

**Post-breeding Emigration and Habitat Use of
Radio-implanted Jefferson and Spotted Salamanders at the
Marsh-Billings-Rockefeller National Historical Park**

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Abstract

The post-breeding movement patterns, emigration distances, and terrestrial habitat use of two sympatric mole salamander species was investigated using radio-implant procedures. Sixteen adult salamanders (8 Jefferson and 8 spotted) were radio tracked for an average of 164 days. No mortality was documented among the study animals, and eleven individuals were tracked to overwintering sites. Although emigration occurred during spring, summer, fall, or it did not occur, most animals emigrated during June and July. Small mammal burrows were used almost exclusively as terrestrial refuges, and those of the short-tailed shrew were used most frequently, particularly between spring and fall. Deeper tunnels of *Peromyscus* spp. were more commonly used during winter, suggesting both mammal species are important to maintaining viable populations of these salamanders. The mean emigration distance from release site for both species was 111.9 m. Among emigrants, females moved significantly farther than males, and there was a significant relationship between mass and distance moved for spotted salamander, but not for Jefferson salamander. Among eleven salamanders that were from known breeding pools, the mean emigration distance from pool edge was 112.8 m for both species combined. Assuming the mean distance encompassed 50% of the population, an area encompassing 95% of the population would extend 157.1 m from the pool's edge. A regional salamander "life zone" that would encompass 95% of most populations of these two species was calculated by combining emigration distance data from this study with those for Jefferson and spotted salamanders from other studies, resulting in an area that would extend 175 m from a pool's edge. Forest management practices in the landscape surrounding amphibian breeding pools must consider this life zone in management strategies in order to conserve local biodiversity and wildlife values associated with amphibian breeding pools.

Introduction

During the past decade, apparent amphibian declines, increased malformation rates, and local extinction events have resulted in global concerns for conservation of amphibian populations. Development of strategies to address these complex issues has been complicated by a lack of solid data to guide conservation efforts. Recently, the Northeast Endangered Species Technical Committee listed the Jefferson salamander (*Ambystoma jeffersonianum*) as a species of regional conservation concern, indicating that; a) the species is at high risk of extirpation from the region, b) few data exist with which to address conservation concerns, and c) a significant portion of the species range occurs in the Northeast and that without conservation attention, the global population could be at risk (Therres 1999). In addition, the Silvio O. Conte National Fish and Wildlife Refuge included the Jefferson Salamander on its list of "wildlife species of special emphasis" within the Connecticut River Watershed (USFWS 1995).

Vernal pool-breeding amphibians such as Jefferson and spotted salamanders (*Ambystoma maculatum*) utilize terrestrial forested habitats for the majority of the year (≥ 11 months). This is where they must acquire enough food to grow and prepare for breeding. It is also where they seek protection from predation, dehydration, and freezing for long periods of time. While breeding sites are critical to the viability of populations, upland areas surrounding vernal pools must also be considered in conservation strategies. Even small-scale habitat disturbances that affect the forest floor environment may affect local populations of salamanders (deMaynadier and Hunter, 1995). These facts led Semlitsch (1998) to suggest

that this critical upland habitat be considered a "life zone," vital for the maintenance of the entire juvenile and adult breeding populations.

Compared to other vertebrates, the post-breeding behavior and movements of amphibians are poorly documented, particularly for *Ambystomatid* salamanders because they spend most of the year in subterranean burrows (Semlitsch, 1998). In the Northeast, where 75% of the landscape is classified as forested and much of that is actively managed for forest products, there is a critical need to develop science-based management guidelines that will protect or enhance biodiversity within working forests. Currently, natural resource managers who strive to balance forest management activities with biological resource needs must rely on somewhat arbitrary guidelines regarding terrestrial life zones around amphibian breeding pools. For example, timber harvesting guidelines in Vermont suggest a 50-200 foot "low ground disturbance zone" around vernal pools, recommending that disturbance to the forest floor be kept to a minimum. Whether or not this is adequate to sustain amphibian populations at all sites is unknown, but radio telemetry data from a study in New York suggests that it may not. Madison (1997) tracked spotted salamanders from breeding sites to overwintering sites and found the average distance traveled was 118 m (387 ft) (range 15-210 m).

The Vermont Institute of Natural Science (VINS) received a 2000 Challenge Cost Share Grant from the Silvio O. Conte National Fish and Wildlife Refuge to investigate the post-breeding emigration, movement patterns and habitat use of both Jefferson and spotted salamanders at the Marsh-Billings-Rockefeller National Historical Park in Woodstock, VT. This report details the results of that study.

Methods

Study Area

The Marsh-Billings-Rockefeller National Historical Park (MABI), located in Woodstock, VT, was established in 1996 as the only national park to focus on conservation history and the evolving nature of land stewardship (Fig. 1). The 555-acre park is dominated by northern hardwood forest, primarily American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and yellow birch (*Betula lutea*), although some stands contain a significant component of Eastern hemlock (*Tsuga canadensis*), particularly along the stream in the eastern half of the park, and in pockets to the east and north of the pond, known locally as the Pogue. In addition, there are several conifer plantations of various sizes and species composition, including red pine (*Pinus resinosa*), Scotch pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), European larch (*Larix decidua*), and white pine (*Pinus strobus*). To the east and south of the Pogue there are several hayfields, totaling 33 acres. The park contains an extensive network of hiking trails and carriage roads that are groomed for cross-country skiing in winter, and open to foot and horse traffic at other times of the year.

A 2-year biological inventory of reptile and amphibian populations within the park was recently completed by VINS under a cooperative agreement with the National Park Service. During that study, a significant population of Jefferson salamanders was discovered in the park, along with more widely distributed species including the spotted salamander. The study detailed in this report was centered around the two primary breeding pools that are located in a hemlock/beech/maple stand east of the Pogue, and a shallow shrub swamp located in a beech/maple/hemlock stand at the base of a steep, 24-degree, south-facing slope approximately 175 m northwest of the breeding pools (Fig. 2). Ten of the 16 salamanders in this study were captured in drift fences as they left one of the two breeding pools, one individual was found approximately 50 m west of the north pool during an active search, and five individuals were captured in drift fence arrays established at the shrub swamp which was not confirmed as a breeding location for either *Ambystomatid* species.

Figure 1. Marsh-Billings-Rockefeller National Historical Park
Woodstock, Vermont



Radio Implant Procedures

Between 16-24 May 2000, radio transmitter units (model BD-2GH) with an estimated battery life of 6 months (Holohil Systems Ltd.), were implanted in 8 (4 m, 4 f) Jefferson salamanders and 8 (5 m, 3 f) spotted salamanders. Each transmitter unit, including radio, battery, and internal helix antenna, was completely encapsulated in inert marine epoxy, resulting in pear-shaped implants measuring 16 mm X 9 mm and weighing 1.75 g (Fig. 3). The surgical technique used was similar to Madison (1997). Prior to surgery, salamanders were immersed in a 0.1% (1 g/l) solution at room temperature of MS-222 (tricaine methanesulfonate), and all instruments and transmitter implants were sterilized with ethyl alcohol. Average induction time was 31 min (range 14 – 50 min). To implant the radio unit, I made a 12 mm longitudinal incision in the left ventrolateral abdominal wall 10 mm anterior to the left hind leg. A transmitter was placed through the incision with the transmitter's fat end posterior. Five to seven 5-0 silk sutures were used to close the incision. Each operation took about 15 min. Immediately following surgery, salamanders were briefly immersed in fresh water at room temperature to remove residual anesthesia, and then placed in individual plastic shoeboxes.

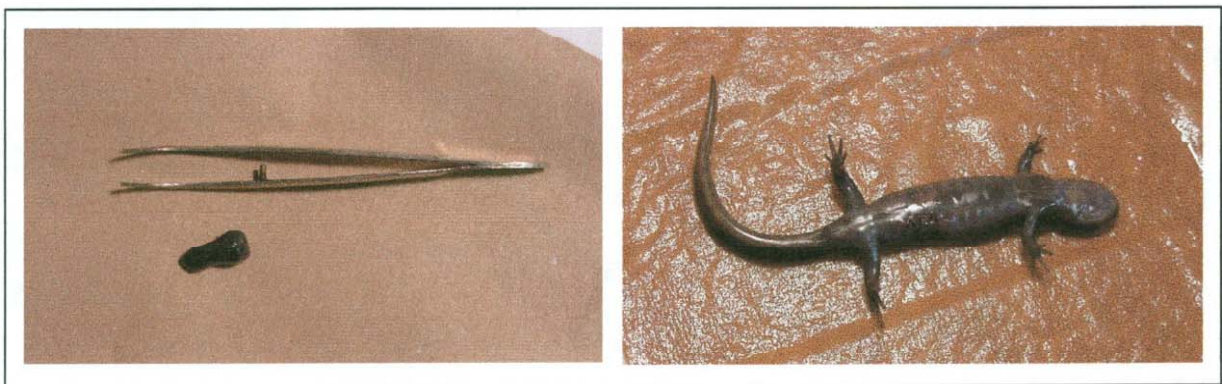


Figure 3. Radio transmitter unit (left), and anesthetized Jefferson salamander (right) immediately following implant surgery.

Radiotracking Procedures

All implanted salamanders were released at a suitable cover object (e.g. log, stump, deep litter, etc) nearest their point of capture less than 24 hours post-surgery. Precise positions of salamanders in underground refuges were obtained by using direct overhead localization with a handheld antenna. All telemetry locations of individual animals were accurate to within 10 centimeters. Radio telemetry was conducted following rain events or at least once per week through 15 November 2000. All new locations were marked with small ground flags on which the transmitter frequency, date, and species was recorded with permanent marker. Salamander positions were then spatially referenced using a Trimble GPS unit and plotted in ArcView.

Emigration

Emigration was considered to have occurred if salamanders moved at least 20 m from their release point. Spring emigrants were those completing at least 67% of their maximum distance from release point between 17 May and 16 July; summer emigrants, at least 67% between 17 July and 15 September; fall emigrants, at least 67% between 16 September and 15 November; and "split" emigrants, those completing more than 33% during any 2 periods.

The occurrence of emigratory movement in association with precipitation was examined by plotting when movement occurred in relation to rainfall. Local precipitation data from Woodstock, VT were obtained via the National Weather Service web page (<http://www.nws.noaa.gov/er/btv/>).

Refuge Use and Habitat Characteristics

Refuge use, microhabitat characteristics, and canopy cover type were evaluated at each salamander location. In addition, I occasionally conducted limited searches to confirm an individual's location, refuge use, and post-operative condition. Searches included delicate removal of leaf litter, turning of cover objects, shining a flashlight into tunnel entrances, and occasionally limited hand-excavation of tunnel systems. Microhabitat characteristics were evaluated in a 1 m² area centered on each salamander location by classifying the habitat feature associated with the occupied tunnel refuge into one or more of the following categories; log, stump, leaf litter, bark, root, coarse woody debris (cwd), sapling, root bole, pit or mound topography, rock rubble, snag, or road-bank.

Tunnel refuges were classified according to the small mammals most likely to have made them based on personal field experience and information from Madison (1997). Essentially, highly branched, horizontal, 2.0-2.5 cm tunnels in the organic layer just beneath the litter were made by short-tailed shrews (*Blarina brevicauda*). Primarily vertical, 2.0 cm tunnels into the soil, usually without horizontal runways under the litter are those of white-footed or deer mice (*Peromyscus spp*). Larger, 4-6 cm vertical tunnels were classified as Eastern chipmunk (*Tamias striatus*). Presence of fecal pellets in tunnel systems often facilitated identification.

Statistical Analyses

I used the Wilcoxon Signed Rank Test (SYSTAT 8.0, SPSS, 1998) to test for differences in mass changes within individuals, and for net emigration distances between species and sexes.

Results

Sixteen salamanders (8 Jefferson, 8 spotted) were radiotracked between 17 May and 15 November 2000 resulting in 466 telemetry fixes (Table 1). The average number of days tracked was 164 (range 119 – 182), although radio contact with 5 individuals (3 Jefferson, 2 spotted) was lost prematurely after a minimum of 119 days. Two of these lost signals were due to suspected transmitter/battery failure (J-M-446, J-F-461), while 3 were due to unknown causes (J-M-488, S-M-211, S-F-288). These latter “losses” could be attributed to undetected emigrations, transmitter/battery failures, depredation, or an individual retreating too deep underground to be detected. Although considerable time was spent searching for lost individuals, with a maximum signal range of 40-50 m which decreased significantly as animals retreated deeper underground, it is possible that sudden, long-distance movements may have been missed.

Of the 16 individuals, 11 (5 Jefferson, 6 spotted) were tracked to overwintering sites where their implant either expired or could not be detected due to depth underground. Although no mortality among the study animals was documented, Jefferson salamander male J-M-409 was found on 21 August lying on the soil surface adjacent to a rotten stump in which it often found refuge. It was highly desiccated and its tail was heavily scarred, presumably with bite marks resulting from a depredation attempt by a shrew. The animal was placed under some bark among the rotten stump roots. More than 1 cm of rain fell the following day, and when checked one week later, its signal was from deep within the stump. Its signal remained in this area, apparently moving 0.75 m north during late-September. On 11 and 17 October, I attempted to excavate J-M-409 to confirm its fate. During the first attempt, digging by hand, I located 2 nearly vertical tunnels (1.5 cm & 4 cm diameters) and excavated them to approximately 20 cm before stopping due to rocks, roots, and compact soil. The radio signal appeared to get weaker in response to my digging. On 17 October I used a shovel to excavate the tunnels, which joined into one 4 cm tunnel, to a depth of 45 cm where it leveled off into a horizontal chamber. Again, the signal appeared to move deeper, weakening as I dug, leading me to assume the salamander was still alive.

Limited searches were conducted to confirm an individual's presence and assess microhabitat use, often resulting in visual and/or physical contact. All 16 individuals were located visually at least once after release. Of 57 visual contacts, 11 animals (5 Jefferson, 6 spotted) were captured on 18 occasions to briefly inspect their suture lines and assess their health in general. Those inspected less than 30 days post-surgery were in excellent health with well-healed, but noticeable suture lines. Those handled greater than 60 days following surgery showed no scarring or other indications of suturing, and appeared to be in excellent health. Out of the 11 animals captured, four individuals were weighed in the field, two on 21 August, and two on 3 October (Table 1). These masses were then compared to those taken during implant surgery in May in order to gauge whether the implants might be affecting their ability to obtain food. No significant mass change had occurred within these individuals (avg. weight change = +2.0 g, $T = 1.46$, $P = 0.144$).

Table 1. Inventory, fate, and movement data of all salamanders tracked during 2000. Provided for each salamander is their sex, initial mass at implant surgery, subsequent mass (* = 21 August, ** = 3 October), the number of days tracked, and the number of positions (Fixes). The fates include animals alive at their last position when their transmitters expired (A), animals with suspected transmitter failures (T), and animals whose fate was unknown (U). The distances moved include total distance during radio tracking (TD), the net maximum distance from the release point (ND), and the maximum distance in a single movement (SD).

ID	Sex	Initial Mass (g)	Autumn Mass (g)	Days Tracked	Date of Last Fix	No. of Fixes	Fate	TD (m)	ND (m)	SD (m)	Type of Emigrant
Jefferson Salamander (<i>A. jeffersonianum</i>)											
J-M-392	M	12.4	11.8*	182	15 Nov	33	A	89	92	36	Summer
J-M-409	M	11.9		180	13 Nov	35	A	66	61	30	Spring
J-M-446	M	13.1		146	3 Oct	24	T	125	97	83	Spring
J-M-488	M	11.7		133	27 Sep	24	U	83	64	42	Spring
J-F-309	F	13.6	15.9*	177	15 Nov	31	A	424	405	355	Spring
J-F-461	F	17.1		153	13 Oct	29	T	93	11	14	
J-F-508	F	17.2		182	15 Nov	34	A	119	57	44	Fall
J-F-526	F	15.4		182	15 Nov	35	A	244	194	125	Spring
Spotted Salamander (<i>A. maculatum</i>)											
S-M-211	M	18.9		119	13 Sep	18	U	104	94	70	Spring
S-M-228	M	19.0	22.9**	175	15 Nov	28	A	62	46	54	Spring
S-M-246	M	11.9		176	15 Nov	29	A	18	12	7	
S-M-268	M	15.2		176	15 Nov	31	A	73	58	39	Spring
S-M-328	M	20.1	22.5**	181	15 Nov	35	A	196	182	133	Spring
S-F-288	F	23.1		141	3 Oct	23	U	237	181	106	Spring
S-F-349	F	24.0		155	19 Oct	28	A	243	218	156	Summer
S-F-371	F	16.4		161	25 Oct	29	A	59	18	13	

During attempts to locate animals visually in subterranean refuges, spotted salamanders were observed on 38 (66.7%) occasions, twice as often as Jefferson salamanders ($n = 19$, 33.3%). By simply shining a flashlight into tunnel entrances, I repeatedly observed 5 different spotted salamanders resting just within tunnel refuges, an observation that never occurred with *jeffersonianum*. Observations of Jefferson salamanders generally took more effort, and often involved pulling up the litter and duff covering tunnel systems, or looking under or within rotten logs, deep litter, and cwd. These observations support those of Klemens (1993), Petranka (1998), and J. Andrews (pers. comm.), suggesting that *jeffersonianum* are more fossorial than *maculatum*.

Observations of 1 individual male (S-M-328) accounted for nearly half (47%) of the *maculatum* sightings. Between 14 June and 7 November, S-M-328 was only located within a short-tailed shrew tunnel beneath the root of a mature sugar maple. Out of 24 consecutive fixes at this location, 13 (54%) resulted in sightings, usually of the salamander resting inside the tunnel with its head just inside the entrance. On

two occasions in August however, S-M-328 was found “basking” outside the tunnel entrance, partially concealed by leaf litter. As I approached to within 1 m, the animal rapidly retreated into the tunnel tail-first. These observations occurred on clear, warm days (80 °F) when the ground was dry, so it seems unlikely that the animal was seeking a more favorable microclimate outside the tunnel, but may have been foraging among the litter.

Emigration

Although emigratory movements occurred in all directions, most were to the north/northwest or south/southeast, consistent with the two major emigration barriers (pond and hayfield) east and west of the study site. By mid- to late-June, most individuals had settled into a defined home range (ca. 15-20 m²) where they remained all summer. Of the 16 individuals tracked, 13 (7 Jefferson, 6 spotted) moved more than 20 m from their release points and therefore could be categorized as to occurrence and type of emigration (Fig. 2, Table 1). Ten salamanders (5 Jefferson, 5 spotted) were spring emigrants, one of each species were summer emigrants, one Jefferson was a fall emigrant, and three (1 Jefferson, 2 spotted) were non-emigrants. Of the ten spring emigrants, major movements of nine individuals occurred during rain events on 12 June, and 3 and 7 July. On 12 June, one Jefferson and three spotted salamanders moved an average of 104.5 m (range = 54 – 133 m), while on 3 and 7 July, three Jefferson and two spotted salamanders moved an average of 107.2 m (range = 30 – 355 m). Of these, several migrations are worth noting.

On 12 July, J-F-309 was located inside a rotten log in a hemlock-dominated stand 355 m northwest of its previous location, having migrated up and over a steep (24°), south-facing hillside, for a net elevation gain of 30.5 m (Fig. 2, Appendix 1). Assuming this movement occurred during overnight rains, it must have happened on 3 and/or 7 July, the only rainy nights during the period.

During a rain event on 12 June, J-F-526, S-F-288, and S-M-328 each migrated more than 100 m in a northwest direction to overwintering sites in hardwood stands (Fig. 2, Appendix 1). The earliest emigration occurred on 24 May – just one week after implant surgery – when J-M-446 moved 83 m northwest to a hemlock-dominated forest stand where it remained until its transmitter prematurely expired on 3 October (Fig. 2, Appendix 1).

The major movements of the two summer emigrants occurred in a southeast direction on 1 August during a heavy rain when J-M-392 moved 36 m toward the north breeding pool, and S-F-349 traveled 156 m away from the south breeding pool, crossing a carriage road and a stream (Fig. 2, Appendix 1). The only fall emigrant was J-F-508, moving 44 m north on 19 October to an overwintering site near the southeast edge of the northern breeding pool (Fig. 2, Appendix 1). All emigrations occurred on nights with precipitation.

The net distance moved from release point to last location for all 16 salamanders was 111.9 m (range = 11 – 405 m). There was a slight, non-significant difference between species, with Jefferson salamanders moving an average of 122.6 m (range = 11 – 405 m), and spotted 101.1 m (range = 12 – 218 m). Although the net distance moved from release point for females (154.9 m, range = 18 – 405 m) was nearly twice that of males (78.4 m, range = 12 – 182 m), the difference was not significant due to the wide variability ($T+ = 1.014$, $P = 0.31$). Among the 13 individuals that were considered emigrants however (Table 1), females moved significantly farther from their release point (211.0 m, range = 57 – 405 m) than did males (86.8 m, range = 46 – 182 m) ($T+ = 1.753$, $P = 0.080$). In addition, there was a significant relationship between mass and net distance moved from release site among spotted salamanders, but not for Jefferson salamanders (Fig. 4).

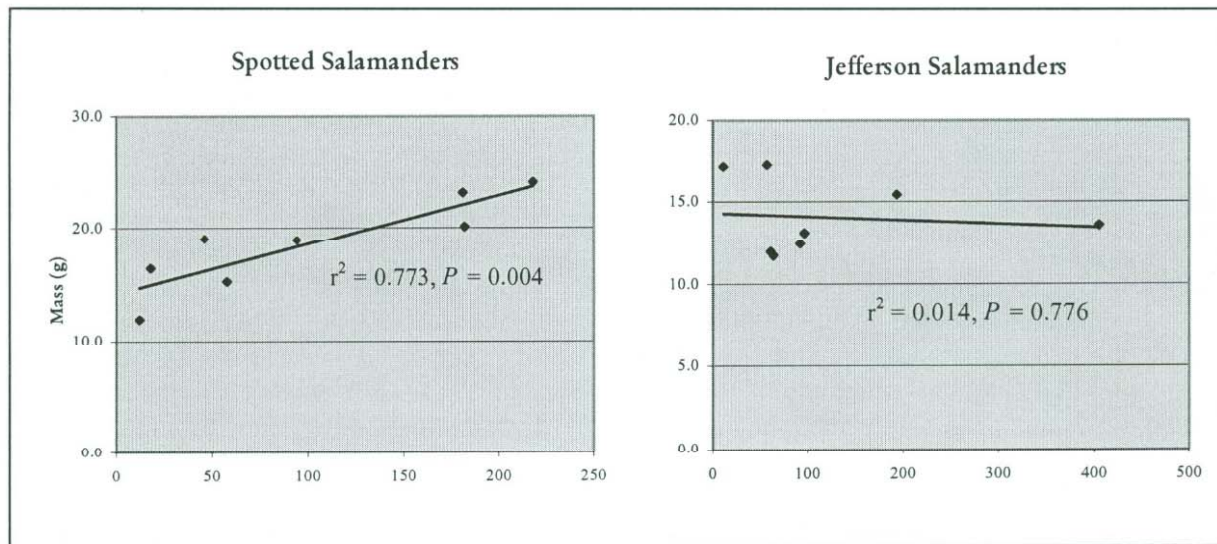


Figure 4. Relationship between mass and distance emigrated from release site for spotted and Jefferson salamanders.

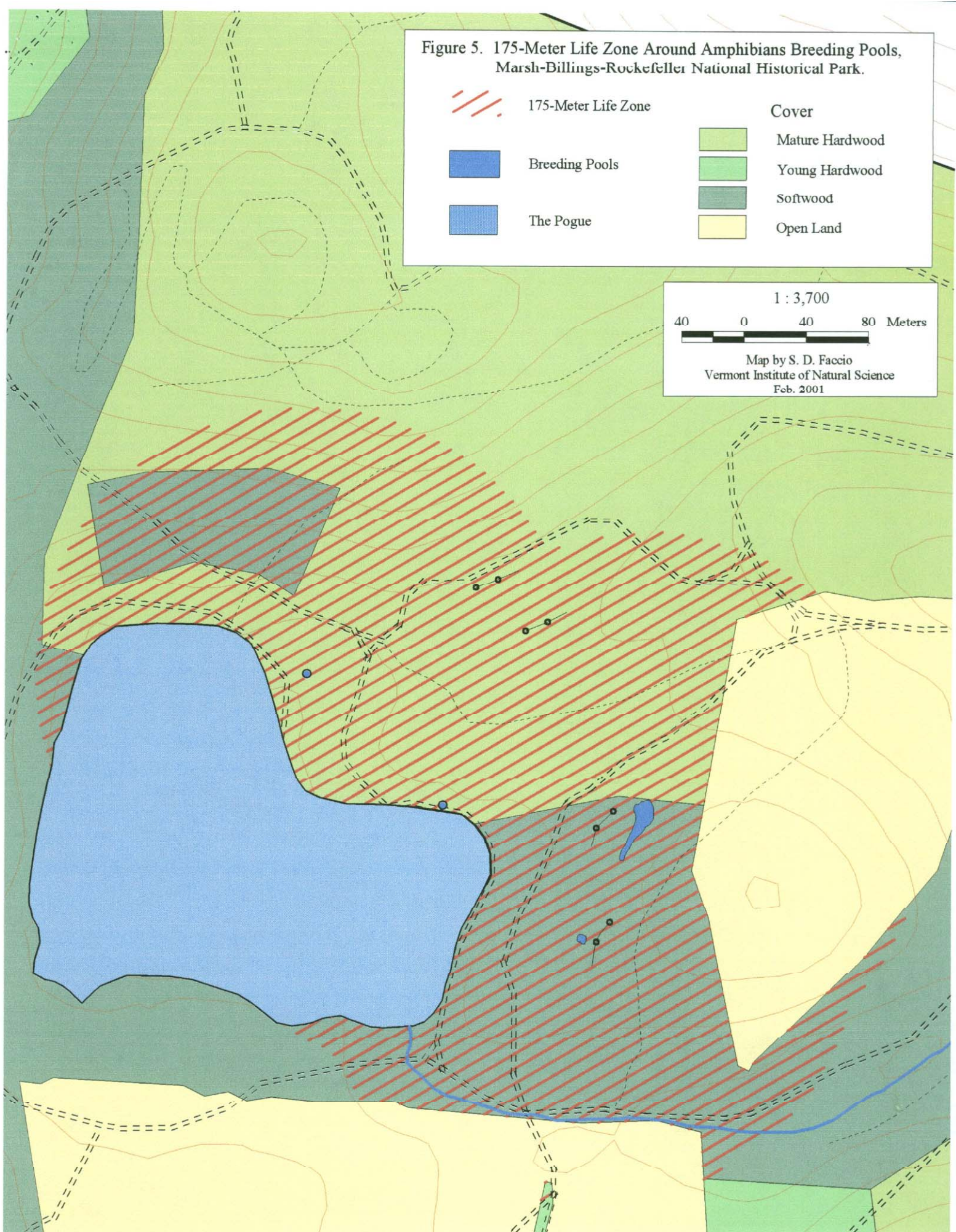
Movement distances from known breeding pools could be determined for 11 individuals in this study, 10 of which were captured exiting one of the two breeding pools, and one that was found in close proximity to a pool. For both species combined the mean distance moved from the closest pool edge was $112.8 \text{ m} \pm 65.9$. The net distance traveled from pool edge for Jefferson salamander was 92.8 m (range = $30 - 205 \text{ m}$, $n = 6$), and 136.8 m for spotted salamander (range = $52 - 219 \text{ m}$, $n = 5$). Following Semlitsch (1998), I then used these data to calculate a biological terrestrial “life zone” that would encompass 95% of the *Jeffersonianum* and *maculatum* populations. By definition, the mean distance traveled from a breeding pool for these two species (112.8 m) represents an area that would include just 50% of the population. I used the following formula to calculate the distance that would encompass 95% of the adult population (95% confidence limits = $\text{mean} \pm 2.23 [t\text{-distribution; } \alpha = 0.05, \text{ df} = 10] \times \text{standard deviation}/\sqrt{n}$). For the breeding pools at MABI, the 95% life zone should extend 157.1 m (516 ft) from a pool’s edge. I then added the mean distances traveled for *Jeffersonianum* and *maculatum* from this study (92.8 , 136.8 respectively) to the means for these species from other studies summarized by Semlitsch (1998) and again calculated the 95% life zone using the same formula. This resulted in a “regional salamander life zone” that would extend 175 m (575 ft) from a pool’s edge (Fig. 5).

The 5 individuals that could not be positively linked to a breeding site were captured at the shrub swamp, which was not confirmed as an *Ambystomatid* breeding location during the biological inventory at MABI (Fig. 2). These individuals may have been non-breeders, may have attempted to breed in the shrub swamp or in one of two small vernal pools south and west of the shrub swamp, or may have emigrated away from the north or south pools after breeding.

Refuge Use

Within a few days of release, most animals moved into subterranean refuges, primarily small mammal tunnel systems. Salamanders were observed in refuges on 56 occasions, 52 of which (91.2%) were within mammal runway systems. Forty-one refuges (73.2%) were *Blarina* runways, four (7.1%) were *Peromyscus*-type runways, seven (12.5%) were in tunnels that could not be classified as to type, two (3.6%) were underneath a rotten log, and 2 (3.6%) were under slabs of bark. Jefferson salamanders were never observed in *Peromyscus*-type runways, while 2 individual spotted salamanders were twice observed using *Peromyscus* burrows.

Figure 5. 175-Meter Life Zone Around Amphibians Breeding Pools,
Marsh-Billings-Rockefeller National Historical Park.



In addition to direct observations, salamander use of mammal runways was inferred from radio telemetry locations. Based on signal strength and habitat features, 444 of 466 radio fixes (95.3%) were pinpointed to small mammal tunnels. One hundred and sixty three of these (36.7%) were *Blarina* tunnels, 106 (23.9%) were *Peromyscus*-type tunnels, three (0.7%) were Eastern chipmunk, and 172 (38.7%) either could not be classified as to type, or the precise tunnel system used could not be determined. A distinct seasonal shift in tunnel use was evident for both species. During summer (May – August), 44% of radio locations were from *Blarina* systems while 16% were from *Peromyscus* tunnels. During fall (September – November) however, the use of *Blarina* tunnels dropped to 25% while *Peromyscus* tunnel use increased to 36%. By November, 54% of radio locations were from deep, vertical *Peromyscus* burrows, 6% were in *Blarina* runways, and 40% could not be identified to tunnel type (Fig 6).

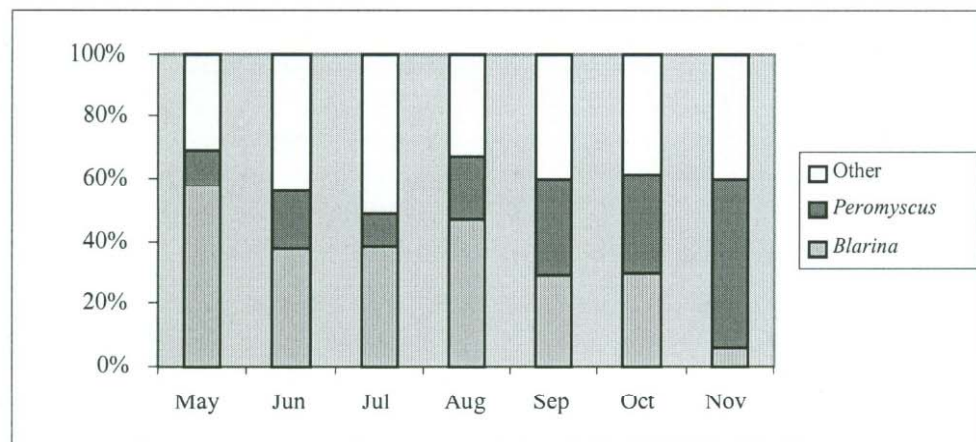


Figure 6. Proportion of tunnel types used each month by both Jefferson and spotted salamanders.

Ten salamanders were tracked until mid-November when transmitter batteries expired or salamanders moved too deep for detection (Table 1). Five of these overwintering sites were in *Peromyscus* burrows. Because multiple tunnel types were present at the overwintering locations of the other five individuals, the exact tunnel systems being used could not be determined. Nine of the ten overwintering sites were in tunnels associated with other habitat features; four were at the base of large (>30 cm dbh) American beech trees (two of these were also associated with a road-bank), two were under rotten stumps, one was beneath a rotten log, one was among beech saplings within a mound (pit/mound topography), and one was among saplings.

Habitat Features

Several microhabitat characteristics were frequently associated with tunnel refuges occupied by salamanders. Mounds associated with pit/mound topography were used frequently by both species. Sixteen percent of Jefferson salamander locations occurred within mounds, while 23% of spotted salamander locations occurred in this feature. An individual of both species used one mound at different times. J-M-446 was found in a mound between 24 May and 27 June before moving to other refuges nearby. On 13 September, S-M-268 moved to the same mound, remaining there to overwinter (Fig. 2, Appendix 1). Coarse woody debris was another important habitat feature, particularly for spotted salamanders. Twenty-two percent of *maculatum* locations occurred among cwd, compared to just 5% for *Jeffersonianum*. Among Jefferson salamanders, 33 locations (14%) were in tunnel systems among dense stands of beech saplings, while 29 locations (12%) were beneath or within rotten stumps. However, a distinct sexual bias was evident among both of these habitat features, with 82% of individuals found among saplings being female, and 79% of those found in stumps being male.

As expected, all salamander locations occurred within the northern hardwood forest community type. Some stands were dominated by Eastern hemlock, particularly around the primary breeding pools east of the Pogue, along the stream, just south of the shrub swamp, and near the park's northern border (Figs. 1, 2). Although available in the study area, no salamanders were found in open field habitats, or conifer plantations. No differences were detected in cover type use between species or sexes.

Discussion

While the radio implant technique employed here has been used successfully with other amphibians, including spotted salamanders (Madison 1997), tiger salamanders (*Ambystoma tigrinum*) (Madison and Farrand 1998), hellbenders (*Chryptobranchus alleganiensis*) (Stouffer et. al. 1983, Blais 1996), green frogs (*Rana clamitans*) (Lamoureux and Madison 1999) and Amercian toads (*Bufo americanus*) (Werner 1991), this is the first known study in which the procedure has been used to track Jefferson salamanders, and to simultaneously track two sympatric species. Overall the technique was very successful, and the increased mass recorded 13 and 20 weeks after implant surgery combined with a high survivorship rate support this conclusion.

I documented no mortality among the 16 animals studied, consistent with annual adult survivorship values reported for *maculatum* which range from 30% to 100% (Husting 1965, Whitford and Vinegar 1966, Douglas and Monroe 1981, Phillips and Sexton 1989). Adult survivorship values for *Jeffersonianum* are lacking, but in an Ohio population only about 10% of adults survived for 3 years (Downs 1989). Even if the three individuals whose fates were unknown due to premature loss of radio contact were considered mortalities (Table 1), the resulting survival rates of 75% for *maculatum* and 88% for *Jeffersonianum* remain high. However, I speculate that these "losses" were more likely due to transmitter failure or sudden emigratory movement away from the study area rather than depredation. Unless depredated by an owl or other large, mobile predator, depredation is unlikely to result in loss of radio contact. The two most common predators of *Ambystomatids* in the study area are the Eastern garter snake (*Thamnophis sirtalis*) and short-tailed shrew. Depredation by a garter snake would likely result in the snake being tracked until the implant is excreted (Madison pers. comm.). When short-tailed shrews preyed upon radio-implanted tiger salamanders in New York, Madison and Farrand (1998) recovered the transmitters within mammal tunnel systems, often with *Blarina* teeth marks on the surface. In this study, a male Jefferson salamander was apparently attacked unsuccessfully by a short-tailed shrew. The salamander, which frequently used *Blarina* tunnels for refuge, was found on the soil surface with a heavily scarred tail, particularly along the dorsal surface. Injury to this portion of the tail would be expected during an encounter with a shrew due to antipredator postures exhibited by *Jeffersonianum* and other salamanders. These postures always involve elevation and undulation of the tail, which places the tail dorsum and its concentration of granular glands in proximity to the attacking shrew (Brodie et. al. 1979).

Emigration

Radio-tagged animals emigrated during overnight rain events and their movement patterns (timing, directions, and distances traveled) varied widely among individuals. Some remained at or near their release site for a month or more before moving, while others made an initial movement within a day or two of release. Some individuals were found in the same spot and position during most telemetry sessions, while others made frequent moves within their home range. Unlike Madison (1997) however, who found that emigratory movements of *maculatum* occurred almost exclusively in April and May or October and November, the majority of emigration in this study occurred in June and the first week of July. This pattern could be attributed to weather, or to a later breeding season than that observed by Madison (1997) in New York. Rainfall during May and June 2000 was well above normal, and this trend continued during the first week of July, although overall, July rainfall was below normal. These damp

conditions may have prompted salamanders to initiate emigration that in other years may occur during autumn rains. In addition, implanted salamanders in this study were released in mid-May, more than a month later than those in Madison's study.

I was surprised that more individuals did not make additional autumn emigrations, although it is possible that the three salamanders I lost radio contact with during September and early-October made sudden, long-distance movements that went undetected. Although Madison (1997) speculated that salamanders showed a strong bimodal, spring/fall emigration, and avoided above-ground movements during summer due to a high risk of snake predation, my results do not support this theory. However, predation pressure from snakes may be lower at more northern latitudes, such as those of central Vermont. In addition, snake activity during the summer of 2000 appeared to be depressed at MABI due to frequent rains and below normal temperatures (S. Faccio, pers. obs.).

The variability in the occurrence and timing of emigratory behavior that I observed is consistent with the findings of Douglas and Monroe (1981), and Madison and Farrand (1998). Major emigrations may be broken into two or more major movements, each being followed by a period of localized subterranean activity, and major movements can occur anytime up to overwintering. Thus, as Madison and Farrand (1998) point out, "if refuges and food are abundant close to breeding pools, if weather is unfavorable for above-ground travel, if the risk of predation is high, or if some combination of these occur, salamanders may prolong emigration or perhaps avoid emigration completely and remain in the vicinity of the breeding pool."

For both species combined, the average minimum emigration distance to overwintering site from release point (112 m) and from breeding pool edge (113 m) is consistent with the findings of others (Wacasey 1961, Whitford and Vinegar 1966, Williams 1973, Douglas and Monroe 1981, Kleeberger and Werner 1983, and Madison 1997). However, I should emphasize that these are minimum distance estimates because they include the 5 individuals that were incompletely radio tracked (Table 1). It seems likely that at least some of these salamanders may have made additional movements away from the pools, thus increasing emigration distances. Therefore, the 157 m life zone value that I calculated for MABI breeding pools probably underestimates the actual area needed to encompass 95% of most populations. It is likely that the 175 m life zone value derived by adding data from this study to those summarized in Semlitsch (1998), is more robust since it includes natural variations due to geographic location, climate, size and type of terrestrial habitat, and other variables.

These results indicate that salamanders use a considerable amount of terrestrial habitat surrounding breeding pools and that to protect the majority of populations these areas must be considered in forest management strategies. The amount of salamander habitat encompassed by a 175-meter life zone around the 4 breeding pools at the MABI study site is 36.6 hectares (90.4 acres) (Fig. 5). This value does not include the hayfield and the Pogue since neither salamander species utilize these habitats. For a small, isolated vernal pool surrounded by contiguous forest, a 175-meter life zone would encompass roughly 10 hectares (25 acres) of forested habitat. This area however, does not include the complex issue of metapopulation dynamics, a topic that is only beginning to be explored among pond-breeding amphibians (Semlitsch 1998, 2000, Marsh and Trenham 2001). Clearly, any successful management plan must also protect additional areas of forested habitat to provide dispersal corridors for amphibians to move between adjacent ponds, thereby helping to maintain source-sink population dynamics.

Refuge Use

This study suggests that an important ecological relationship exists between *Ambystomatid* salamanders and small mammals, particularly short-tailed shrews and white-footed/deer mice. Both salamander species heavily utilized runways of these small mammals as subterranean refuges. Madison (1997) showed that access to small mammal runways, particularly in the hours before sunrise, is crucial to

salamander survival. In addition, the distinct seasonal shift I detected in salamander runway use, from *Blarina* in summer to *Peromyscus* in fall, supports the findings of Madison (1997), and suggests that populations of both mammal species may be important to maintaining viable salamander populations by providing both summer and winter refuges. Loredó et al. (1996) demonstrated the importance of ground squirrel burrows for California tiger salamanders (*Ambystoma californiense*) and suggested that loss of these habitat features may have strong negative consequences for salamander populations. Therefore, management strategies that effect small mammal populations may effect salamander populations as well. Studies investigating how small mammal runway densities and distribution effect salamander populations and emigration distances, and how salamanders detect, select, and utilize mammal runways are crucial to better understand the terrestrial ecology of these, and possibly other, *Ambystomatid* salamanders.

Habitat Features

In addition to mammal runways, numerous studies have identified a variety of microhabitat features that appear important to salamander abundance. These include deep, uncompacted leaf litter (Pough et al. 1987, DeGraaf and Rudis 1990, Bonin 1991, deMaynadier and Hunter 1998), coarse woody debris (Bury and Corn 1988, Petraska et al. 1994, Dupuis et al. 1995, Windmiller 1996), rotten logs, stumps, and roots (Aubry et al. 1988, Corn and Bury 1991), understory vegetation density (Pough et al. 1987), a closed forest canopy (DiMauro 1998, unpub data), and large tree root boles (deMaynadier and Hunter 1998). These structural habitat features provide a suitable forest floor microclimate, as well as surface and additional subterranean refuges for salamanders. In this study, these and other microhabitat features were frequently associated with salamander locations. The tendency for spotted salamander locations to be associated with cwd supports the results of Windmiller (1996) who found radio-tagged spotted salamanders were usually directly under or within 0.5 m of coarse woody objects, and the majority of debris objects were >45 mm in diameter. In addition, I frequently located salamanders in refuges associated with pit/mound topography, dense stands of beech saplings, and rotten stumps. To a lesser degree, live root boles and road-banks associated with construction of unimproved carriage roads, were also used by salamanders, particularly as overwintering sites. Of these, I could find no reference to salamander use of pit/mound topography in other studies. A fairly common feature of mature forest stands, pit/mound topography results when a large diameter tree is blown down, pulling up soil attached to the root system as it falls and leaving a pit in its place (Wessels 1997). As the trunk and root ball decay, a mound of loose, organic matter is left over. Pits often accumulate deep layers of leaf litter that may provide highly favorable microclimatic conditions for salamanders seeking refuge. Deep litter maintains a moist forest floor, provides cover for amphibians and invertebrates, and influences the forest floor chemistry. In contrast, the mounds used by salamanders in this study were often devoid of deep litter accumulations. However, most mounds had numerous small mammal tunnels clearly evident and may serve as high quality refuge sites for salamanders.

Forest Management Recommendations

Forest management practices may directly effect vernal pools and adjacent habitats used by amphibians outside of the breeding season. While it is imperative that amphibian breeding pools be protected from alteration during forestry operations, it is also critical that the surrounding forest be considered in management strategies. Forest practices may be compatible with conservation of pools and breeding populations of amphibians provided these general guidelines are followed. Much of what is presented here is based upon the Best Management Practices being developed in Maine (A. Calhoun, pers. comm.).

The Vernal Pool Basin – This includes the vernal pool depression (at spring high water) which may or may not be wet during the period when timber is being harvested.

Management Goal: To maintain the vernal pool depression in an undisturbed state.

Recommendations:

- ◆ Avoid harvesting in or around the vernal pool depression;
- ◆ Heavy equipment should not be permitted in pool depressions at any time of the year;
- ◆ Avoid locating landings, skid roads, or haul roads through or near these depressions. Rutting, siltation, or compaction in the pool depression can alter the pool's water-holding capacity, disturb eggs or larvae buried in the organic layer and alter the environment in which organisms live;
- ◆ Avoid harvesting operations in the pool depression, even during the winter. This can disturb woody vegetation that may serve as egg attachment sites or that may provide shading;
- ◆ Slash and treetops from forestry operations should not be allowed to fall or be placed in the pool as they can hinder amphibian movement and alter water chemistry. If slash or other woody debris accidentally fall into the pool during the breeding season (April to June), it is best to leave it in place to avoid disturbing egg masses or other breeding activity.

The Amphibian Life Zone – this includes the forested habitat extending at least 175 meters (575 feet) from the pool edge.

Management Goals:

- ◆ To provide quality non-breeding habitat for amphibian populations.
- ◆ Maintain forest floor conditions that will support amphibian populations including:
 1. deep, uncompacted, natural litter
 2. minimal disturbance to the organic layer beneath the litter
 3. a continuous supply of coarse woody debris of various sizes and levels of decay,
 4. a shaded, moist forest floor, and
 5. undisturbed drainage patterns within the pool watershed.

To support amphibian populations, uplands adjacent to vernal pools must be dominated by areas of uncompacted deep litter, large coarse-woody-debris, and patches of canopy shade for maintaining a suitable forest floor microclimate. In addition, rutting and scarification of the forest floor may interfere with salamander migrations to breeding pools. If shallow ruts fill with water, vernal pool amphibians may deposit eggs in ruts that do not hold water long enough to produce juveniles. While these microhabitat components may be best achieved by a “no cut” policy, light to moderate partial cuts within the amphibian life zone can maintain suitable conditions. Foresters who incorporate the following harvest guidelines in the landscape surrounding breeding pools will greatly help to conserve local biodiversity and wildlife values associated with the vernal pool.

Recommendations:

- ◆ Minimize disturbance to the forest floor by:
 - Harvesting only when the ground is frozen (this will control rutting and scarification of the forest floor);
 - locating log landings and roads outside this zone whenever possible, and avoid disturbing pit/mound topography.
- ◆ Maintain natural litter composition by:
 - maintaining the existing forest type (hardwood or softwood) in order to avoid changes in natural litter composition. Amphibians are sensitive to changes in microhabitat variables dictated by litter chemistry (deMaynadier and Hunter 1995);
 - avoiding plantations around breeding pools.
- ◆ Maintain coarse-woody-debris by:
 - leaving limbs and tops on site as part of the harvest operation plan;

- leaving large diameter snags and den trees;
- when available, leaving long-lived trees such as hemlock, spruce, pine, oak, and northern hardwoods as recruitment for future snags and coarse woody debris.
- ♦ Maintain a shaded, moist forest floor by:
 - Encouraging a closed canopy. Limit harvesting to uniformly distributed, light to moderate partial cuts, leaving a minimum of 80% canopy cover within 30.5 m (100 ft) of the pool, and 70% canopy cover between 30.5 m and 175 m. The base of canopy foliage should be, at a minimum, 10 feet above the ground. Large, long-lived hardwoods are particularly beneficial because their large crowns provide critical shade during dry periods and provide a good source of litter each year.
 - practicing uneven-aged management. Where even-aged management is present, use systems such as extended shelterwood, patch cuts, and group selection to help maintain forest floor conditions suitable for amphibian habitat. Delay subsequent harvesting until regeneration has provided shade to the forest floor of cut-over areas (i.e., tree foliage at a minimum of 10 feet above the ground).

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Appendix 1. Movement history maps for 16 radio-implanted salamanders (8 Jefferson, 8 spotted salamanders) at the Marsh-Billings-Rockefeller National Historical Park, Woodstock, VT. Arrows indicate direction of travel, and numbers adjacent to telemetry locations correspond to the I-D number in embedded Table of substrate type, dates, and refuge use.

Movement History for Jefferson Salamander Female .309



J-F-309movem.shp



Drift Fence



Carriage Roads



Hiking trails



20-foot contours

Cover



Mature Hardwood



Young Hardwood



Softwood



Open Land



20 0 20 40 Meters

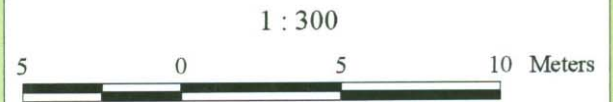
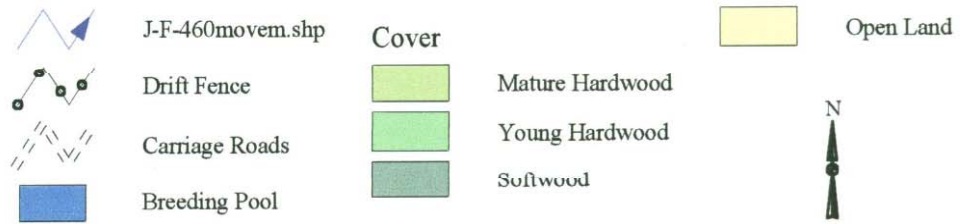


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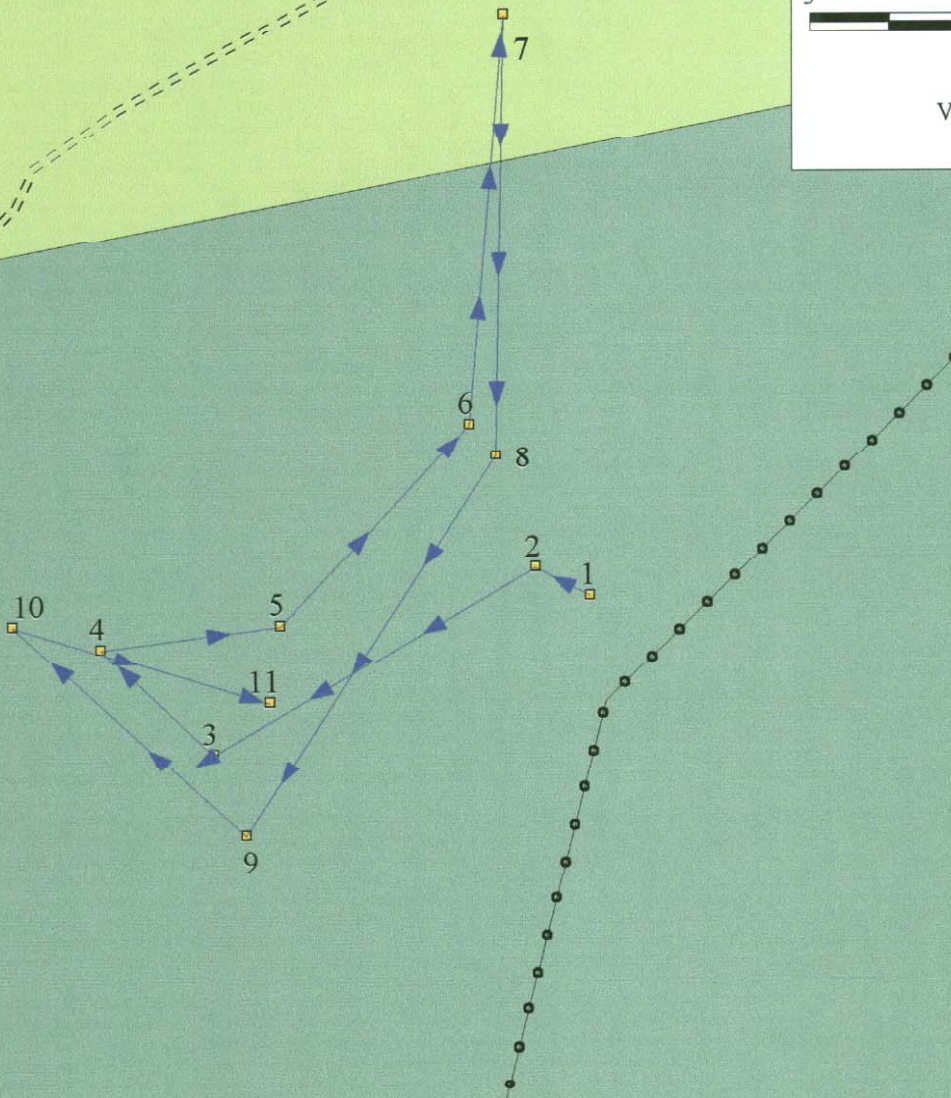
Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
309	log	20000522	20000523	Unknown	1
309	root bole	20000524	20000620	STSH	2
309	log	20000712	20000718	Unknown	3
309	litter	20000728	20000821	STSH	4
309	litter	20000802	20000802	Unknown	5
309	litter	20000808	20000808	STSH	6
309	litter	20000830	20000913	STSH	7
309	litter	20000920	20000922	Unknown	8
309	litter	20000927	20001101	WFMO	9

Movement History for Jefferson Salamander Female .460

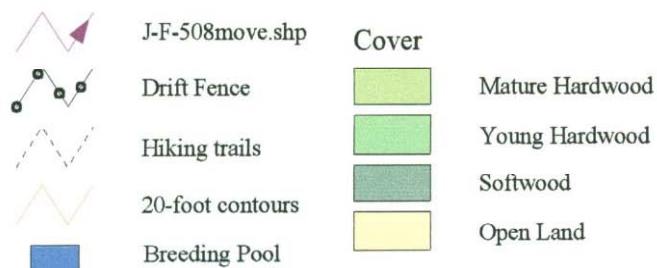


Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001



Frequency	Substrate	Startdate	Enddate	Tunnel	ID
460	log	20000517	20000518	Unknown	1
460	stump	20000519	20000523	STSH	2
460	litter	20000602	20000728	STSH	3
460	litter	20000802	20000802	Unknown	4
460	litter	20000808	20000808	WFMO	5
460	root bole	20000817	20000821	STSH	6
460	litter	20000830	20000830	STSH	7
460	litter	20000906	20000906	STSH	8
460	other	20000913	20000913	Unknown	9
460	log	20000920	20000920	STSH	10
460	litter	20000922	20001013	STSH	11

Movement History for Jefferson Salamander Female .508

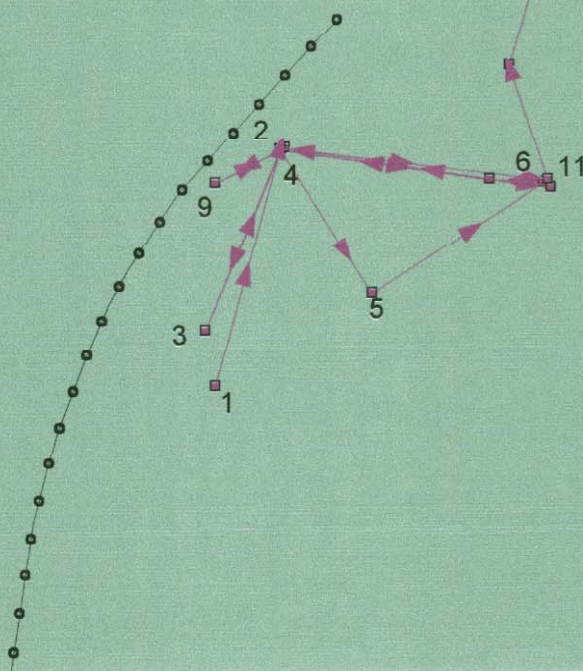


1 : 300



Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
508	log	20000517	20000518	Unknown	1
508	root bole	20000519	20000608	STSH	2
508	root bole	20000612	20000612	STSH	3
508	root bole	20000614	20000620	STSH	4
508	log	20000627	20000627	STSH	5
508	root bole	20000705	20000728	Unknown	6
508	log	20000802	20000802	STSH	7
508	root bole	20000808	20000808	STSH	8
508	log	20000817	20000817	STSH	9
508	root bole	20000821	20000821	STSH	10
508	root bole	20000830	20000906	Unknown	11
508	root bole	20000913	20000913	STSH	12
508	root bole	20000920	20001003	Unknown	13
508	log	20001010	20001017	STSH	14
508	litter	20001019	20001101	STSH	15



Movement History for Jefferson Salamander Male .488



1 : 350

5 0 5 10 Meters

Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
488	other	20000517	20000517	Unknown	1
488	litter	20000518	20000518	STSH	2
488	rock	20000519	20000608	Unknown	3
488	stump	20000612	20000627	STSH	4
488	stump	20000705	20000710	Unknown	5
488	litter	20000712	20000913	STSH	6
488	stump	20000919	20000919	Unknown	7

5 7 6

Movement History for Jefferson Salamander Female .526



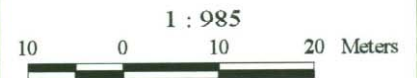
1 : 900

10 0 10 20 Meters

Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
526	litter	20000517	20000518	other	1
526	stump	20000519	20000523	STSH	2
526	litter	20000524	20000608	STSH	3
526	litter	20000610	20000610	STSH	4
526	other	20000614	20000620	Unknown	5
526	litter	20000627	20000817	STSH	6
526	litter	20000817	20000817	Unknown	7
526	litter	20000821	20000821	STSH	8
526	rock	20000830	20000830	Unknown	9
526	other	20000906	20000906	Unknown	10
526	other	20000913	20000913	WFMO	11
526	root bole	20000920	20000920	Unknown	12
526	other	20000922	20000922	WFMO	13
526	root bole	20000927	20001003	Unknown	14
526	other	20001013	20001013	Unknown	15
526	other	20001017	20001101	WFMO	16

Movement Histories for Jefferson Salamander Male .392 & Spotted Salamander Male .328

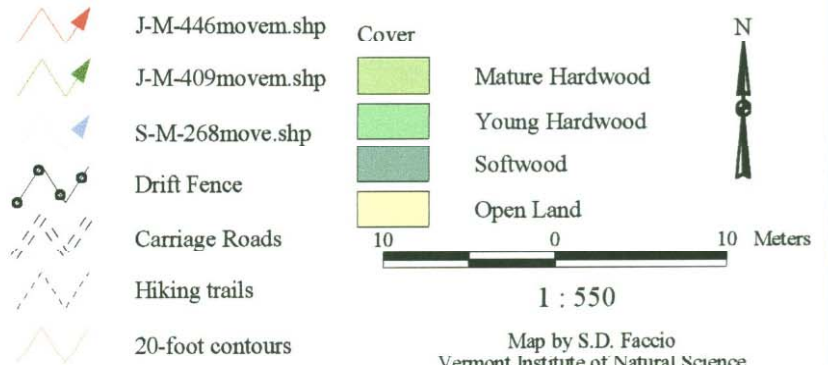


Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
328	stump	20000518	20000518	Unknown	1
328	litter	20000519	20000601	STSH	2
328	log	20000608	20000610	STSH	3
328	other	20000614	20001101	STSH	4
328	rd bank/roots	20001107	20001115	Unknown	5

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
392	litter	20000517	20000517	Unknown	1
392	root bole	20000519	20000718	STSH	2
392	stump	20000728	20000728	Unknown	3
392	log	20000802	20000913	STSH	4
392	root bole	20000920	20001101	WFMO	5

Movement Histories for Jefferson (males .409 & .446) & Spotted salamander Male .268



Frequency	Substrate	Startdate	Enddate	Tunnel	ID
268	log	20000523	20000523	STSH	1
268	stump	20000524	20000616	Unknown	2
268	litter	20000620	20000627	STSH	3
268	litter	20000705	20000712	STSH	4
268	litter	20000718	20000906	STSH	5
268	other	20000913	20001013	Unknown	6

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
446	log	20000517	20000519		1
446	root bole	20000522	20000524	STSH	2
446	other	20000524	20000705	Unknown	3
446	root bole	20000710	20000728	Unknown	4
446	stump	20000802	20000802	STSH	5
446	stump	20000808	20000817	STSH	6
446	litter	20000821	20000821	Unknown	7
446	litter	20000830	20000830	STSH	8
446	log	20000906	20000913	Unknown	9
446	log	20001003	20001003	Unknown	10

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
409	log	20000517	20000602	Unknown	1
409	root bole	20000608	20000620	Unknown	2
409	stump	20000627	20000705	Unknown	3
409	log	20000710	20000728	STSH	4
409	root bole	20000802	20000802	Unknown	5
409	root bole	20000817	20000821	Unknown	6
409	stump	20000821	20001013	Unknown	7

Movement History for Spotted Salamander Female .288



S-F-288movem.shp

Carriage Roads

Hiking trails

20-foot contours

Cover



Mature Hardwood

Young Hardwood

Softwood

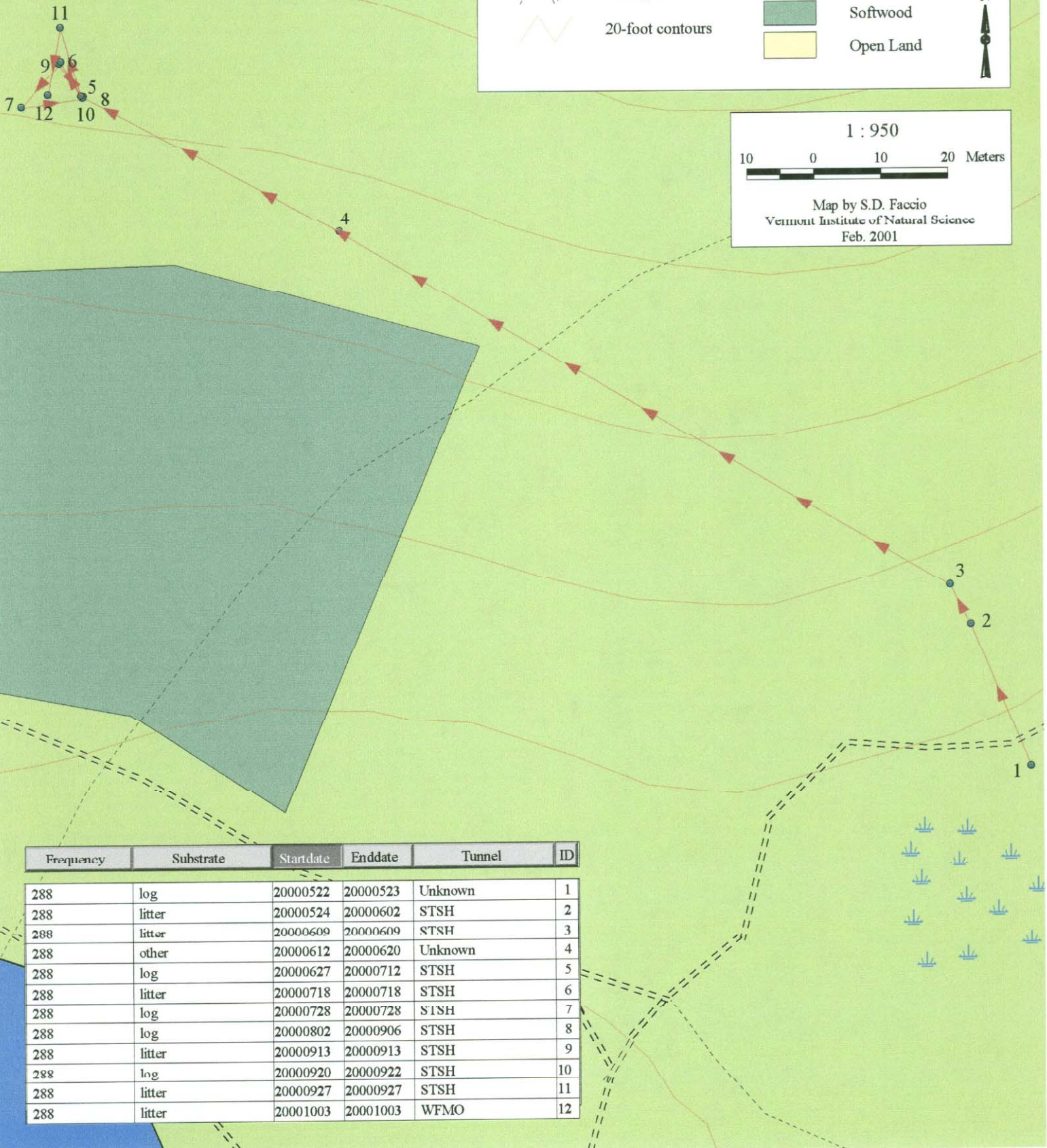
Open Land



1 : 950

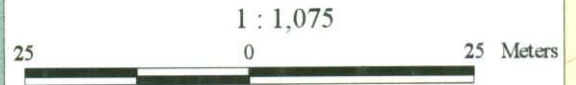
10 0 10 20 Meters

Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001



Frequency	Substrate	Startdate	Enddate	Tunnel	ID
288	log	20000522	20000523	Unknown	1
288	litter	20000524	20000602	STSH	2
288	litter	20000609	20000609	STSH	3
288	other	20000612	20000620	Unknown	4
288	log	20000627	20000712	STSH	5
288	litter	20000718	20000718	STSH	6
288	log	20000728	20000728	STSH	7
288	log	20000802	20000906	STSH	8
288	litter	20000913	20000913	STSH	9
288	log	20000920	20000922	STSH	10
288	litter	20000927	20000927	STSH	11
288	litter	20001003	20001003	WFMO	12

Movement History for Spotted Salamander Female .349



Map by S.D. Faccio
Vermont Institute of Natural Science
Feb. 2001

Frequency	Substrate	Startdate	Enddate	Tunnel	ID
349	stump	20000517	20000608	STSH	1
349	log	20000616	20000620	STSH	3
349	log	20000612	20000614	STSH	2
349	log	20000627	20000712	Unknown	4
349	stump	20000717	20000717	Unknown	5
349	litter	20000725	20000728	STSH	6
349	other	20000802	20000927	STSH	7
349	litter	20001003	20001003	STSH	8
349	stump	20001010	20001019	WFMO	9

