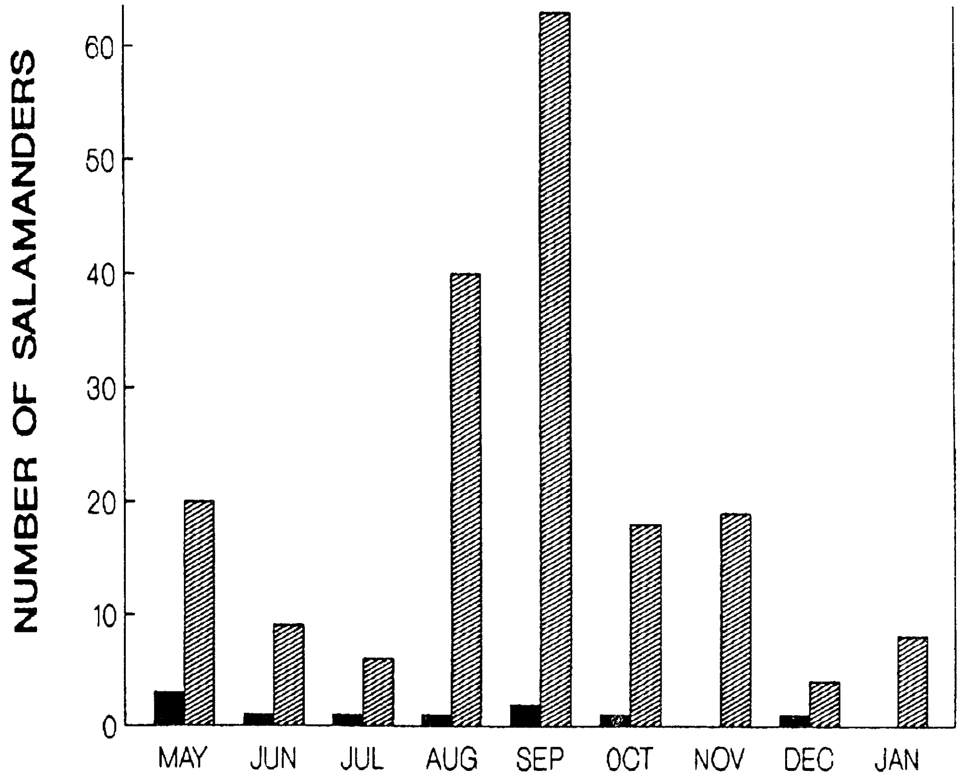

Figure 2.—Seasonality of drift fence captures of *Plethodon cinereus* and *P. punctatus* at Site E (Tomahawk Mountain), George Washington National Forest. Adults and juveniles are included, but not hatchlings. Sampling period is 5 May 1987 to 24 January 1988.

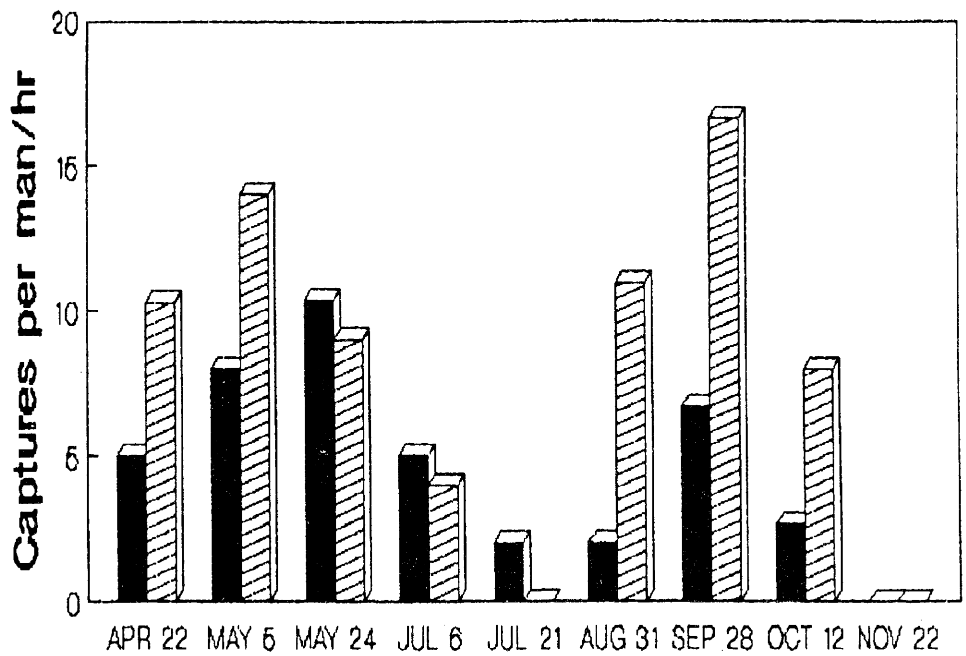

Figure 3.—Seasonality of captures per man hour of *Plethodon cinereus* and *P. punctatus* on Tomahawk Mountain, George Washington National Forest. Black bars represent *P. punctatus* and bars with diagonal lines represent *P. cinereus*. Sampling dates are 22 April to 22 November 1987.

tions would cause the least impact on salamanders at or near the surface.

The benefits of the drift fence technique outweighed the low numbers of captures of *P. punctatus*. We probably would not have otherwise found this species in Site D because there were few surface rocks to turn over. Although the individuals caught may have been transients, this species does occasionally occur at this site. This result would not have been obtained by hand-collecting alone.

The drift fence method also provided estimates of the relative abundance of the salamander fauna and other species in the community. The relative numbers of these species and species groups can generate additional information on the structure of the community in which the focal species lives. Drift fence techniques have been used for a variety of ecological studies (e.g., Gibbons, 1970; Gill, 1978; Pechmann and Semlitsch, 1986) but only recently to answer questions about vertebrate communities in relation to forest management (e.g., Bennett et al., 1980; Gibbons and Semlitsch, 1981; Enge and Marion, 1986; Bury and Corn, 1987). Our results indicate this technique can be effective in mountainous terrain and can be used to gain information on apparently rare terrestrial salamanders.

Table 2.—Seasonal differences in surface abundance of *Plethodon punctatus* at Flagpole Knob and Skidmore Tract, Shenandoah Mountain, George Washington Forest. These sites are <1 km apart. Flagpole Knob is a rocky, grassy ridge habitat containing young oak (*Quercus* sp.) and maple (*Acer* sp.) pole timber, and Skidmore is a virgin hemlock (*Tsuga canadensis*)/yellow birch (*Betula lutea*) forest. Numbers of salamanders are followed by number of man hours in parentheses. All data are based on hand-collecting results.

Date	Flagpole	Skidmore
June 2	11 (0.5)	10 (1.7)
June 8	0 (0.5)	2 (2.0)
Sept. 28	0 (1.0)	3 (3.0)

If an endangered or otherwise protected species is the focus of study and cannot be collected, then slight modifications of the drift fence-pitfall design must be made. Traps would need to be checked on a daily basis, or nearly so, in order to release the animals unharmed (Gibbons and Semlitsch, 1981). Water or wet leaves can be placed in the pitfalls for cover and moisture. Potential problems include killing of the salamanders in the pitfalls by small mammals, especially shrews, and desiccation. The loss of animals by shrew or raccoon predation in pitfall containers affects the samples and may prevent quantitative comparisons among sites. Data obtained from visitation frequencies of every three days (Bury and Corn, 1987) to once a week (Enge and Marion, 1986) probably underestimate actual captures.

The detection of *P. punctatus* at a particular site depends on the time of year, substrate type, soil depth, soil moisture, soil temperature, and weather conditions (see Habitat Requirements). A simple survey of sites by hand searching and rock turning in daylight hours without attention to weather and seasonality will underestimate actual abundance and fail to detect presence of a species. Table 2 contains comparative data for two sites searched the same day at different times of the year and demonstrates a strong seasonal effect. In order to construct effective management plans, the range and abundance of a terrestrial salamander must be known. Therefore, researchers conducting distributional surveys must take seasonal and diel changes in surface activity into consideration.

Results of our 1987 mark-recapture efforts are preliminary; only four recaptures were made. One *P. punctatus* captured 28 May was recaptured on 15 October. It had moved 17.4 m. Three salamanders were recaptured within ten days of original capture and had moved ≤ 2 m. Knowledge of movement capabilities by *P. punctatus* is an important part of evaluating the consequences of population fragmentation through logging operations. Are salamanders able to move out of a logged area or repopulate it when suitable habitat conditions return? We believe mark-recapture studies can provide useful information on rare terrestrial salamanders, but realize that data may need to be collected over several years and under standardized conditions in order to provide direct answers.

Habitat Characteristics

Preliminary evaluation of microhabitat data indicate that four site characteristics are most important in determining the presence of *P. punctatus*. We found *P. punctatus* at elevations between 732 m and 1317 m (fig. 4). Most sites (87%) with this species occurred above 960 m. *Plethodon punctatus* occurred on all slopes but were more common on north-facing aspects (87% of 11 sites) than east (38% of 13), south (36% of 8), or west aspects (40% of 7). Most of the captures (67% of 21) were on slopes of 20-45°. Seven sites were on slopes less than 20° and between 46° and 60°. Sites without this salamander were on a similar range of slopes (< 20°, 28.6%; 20-45°, 57.1%; > 45°, 14.3%).

Soil temperatures under cover objects at sites with *P. punctatus* (x = 12.3 C, 9.4-16.1, n = 36) were nearly identical to temperatures at sites without this species (x = 12.8 C, 9.4-15.8, n = 15). Soil pH under cover objects were also similar (with *P. punctatus*: x = 6.3, 5.4-6.8; without *P. punctatus*: x = 6.4, 5.8-6.8). Average soil moisture at sites with *P. punctatus* was 37.1% (12- 70%) and 42.8% (24-

80%) at sites without this species. Soils in which *P. punctatus* were found are characterized by shallow black humus intermixed with rocks (72% of 39 sites). One site where eleven salamanders were captured consisted of brown humus and extensive log cover, but few rocks. Cover objects under which this salamander was found were rocks < 645 cm^2 (13.6%), rocks 645-1290 cm^2 (40.0%), rocks > 1290 cm^2 (34.8%), and logs (10.6%). Over 89% of the captures were found under rock cover. Number of cover objects within a 2 m circle of the captured salamander averaged 15.1 (1-45). Sites without *P. punctatus* ranged from 100% rock cover to 0% rock cover. Sites with canopy cover equal to or greater than 50% accounted for 88.2% of the captures (n = 52).

We found *P. punctatus* in the following forest types: mature oak/hickory (38.5% of 13), oak/maple/birch (62.5% of 8), oak/pine (33.3% of 3), young oak/maple/ hemlock (50% of 8), virgin hemlock/yellow birch (100% of 2), hemlock/maple/basswood (62.5% of 8), white pine (0% of 2), and grassy balds (20% of 5). Of the site characteristics we examined, the following appear to be most important in identifying *P. punctatus* habitat: elevation, aspect, soil characteristics, and number of cover objects (rocks).

Habitats of terrestrial salamanders differ among species and, in some cases, among geographic areas within species (e.g., Semlitsch, 1980; Tilley, 1973). Data derived from the literature for management studies and plans must be used with caution. Baseline habitat and life history studies should be conducted on the focal species at the location in question before developing management plans.

Effects of Logging

Tree removal effects the terrestrial salamander community in several ways. Removal of canopy cover eliminates the moisture-retaining potential of the soil and leaf litter, allows an increase in insolation (with a concomitant increase in soil temperatures), and increases soil erosion (Bury, 1983).

The use of heavy machinery compacts soil and destroys leaf litter. Enge and Marion (1986) found that machine site preparation and clearcutting had little effect on amphibian species richness in a Florida slash pine forest. However, of the 15 amphibian species they recorded, none was a terrestrial salamander. On Shenandoah Mountain, where most of the terrestrial amphibian community is comprised of terrestrial salamanders, logging and clearcutting are likely to have detrimental effects. Salamander abundance in a 60-100 yr-old deciduous forest in another Virginia site was more than four times that in 2 yr-old and 6-7 yr-old clearcuts (Blymer and McGinnes, 1977). Bury (1983) found that terrestrial salamanders were more abundant in old growth compared to logged redwood forest habitats. *Plethodon cinereus* was significantly less abundant in a clearcut site compared to an old-growth site in a deciduous forest in New York (Pough et al., 1987).

Populations of *Plethodon punctatus* inhabiting rocky substrates with a thin soil cover may be able to withstand some logging operations. Our Site B was logged in a salvage operation after ice storm damage. Not all trees were removed and the substrate was not as damaged as that in Site A, which was clearcut. These factors, combined with the presence of a seep near the drift fence array, probably explain the high numbers of *P. punctatus* found at Site B compared to other logged sites.

We found no *P. punctatus* on Sites A and C for apparently different reasons. Site A was clearcut, the substrate was greatly disturbed, and the lack of canopy cover prevented moisture retention. The fact that *P. punctatus* occurred on the same ridge in a nearby hardwood stand suggests this salamander may have occurred on Site A prior to logging. Site C was

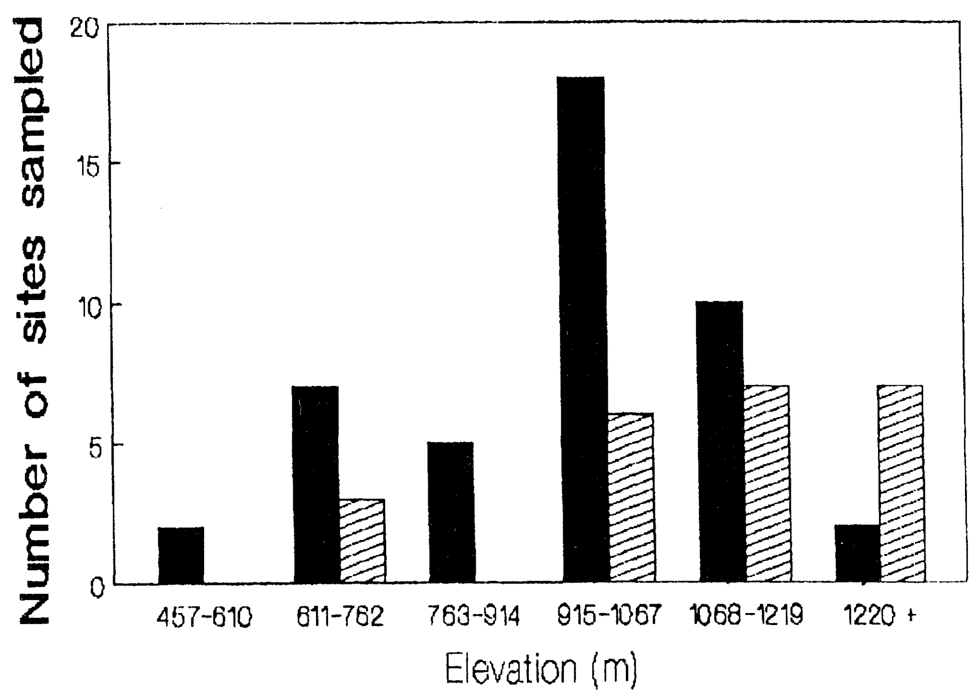

Figure 4.—Elevational distribution of *Plethodon punctatus* on Shenandoah Mountain, George Washington National Forest. Solid bars represent sites where *P. punctatus* was not found and bars with diagonal lines represent sites where this species was found.

logged 30 years ago but was replanted with white pine (table 1). The logging operation and change in vegetation type may have affected the salamander populations previously present. However, because of the lack of rocky substrate, we cannot disprove the hypothesis that *P. punctatus* may not have occurred there historically.

Plethodon punctatus appears to occur in greatest abundance on rocky sites that contain virgin hardwoods (Site E) and sites that are not heavily disturbed by logging operations (Site B). Clearcutting and associated disturbance does appear to eliminate populations of this salamander. Salamander mortality can be minimized if logging operations are conducted outside the seasonal activity period. If size of the area logged is small, or if the area is logged in a mosaic, or if corridors are allowed to remain, reinvasion may eventually be possible from peripheral populations when suitable conditions return. Fragmentation of the limited range of *P. punctatus* by a patchwork of clearcuts could seriously affect its long-term survival.

Conclusions

Because of budget and time constraints, our study attempted to obtain baseline data and evaluate the effects of logging simultaneously. We offer the following conclusions to researchers and managers who must study a salamander whose ecology is little known.

1. Multiple capture techniques should be used when studying an apparently rare terrestrial salamander.

2. The life history and basic ecology of the study species needs to be understood before the project's experimental design can be erected to evaluate logging effects.

3. Seasonal and daily activity patterns of salamander activity must be taken into consideration when surveys are conducted to determine range and population abundance.

4. Project proposals to federal and state agencies should contain a two step process, a field survey phase to obtain baseline data on ecology and life history and an experimental phase in which logging or other concerns are evaluated. The design of the experimental phase should be based on the results of the field survey.

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