SHREW SPECIES RICHNESS AND ABUNDANCE IN RELATION TO VERNAL POND HABITAT IN SOUTHERN NEW ENGLAND

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ABSTRACT - Vernal ponds are important aquatic habitat for many species of amphibians and invertebrates. While many aspects of such ponds have been investigated, small mammal populations in the adjacent upland [catchment] habitat are largely unstudied. We selected three ponds in central Massachusetts to determine whether the presence of vernal ponds in forested habitat influences shrew species composition and abundance. Pitfall-trap arrays were installed in pond catchment basins and in adjacent upland forest habitat. A total of 2124 small mammals of nine species were captured during 3880 trap nights. Of these, 341 were shrews of three species. We found no significant differences in abundance between pond-side and upland habitat for any shrew species. In addition, no differences were found in structural and vegetation characteristics between habitats. While there may be some indication that vernal ponds provide some residual effects during dry periods, vernal ponds in the northeastern United States are small and highly variable in hydroperiod, apparently providing an unreliable resource for shrews.

INTRODUCTION

Ephemeral forest ponds, commonly known as vernal ponds, are unique aquatic habitats defined as confined basin depressions with fluctuating water levels and extended dry periods (Wiggins et al. 1980). Such conditions result in habitats rich in nutrients but free of fish. Ephemeral ponds are highly variable in size and hydroperiod, or annual duration of the wet period (Williams 1987). The hydroperiod of a single pond can fluctuate greatly from year to year depending largely on the amount and periodicity of rainfall (Semlitsch et al. 1996).

Ephemeral ponds can be more specifically described by their time of filling: vernal ponds are defined as temporary bodies of water that fill as a result of spring rains and snowmelt, whereas autumnal ponds fill in the fall (Brooks et al. 1998). However, the term "vernal pond" is widely used to refer to any ephemeral pond regardless of time of filling and is the term most often seen in popular literature. For this reason, we will refer to our study ponds as vernal ponds.

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Vernal ponds provide essential habitat for many species of amphibians and invertebrates, some of which require these ponds for all or part of their life cycle (Williams 1987). Examples of these organisms include wood frogs (*Rana sylvatica* Le Conte), mole salamanders (*Ambystoma* spp.), and fairy shrimp (*Eubranchipus* spp.) (Massachusetts Division of Fisheries and Wildlife 1988). Pond catchment basins provide additional feeding and overwintering habitat for many of these species. Species that inhabit vernal ponds have developed strategies to survive fluctuating water levels and extended dry periods (Williams 1987). As water levels recede, amphibian metamorphs and many invertebrates emerge in large numbers. This emergence provides an increase in potential prey for predators in adjacent terrestrial habitat (Stone 1992). Other invertebrates survive dry periods by remaining in the pond substrate as eggs, pupae, or aestivating adults. Dry pond beds may also provide additional foraging area for predators as well as previously unavailable habitat for small mammals (Winfield et al. 1981).

The distribution, water chemistry, ecology, hydrology, limnology, and invertebrate and amphibian fauna of vernal ponds have been investigated (Brooks et al. 1998, Jackson 1990, Kenk 1949, Williams 1987). However, few studies have focused on how these ponds and the surrounding forest (i.e., pond catchments) are used by small mammals. Winfield et al. (1981) studied small mammal use of vernal ponds in San Diego County, California; of seven small mammal species captured, only the western harvest mouse (*Reithrodontomys megalotis* Baird) was reported to have a higher estimated population at the pond than at the non-pond control site. Since *R. megalotis* was the only species captured for which insects are a large part of the diet, Winfield et al. (1981) speculated that their greater abundance in the vernal pond area may be due to the greater abundance of insects at the pond locations (Kenk 1949, Wiggins et al. 1980). Although most small mammals are not influenced by the occurrence of vernal ponds, those species that prey on invertebrates may be more abundant in vernal pond catchments than in upland habitats.

In addition to providing additional food resources, vernal pond catchments are characterized by moist soils and loose leaf litter which are preferred habitat characteristics for shrew species occurring in Massachusetts (DeGraaf and Rudis 1986). Preferred habitat and abundant prey present in the immediate vernal pond area may benefit shrews during vulnerable life stages. For example, five immature northern water shrews (*Sorex palustris* Richardson) were captured during preliminary trapping conducted on the Quabbin watershed in 1992 (unpubl. data, R. Brooks, Amherst, MA). This shrew is listed as a species of special concern in Massachusetts with only 13 records of occurrence statewide previous to this study. Although these shrews were most likely dispersing from an adjacent permanent water body, vernal pond habitat may serve as an important resource during dispersal.

By providing potential habitat and abundant prey, vernal pond catchments may have a positive seasonal effect on the diversity and abundance of shrew species. The objective of this study was to compare shrew abundance in habitat adjacent to vernal ponds to that in upland forest habitat to determine whether vernal ponds in temperate, mixed hardwood forests have any influence on shrew distribution and abundance. We also examined the structure of each species' population, determining whether the presence of vernal ponds affected the gender composition, age structure, or reproductive status. Alternatively, due to the ephemeral nature of vernal ponds, their occurrence in a forest may have no effect on the composition or relative abundance of shrews.

MATERIALS AND METHODS

Study Area

The study was conducted on the Prescott Peninsula, a 50 km^2 forest management block within the Quabbin Reservation, New Salem, Massachusetts. The Quabbin Reservoir was formed in 1939 when the Swift River watershed was dammed and diverted to provide water for the metropolitan Boston area (O'Connor et al. 1995). The reservoir and adjacent upland watershed are managed by the Metropolitan District Commission (MDC). We selected 3 vernal pond-centered study sites on the Prescott Peninsula based on 2 criteria: 1) pond catchments and adjacent upland habitats having visually similar over- and understory composition and structure, and 2) ponds supporting abundant amphibian and invertebrate fauna based on preliminary surveys. The sites (ponds) are identified as sites 4, 6, and 12, based on the MDC designation of the stand in which they occur.

Shrew Trapping

Pitfall-trap arrays were used to survey shrews. Pitfall traps have been shown to be efficient for sampling small mammal communities, particularly for shrew species (Kirkland and Sheppard 1994, Williams and Braun 1983). Pitfall-trap arrays were installed within each pond catchment and in upland forest habitat outside but adjacent to the pond catchment. Each array consisted of three 15 m arms 120° equidistant and joined at the center (Kirkland and Sheppard 1994). Along each arm three 2.5 L plastic containers were buried flush with the ground surface (Fig. 1). A tenth trap was located in the center of the array. The traps were located 5 m apart. The traps were connected by drift fencing constructed of 25 cm aluminum flashing. The flashing was buried approximately 5 cm deep to reduce the chance of shrews burrowing underneath. Trapping was conducted for three 10-12 day sessions in 1994. Trapping sessions were timed as follows: early spring when all ponds were full (April 13-25), late spring when ponds were almost dry (June 3-13 at one pond, and June 6-16 at the remaining 2 ponds), and fall when ponds were completely dry (October 31-November 10). Summer sampling dates varied due to the different hydrology of each pond. Traps were checked once daily. When open, traps were half-filled with water to drown all captures. All shrew captures were necropsied to determine sex and reproductive condition; age was determined by examining tooth wear and the degree of cranial ossification (Rudd 1955).

The pond-side arrays were installed on opposite sides of, and adjacent to the edge of the pond when full. The two upland arrays were installed no less than 100 m from the high water mark of each pond and greater than 100 m from each other. Generally, the upland arrays were located at 90 degree directions from the orientation of the pond-side arrays and more than 100 m from other wetland areas to maintain independence from other wetland habitats. We use the 100 m distance based on estimates of home range size, in an attempt to ensure that shrews caught in upland arrays were not influenced by vernal ponds or other wetlands. The northern short-tailed shrew (*Blarina brevicauda* Say) has the largest home range (2.5 ha) of shrews common in central Massachusetts (Banfield 1974, Churchfield 1990, George et al. 1986); normal movements and habitat use should occur within 90 m of a capture site. We believe that it is unlikely that shrews captured at either pond-side or upland sites would use resources available in the alternate site.

Vegetative and Structural Habitat Measurements

Overstory vegetation was surveyed by recording species and diameter-at-breast-height (DBH) for each tree on the 700 m^2 circular plot defined by the 15 m pitfall-trap arrays (Fig. 1). We measured the amount of coarse woody debris (CWD) on the same plot at each array, recording species, diameter of the largest end, length, and decay class, for debris greater than 7.5 cm in diameter and greater than 1 m in length. Understory vegetation was measured on three, 5 m^2 circular plots located midway between each arm of the array, 7.5 m from the array center (Fig. 1). The understory was surveyed by estimating percent total vegetative cover, and percent cover for the following vegetative and other ground cover: coniferous, broad-leaf deciduous, fern, grass, herbaceous, moss, lycopodium, and rock. Counts of individual stems of woody-stemmed plants over 25 cm in height were recorded by species. At two points on the perimeter of the understory plots, we first measured percent soil moisture using a portable soil acidity and moisture meter, and then made a cut to the mineral soil and measured litter and humus depth.

Data Analysis

We used analysis of variance to determine if there were any differences in habitat structure between pond-side and upland arrays. All percent values were arcsine-transformed prior to analysis (Zar 1974:185). We calculated catch per unit effort (number of individuals/

trap night) for each shrew species, array, and trapping period. Repeated measures analysis of variance was used to test for differences in the relative abundance of shrew species between pond-side and upland habitats. A more conservative analysis of habitat effects was done by analyzing only the captures during the first three days of each session, assuming that these captures were residents and not immigrants from activity areas outside the trapping site (Hansson 1992). This analysis was done for masked shrews, the only species captured in sufficient numbers for an analysis of a subset of the data. Demographic differences between habitats and among sessions were analyzed for masked shrews by contingency tables (X^2).

RESULTS

Species Composition and Relative Abundance

Three shrew species, totaling 341 specimens were captured during the 3880 trap nights (Table 1). All three species were captured at each site and in each habitat. An additional 1783 specimens of 6 other small mammal species and 1486 amphibian specimens of 10 species were also captured.

Masked shrew (*Sorex cinereus* Kerr) with 290 captures, was the most abundant shrew species. Northern short-tailed shrew was second most

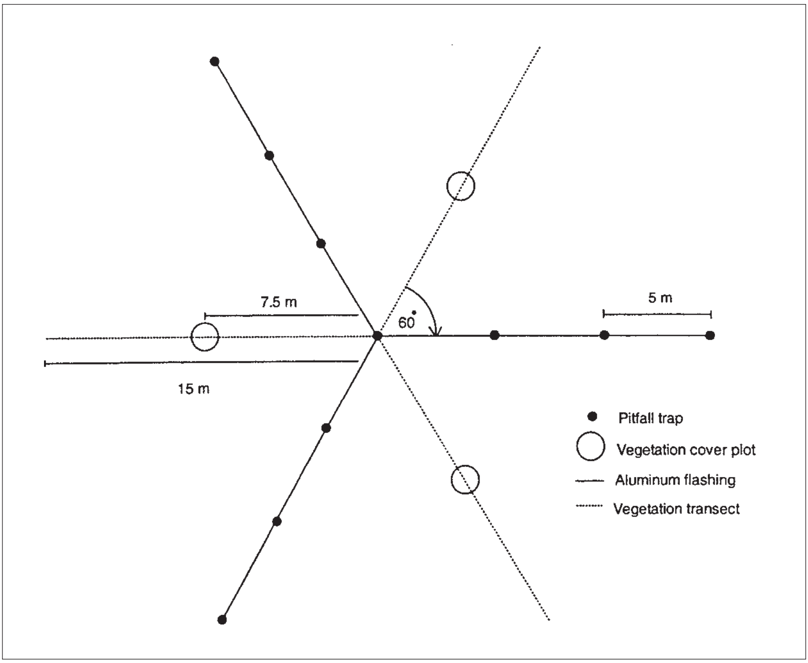

Figure 1. Detail of pitfall trap array and vegetation cover plots, Prescott Peninsula, Quabbin Reservation, 1994.

abundant with 43 specimens, and smoky shrew (*S. fumeus* Miller), with only eight captures, was the least abundant shrew species. We found no significant differences in capture numbers between pond-side and upland habitat for either masked ($F_{1,6} = 0.044$, $p = 0.841$) or northern short-tailed shrews ($F_{1,6} = 0.023$, $p = 0.885$). Insufficient numbers of smoky shrews were captured to perform an analysis. Captures of masked shrews during the first three days of each session did not differ significantly between habitats ($F_{1,6} = 0.105$, $p = 0.757$). The number of captures of masked shrews differed significantly among ponds ($F_{2,6} = 6.811$, $p = 0.029$) due to much reduced captures at pond 4 (Table 1); numbers of northern short-tailed shrews were similar among ponds ($F_{2,6} = 1.605$, $p = 0.276$).

Captures of both masked and northern short-tailed shrews were dominated by males; smoky shrew captures was evenly distributed by sex (Table 2). The majority of captures of all species were less than 36 weeks of age and sexually undeveloped. For masked shrews, only 10 of 226 sexually undeveloped specimens were 36 weeks of age or older and no sexually mature individuals were less than 36 weeks of age. For northern short-tailed shrews, all sexually mature specimens were male and none were less than 42 weeks of age, while 13 of 43 sexually immature specimens were older than 42 weeks. No significant difference ($X^2 < 1.0$, $v = 1$, $p > 0.5$) was found in any demographic feature between pond-side and upland habitat for either masked or northern short-tailed shrews. The pattern of dominance of male captures of masked shrews was found across all three ponds ($X^2 = 2.63$, $v = 2$, $0.5 > p > 0.25$). There were more younger (< 36 weeks) masked shrew captures in ponds 4 and 6 and fewer in pond 12 than expected ($X^2 = 4.77$, $v = 2$, $0.1 > p > 0.05$). Likewise, ponds 4 and 6 had more undeveloped masked shrew captures and pond 12 had fewer than expected (= 10.5, $v = 2$, $0.01 > p > 0.005$).

Table 1. Total shrew, other small mammal, and amphibian captures by site, location, and species, Prescott Peninsula, Quabbin Reservation, Massachusetts, 1994.

	Site 4		Site 6		Site 12		
Species	Pond-side	Upland	Pond-side	Upland	Pond-side	Upland	Total
Shrew species							
Sorex cinereus	27	32	55	59	58	59	290
Blarina brevicauda	6	9	5	4	10	9	43
S. fumeus	1	1	2	1	3	0	8
Other small mammal species							
Clethrionomys gapperi	164	143	215	228	273	259	1282
Peromyscus leucopus	90	87	74	53	62	82	448
Microtus pinetorum	2	3	4	3	7	7	26
M. pennsylvanicus	6	1	2	1	4	4	18
Synaptomys cooperi	1	0	1	4	0	0	6
Condylura cristata	0	0	0	1	1	1	3
Amphibian species	118	160	196	308	312	392	1483

Capture rates varied temporally. Numbers of captures of both shrew species differed significantly among the three trapping sessions, more so for masked shrews ($F_{2,12} = 182.3$, $p < 0.001$) than northern short-tailed shrews ($F_{2,12} = 6.592$, $p = 0.012$). Both masked shrew and northern short-tailed shrew captures increased from the early-spring session (27 and 3 respectively) to the late-spring session (199 and 31), and then declined to intermediate levels (64 and 9) in the fall session. The only significant interaction effect with time for the two species was between session and pond for masked shrews ($F_{4,12} = 11.02$, $p = 0.001$), with the increase in capture numbers in the late-spring session in pond 4 much less than for the other 2 ponds. Smoky shrews were only captured during the late-spring session.

The dominance of male masked shrew captures occurred in all 3 trapping sessions, but with a non-significant increase in the frequency of females in the last spring session ($X^2 = 3.35$, $v = 2$, $0.25 > p > 0.1$). The distribution of masked shrew captures by age class differed significantly by session ($X^2 = 92.6$, $v = 2$, $p < 0.001$), with no young specimens (< 36 weeks) caught in the first, early-spring session, but dominating in the last 2 sessions. Likewise, the distribution of captures differed significantly by reproductive class ($X^2 = 45.7$, $v = 2$, $p > 0.001$), with few undeveloped specimens captured in the first session, but dominating in the later sessions.

Table 2. Distribution of shrew captures by species and demographic features, Prescott Peninsula, Quabbin Reservation, Massachusetts, 1994.

Demographic feature	Masked shrew	Smoky shrew	Northern short-tailed shrew
Sex			
Male	177	4	24
Female	113	4	19
Age class			
< 36 weeks	217	6	27
≥ 36 weeks	73	2	16
Reproductive condition			
Undeveloped			
Males	122	2	16
Females	104	3	19
Males			
Scrotal	44	1	3
Abdominal	11	1	5
Females			
Uterus developed/not pregnant or lactating	1	0	0
Lactating	3	1	0
Lactating and pregnant	1	0	0
Post-lactating	4	0	0

Habitat attributes

Spring (maximum) pond surface areas measured 0.03 ha (pond 4), 0.08 ha (pond 6) , and 0.10 ha (pond 12). Pond 4 dried the week of 3 June, the other two ponds dried the following week. A subsequent study has found that early June drying dates are typical for these ponds (R. Brooks, per. obs.) and that amphibian metamorphosis is typically unsuccessful in most years.

No significant habitat differences were found between pond-side and upland forest habitat attributes (Table 3). Red oak (*Quercus rubra* Linnaeus) was the dominant overstory species in both pond-side and upland habitats. The dominant understory life form in both habitats was deciduous trees and shrubs. Blueberry (*Vaccinium* sp.) was the dominant understory taxa followed by witch-hazel (*Hamamelis virginiana* Linnaeus) at pond-side habitats and black birch (*Betula lenta* Linnaeus) was dominant in upland habitats. Deciduous understory cover was greater in the pond-side habitat ($F_{1,6} = 3.648$, $p = 0.105$). No significant differences in percent soil moisture ($F_{1,6} = 0.015$, $p = 0.908$), humus ($F_{1,6} = 0.057$, $p = 0.820$), and litter depth ($F_{1,6} = 0.385$, $p = 0.558$), and CWD $F_{1,6} = 0.912$, $p = 0.377$) were found between habitat types.

Several forest habitat attributes differed significantly among ponds. Differences in overstory dominance (basal area) ($F_{2,6} = 12.139$, $p = 0.008$) were due to exceptionally high stocking of white pine (*Pinus strobus*) at pond 12. The density of overstory trees differed significantly among ponds ($F_{2,6} = 6.953$, $p = 0.07$), with progressively greater density of trees between ponds 4, 6, and 12 (Table 3). No significant differences were found in understory stem density among ponds. Surprisingly, no under-

Table 3. Mean structural habitat attributes by site and location, Prescott Peninsula, Quabbin Reservation, Massachusetts, 1994.

	Site 4		Site 6		Site 12	
Attribute	Pond-side	Upland	Pond-side	Upland	Pond-side	Upland
Overstory:						
Total basal area (m^2/plot)[a]	9.6	10.0	19.7	20.6	27.6	29.0
Total number of trees/plot[a]	24.5	44.5	63.0	81.5	120.5	112.0
Understory:						
Total cover (%)	59.5	32.3	79.8	81.8	67.6	55.0
Total understory stems/plot[b]	0.0	0.0	32.0	4.7	40.8	36.5
Ground/Cover:						
Humus depth (cm)	20.0	28.1	51.3	65.8	85.4	71.7
Litter depth (cm)	57.8	61.2	45.8	55.0	67.5	67.9
Mean soil moisture (%)	31.0	26.1	36.2	28.7	25.2	38.5
Course woody debris area (m^2/plot)[a]	0.7	0.5	0.8	0.6	0.9	0.8

[a] per 0.4 ha plot
[b] per 5 m^2 plot

story stems were recorded at pond 4, either pond-side or in the upland. Total understory vegetative cover differed among ponds ($F_{2,6}$ = 2.488, *p* = 0.163), mostly due to abundant fern cover at pond 6 and an absence of broad-leaf herbaceous cover at pond 4. Humus depth differed significantly among ponds ($F_{2,6}$ = 6.51, p = 0.031), with progressively greater humus depths among ponds 4, 6, and 12 (Table 3). Neither litter depth, soil moisture, nor area of CWD differed significantly among ponds.

DISCUSSION

Several factors may explain why we found no significant differences in abundance between habitats for any shrew species. The abundance of some shrew species increases in relation to increases in prey density (Churchfield 1990, Holling 1959, Stewart et al. 1989). However, because all ponds dried before most species of amphibian and invertebrate larvae were able to metamorphose and emerge, we were unable to determine whether the potential influx of prey into the surrounding habitat affects shrew abundance in the habitat. In a separate component of this study, more invertebrates were trapped in upland arrays but most were Collembola (Doyle 1997). The second most common taxon was Acarina, which was most common in pond-side arrays. If these two taxa are ignored, invertebrate numbers were nearly equivalent between upland and pool-side arrays.

Vernal ponds in the northeastern United States tend to be small, less than 0.1 ha (Brooks et al. 1998), and highly variable in hydroperiod from year to year. Hydroperiod has a great effect on amphibian and invertebrate recruitment. In wet years, ponds dry in late summer or early fall, and large numbers of invertebrates and amphibians emerge and disperse into the surrounding catchment basin (Semlitsch et al. 1996). In dry years, such as the year of this study, ponds were dry by mid-June, invertebrate and amphibian larvae were unable to develop enough to metamorphose and emerge from the water. These factors result in an unreliable forage resource.

Differences between habitat characteristics of vernal pond catchment basins and adjacent upland habitat vary by location. In southern California, upland habitat can be markedly drier than adjacent vernal pond catchment basins. The vernal pond studied by Winfield et al. (1981) measured 0.9 ha and was surrounded by chaparral and coastal sage habitat, which is typically extremely dry during summer months. The vernal pond habitat would provide vegetation and invertebrates for a longer period of time during drought. In contrast, the vernal ponds at our study sites were specifically chosen with catchment habitat similar to surrounding upland forest in an attempt to isolate any potential vernal pond effects. Since there were no measurable differences in habitat variables between habitat type, and we observed little recruitment from pond organisms, the upland forest habitat appeared to provide adequate resources for shrews with the vernal ponds adding little if any additional resources to the surrounding habitat.

In southern New England, the smoky shrew tends to be found in association with wetland areas and has been used in some models as a wetland indicator species (DeGraaf and Rudis 1986, Whitlock et al. 1994). Although the total number of smoky shrews captured was low (8), more (6) were captured in the pond-side habitat. These results may suggest that the ponds may have some residual effect as wetland habitat that remains into the dry periods. This effect may be insufficient for a species that is a habitat specialist. For example, northern water shrews are primarily found near wetland habitats including streams with overhanging banks, grass-sedge marshes, and shrub zones bordering streams and ponds (Beneski and Stinson 1987, Conaway 1952). During this study, no water shrews were captured despite extensive trapping at locations where this species has been previously documented.

Although we did not find any differences in shrew abundance or habitat variables between habitats, we found differences among locations and trapping sessions. Differences in capture numbers between the 3 study sites for masked shrews corresponded with differences found in habitat cover measurements. Numbers of masked shrews were greatest at sites (ponds 6 and 12) with the most trees and where the average total understory cover was greater than 50 percent. This is consistent with results from other studies (Miller and Getz 1977, Yahner 1986). Masked shrews require habitat with high ground-level humidity due to their high water requirements (Miller and Getz 1977, Pagels et al. 1994). Dense over- and understory cover traps moisture and maintain higher ground-level humidity than more open sites. The increase in the number of captures between the early- and late-spring trapping sessions likely reflects spring reproduction, which is supported by the large increase in young, sexually undeveloped specimens in the late-spring session. The decrease in the number of fall captures could reflect natural mortality of overwintering adults and losses due to two prior removal-trapping sessions.

Patterns of demographic characteristics (i.e., sex and age and reproductive class) of masked shrew captures were similar between habitats but differed among ponds and/or trapping sessions. Pond 4 differed most, with a large positive deviation from expected in the number of young, sexually undeveloped specimens. This could be related to the poorer habitat conditions mentioned previously, resulting in lower adult survival and proportionally greater numbers of young. The differences in demography of masked shrews by trapping session likely reflect reproductive patterns, with reproduction and recruitment following the early-spring session but represented in the late-spring and fall sessions.

In conclusion, typical forested vernal ponds in the northeastern United States are small with highly variable hydroperiods resulting in, at best, an unpredictable resource for shrews. While we found some indication that vernal ponds may provide some residual effect for species preferring wetland habitat, other niche attributes had much greater influence on shrew abundance.

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