An experimental approach to understanding the impact of vernal pool buffer size on wood frogs (Rana sylvatica)

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An experimental approach to understanding the impact of vernal pool buffer size on wood frogs (Rana sylvatica)

Abstract
Strategies to conserve vernal pool-dependent amphibians emphasize the maintenance of adequate areas (buffers) of terrestrial habitat surrounding the pool. I conducted a large-scale field study that specifically examined the effects of buffer width manipulation on adult and metamorph wood frogs at eleven vernal pools in a managed forest in central Maine. Buffer width treatments were 30 m or 100 m forest buffer surrounded by a 100 m clearcut, or no cut (reference). I encircled pools with drift fences and monitored wood frogs from April--November, 2004 and 2005 using pitfall traps and radio-telemetry. Buffer width had no effect on the number of immigrating adults, emigrating metamorphs, or metamorph size. Adult wood frogs from reference sites were larger than those from buffer treatment sites. Smaller buffers had lower adult recapture rates. Frogs from buffer treatment sites moved farther than those from reference sites, and females moved on average 92 m farther than males. Clearcuts were permeable, but generally avoided. Smaller buffers provide less available upland habitat, and force more wood frogs to seek alternate habitat beyond the clearcut perimeter.

Keywords
Agriculture, Forestry and Wildlife, Biology, Ecology
AN EXPERIMENTAL APPROACH TO UNDERSTANDING THE IMPACT OF VERNAL POOL BUFFER SIZE ON WOOD FROGS (*Rana sylvatica*)

BY

NICOLE ALEXIS FREIDENFELDS

B.S., Eastern Connecticut State University, 2001

THESIS

Submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of Master of Science in Natural Resources: Wildlife

December, 2006
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27 Nov 2006
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ABSTRACT

AN EXPERIMENTAL APPROACH TO UNDERSTANDING THE IMPACT OF VERNAL POOL BUFFER SIZE ON WOOD FROGS (*RANA SYLVATICA*)

by

Nicole Alexis Freidenfelds

University of New Hampshire, December, 2006

Strategies to conserve vernal pool-dependent amphibians emphasize the maintenance of adequate areas (buffers) of terrestrial habitat surrounding the pool. I conducted a large-scale field study that specifically examined the effects of buffer width manipulation on adult and metamorph wood frogs at eleven vernal pools in a managed forest in central Maine. Buffer width treatments were 30 m or 100 m forest buffer surrounded by a 100 m clearcut, or no cut (reference). I encircled pools with drift fences and monitored wood frogs from April – November, 2004 and 2005 using pitfall traps and radio-telemetry. Buffer width had no effect on the number of immigrating adults, emigrating metamorphs, or metamorph size. Adult wood frogs from reference sites were larger than those from buffer treatment sites. Smaller buffers had lower adult recapture rates. Frogs from buffer treatment sites moved farther than those from reference sites, and females moved on average 92 m farther than males. Clearcuts were permeable, but generally avoided. Smaller buffers provide less available upland habitat, and force more wood frogs to seek alternate habitat beyond the clearcut perimeter.
INTRODUCTION

Amphibians, because of their high diversity and abundance, may play a critical role in structuring forest communities (Burton and Likens 1975; Chazal and Niewiarowski 1998; deMaynadier and Hunter 1998; Dodd and Cade 1998). The biphasic life cycle typical of many amphibian species represents a major shift in biomass from aquatic to terrestrial habitats as larvae metamorphose into juveniles. In addition, their semi-permeable skin and unique life history characteristics make amphibians valuable as an indicator taxon of general environmental condition (Blaustein and Wake 1990; Vitt et al. 1990; Alford and Richards 1999; Collins and Storfer 2003). Ecologists are therefore concerned about how the loss of amphibians, or decrease in amphibian numbers, could effect ecosystem function (Beebee 1996; Dodd and Cade 1998; Regosin et al. 2003).

Anthropogenic land use including urban/suburbanization, forestry, and agriculture can negatively affect the movement patterns and breeding distributions of pond-breeding amphibian species by leaving inhospitable habitats around wetlands, effectively isolating populations (Chazal and Niewiarowski 1998; Regosin et al. 2003). Habitat loss through such land uses is likely the primary cause of many reported amphibian species declines (Alford and Richards 1999; deMaynadier and Hunter 1998; Heenar and M’Closkey 1996; Semlitsch 2000; Collins and Storfer 2003). Careful management of anthropogenically modified habitats at the landscape level is critical to maintaining viable populations and regional diversity; however, data on amphibian responses to anthropogenic land use are limited (Harlow and Van Lear 1987; Chazal and Niewiarowski 1998; deMaynadier and Hunter 1998).
Vernal pools are seasonally inundated wetlands that can range widely in hydroperiod and in types and amount of vegetation they contain (Calhoun et al. 2003). Vernal pools are commonly found throughout northeastern North American woodlands, and are important in forested landscapes because they provide the primary or exclusive habitat for discrete larval amphibian assemblages that are dependent on fishless pools for successful recruitment (Brooks and Hayashi 2002; Calhoun et al. 2003; Zedler 2003; Hermann et al. 2005). Periodic drying of these wetlands eliminates predatory fishes, some predatory invertebrates (Tarr et al. 2004), and some breeding populations of amphibians (e.g., bullfrog, *Rana catesbeiana* and green frog, *Rana clamitans*), which may also compete for food resources.

Vernal pools make up the vast majority of the total number of wetlands in the landscape and, because of their small size, hydrology, and predominantly private ownership, are wetlands at high risk of loss (Gibbs 1993; Semlitsch and Bodie 1998; Snodgrass et al. 2000). Functionally, seasonal pools provide a network of wetland refuges for wildlife by providing foraging and resting areas in otherwise forested landscapes (Gibbs 1993, 2000; Semlitsch 1998; 2002; Semlitsch and Bodie 1998; Calhoun and Hunter 2003). The current Maine regulatory draft (from Calhoun et al. 2003) defines vernal pools as:

Naturally occurring, temporary to semi-permanent bodies of water occurring in shallow depressions that typically fill during the spring or fall and may dry during the summer. Vernal pools have no permanent or viable populations of predatory fish. Vernal pools provide the primary breeding habitat for wood frogs (*Rana sylvatica*), spotted salamanders (*Ambystoma maculatum*), blue-spotted salamanders (*Ambystoma laterale*), and fairy shrimp (*Eubranchipus* spp.), and provide habitat for other wildlife including several endangered and threatened species.
Although vernal pools provide critical breeding habitat, amphibians that depend on these wetlands for breeding spend the majority of the year (≥ 11 months) in terrestrial habitats surrounding breeding ponds and move among different sites. During this time they must acquire enough food to grow and prepare for breeding and seek protection from predation, dehydration, and freezing (Madison 1997; Pope and Matthews 2001; Faccio 2003; Regosin et al. 2003). Thus, protection of adequate upland habitat is also critical to ensure persistence of vernal pool-dependent amphibian populations.

Because vernal pools often occur in discrete patches within a matrix of upland habitat, amphibians often exist as metapopulations, in which species persistence in the landscape is partially dependent on inter-wetland dispersal and colonization (Sjögren, 1991; Marsh and Trenham 2001; Dodd 1997; Semlitsch and Bodie 1998; Roe et al. 2003). The removal of upland vegetation through timber harvesting typically produces an initial increase in wetland hydroperiod (due to a decrease in evapotranspiration) and sedimentation (Corn and Bury 1989; Sun et al. 2001; Welsh and Droege 2001). However, the loss of canopy can decrease the carrying capacity and habitat quality of forests for amphibians by eliminating shade, reducing leaf litter, increasing temperature extremes, and reducing soil-surface moisture (Petranka et al. 1993; Richter et al. 2001; Welsh and Droege 2001). In addition to direct impacts, logging may also impede critical metapopulation processes such as the recolonization of isolated wetlands by amphibian populations (Hanski and Gilpin 1991). In a study by Richter et al. (2001), no radio-tagged gopher frogs (Rana sevosa) were observed entering an experimental clearcut in Mississippi.
The forest products industry faces the challenge of developing management plans that balance optimal timber production with the conservation of forest biodiversity and environmental health (Petranka et al. 1993; Chazal and Niewiarowski 1998; Hanlin et al. 2000). To attain such objectives, several states in New England (e.g., Massachusetts, New Hampshire and Maine) have implemented voluntary or regulatory Best Management Practices (BMPs) that set guidelines for water quality, replanting, and road building, and provide recommendations to improve the stewardship of local forests by landowners. The New Hampshire Department of Resources and Economic Development defines BMPs as proper methods for the control and dispersal of water on truck roads, skid trails, and log landings to minimize erosion and reduce sediment and temperature changes in streams (Chapman et al. 1997). Nonetheless, efforts toward sustainable forestry vary, and state regulations or guidelines are often inadequate, weakly enforced, or hampered by a lack of empirical data.

Recently, strategies to conserve amphibians have emphasized the importance of maintaining adequate areas (buffers) of suitable terrestrial habitat surrounding vernal pools. Forestry BMPs in some states require or recommend buffer zones around vernal pools to minimize the impacts of timber harvesting operations on aquatic and semi-aquatic organisms (Calhoun and deMaynadier 2004). Amphibians with complex life cycles are undoubtedly affected by the area of a terrestrial buffer zone around wetlands (Semlitsch 1998). Current buffer zone recommendations range from 15 m (Massachusetts Forest Cutting Practices Act; from Burne and Griffin 2005b) to 164 m (Semlitsch 1998) to 1000 m (Richter et al. 2001). The state of New Hampshire recommends maintaining a shaded and minimally disturbed buffer zone extending 50 ft
(approximately 15 m) outward from the high water line to avoid siltation and temperature increases (Chapman et al. 1997). In an analysis of 106 vernal pools in Massachusetts, Stone (1992) found that the most important characteristic distinguishing sites utilized by obligate vernal pool breeders was the percentage of forest within a 152 m radius of the pool. Mattfeldt (2004) surveyed vernal pools in New Hampshire and determined that both hydroperiod and area of continuous forest within 300 m positively influenced the number of wood frog egg masses.

Although amphibians may be adversely affected by high-intensity landscape changes, little is known about the influences of more subtle landscape gradients in less disturbed or predominantly forested areas (deMaynadier and Hunter, 1998; Hermann et al. 2005). Although efforts must be taken to ensure that smaller buffer zones immediately surrounding wetlands are protected to avoid direct impacts to the wetland itself, large buffer zones may not be as important to species survival in forests as those in more developed (e.g., urban) areas, because forested landscapes are more connected and thus conducive to metapopulation dynamics (Hermann et al. 2005). Hermann et al. (2005) suggest that, rather than a conservation strategy that focuses on exclusive protection of upland habitats immediately surrounding a wetland, it may be better to focus on protecting a large proportion of suitable upland habitat within a larger area. It is possible that the implementation of buffer zones alone will not safeguard amphibian metapopulation processes (Semlitsch, 1998; Marsh and Trenham, 2001). In addition, Hermann et al. (2005) propose maintaining a matrix of suitable upland and wetland habitat, with a spatial configuration that emphasize wetland connectivity and upland-wetland linkages.
Recent studies have begun to measure the movement and dispersal behavior of amphibians, particularly those affected by habitat disturbance. However, few studies examine the effects of clearcutting on vernal pool-breeding species. Calhoun and deMaynadier (2004) report the maximum distance moved by adult wood frogs (472 m), and the mean distance for spotted salamanders and blue-spotted salamanders (118 m and 145 m, respectively) in undisturbed forest habitats. A better understanding of vernal pool-breeding amphibian movement patterns, particularly in working forests, is essential for the management of these species.

While some data are emerging on the effects of forestry on stream-breeding amphibians, the impact of logging practices on the amphibian fauna of other aquatic systems (e.g., vernal pools) is still mostly lacking (deMaynadier and Hunter 1995). Because of their small size and isolation from other surface waters, vernal pools receive minimal federal regulatory oversight (Calhoun et al. 2003; Roe et al. 2003), and even where isolated wetlands are protected, state and federal wetland regulations generally protect little or no upland surrounding wetlands (Burke and Gibbons 1995; Semlitsch 1998; Regosin et al. 2003). Biological information remains limited concerning the use of terrestrial habitats adjacent to wetlands, the definitions of biologically relevant distances from the shoreline, and the size of areas required during the life cycle of some amphibian species (Semlitsch 1998).

To date, there has been no field experiment designed specifically to test whether wetland buffers provide adequate protection for amphibians, or to compare buffers with different widths. I conducted a large-scale field study that specifically examined effects of timber harvesting and buffer width manipulation on wood frogs. My overall objective
was to investigate the influence of vernal pool buffer size on adult and metamorph wood frogs in a Maine forest. In Chapter I, I discuss the effects of buffer width on adult and metamorph numbers, relative adult survival, and relative adult and metamorph fitness. In Chapter II, I discuss the effects of buffer width on adult movement and habitat use.
CHAPTER I

THE EFFECTS OF FOREST BUFFER SIZE ON ADULT AND METAMORPH WOOD FROG SIZE AND ABUNDANCE

Introduction

Amphibians have been recognized as important components of ecological communities (Burton and Likens 1975; Chazal and Niewiarowki 1998; deMaynadier and Hunter 1995), yet are often overlooked in management decisions concerning biodiversity protection (Petranka et al. 1993). Amphibian breeding populations naturally undergo wide fluctuations in number, and may only represent a fraction of the surrounding adult population (Berven 1990; deMaynadier and Hunter 1995; Semlitsch 2000). There are numerous factors and combinations of factors (e.g., resource availability, hydroperiod, disease, chemical contaminants, and habitat alteration), both natural and anthropogenic, that affect amphibian population size and fitness (Alford and Richards 1999; Dodd 1997; Semlitsch 2000). It is possible to use amphibian life-history traits, such as size at metamorphosis, female fecundity, and juvenile recruitment, to measure responses to these factors.

The impacts of hydroperiod on amphibian species diversity and abundance have been well studied (Babbitt et al. 2003; Pechmann et al. 1989; Semlitsch et al. 1996; Snodgrass et al. 2000). Wetland hydroperiod often varies among years; the number and composition of amphibians using a wetland in a given year is a function of hydroperiod...
length (Babbitt et al. 2003; Pechmann et al. 1989; Semlitsch et al. 1996; Snodgrass et al. 2000). Pechmann et al. (1989) concluded that variation in the dates of wetland filling and drying interacts with other factors to determine amphibian community structure and diversity. The effects of wetland hydroperiod are especially important for vernal pool-breeding amphibians, where the advantages of rapid larval growth and large size at metamorphosis are pitted against the risks of mortality, primarily through pool drying (Morey 1998). Hermann et al. (2005) found hydroperiod to be the most important variable influencing wood frog distribution in southern and central New Hampshire. Mattfeldt (2004) determined that hydroperiod was the most significant factor influencing the number of wood frog egg masses (an index of the number of breeding females) at vernal pools in southern New Hampshire. If successful metamorphosis occurs, subsequent adult fitness is often strongly correlated with body size at metamorphosis (Morey 1998; Wilbur and Collins 1973). Morey (1998) found that larval period length and body mass at metamorphosis of the western spadefoot toad (Scaphiopus hammondii) were both positively correlated with pool duration.

Wood frogs are explosive breeders that congregate in large numbers for a very brief (e.g., two week) breeding event. They produce large numbers of fast-developing larvae that compete for limited food through exploitative and interference competition (Semlitsch 2000). Interspecific competition for food reduces growth and developmental rates, increases length of larval period, and hence, vulnerability to desiccation (Semlitsch 2000, Wilbur 1987). Reduced growth and developmental rates also reduce body size at metamorphosis, which in turn, may increase age at first reproduction and decrease size at
Body size positively influences amphibian survival, reproduction, and recruitment (Gray and Smith 2005; Wilbur 1984). Larger amphibians within a species are better at acquiring food resources, escaping predators, withstanding dehydration, and attracting mates than are smaller individuals (Berven 1981; Gray and Smith 2005). Additionally, larger female amphibians produce more eggs than smaller females (Berven 1982).

Negative impacts of some forest management practices (e.g., clearcutting) on amphibian habitat include greater fluctuation in air and soil temperature, relative humidity, evaporation rates, light intensity, and hydroperiod (deMaynadier and Hunter 1999). Habitat modification (e.g., urbanization, forestry, and agriculture) have the potential to alter factors such as female fecundity, offspring survival, body condition, and life history for two species of anurans in the eastern United States (Tarnita et al. 1997). However, data on amphibian responses to anthropogenic land use are limited (Harlow 1999). Such life-history changes can have implications for amphibian fitness and abundance (Hecnar and M'Closkey 1999; Lauck 2003; Semlitsch 2000). Forestry and agriculture have the potential to alter factors such as female fecundity, offspring survival, body condition, and the age and size at first reproduction by reducing available habitat, thereby reducing resource availability and increasing habitat and body size positively influence amphibian survival, reproduction, and recruitment (Berger 1988, 1990; Semlitsch 2000).

First reproduction, survival to first reproduction, and fecundity (Berger 1988, 1990; Semlitsch 2000).
Tasmania. Egg size was significantly greater at reference than at logged sites for both species. For the brown tree frog (Litoria ewingii), size at hatching was also significantly greater at reference sites, but for the eastern common froglet (Crinia signifera), size at hatching was independent of logging treatment. Lauck (2004) concluded that the post-logging environment produced conditions that were ecologically distinct from those in unlogged forest. DeMaynadier and Hunter (1995) reviewed previously reported amphibian abundance data from 18 sources and determined the total captures of amphibians on reference sites had a median value 3.5 times that of clearcut sites.

Vernal pools are commonly found in forested landscapes and provide patchily distributed larval habitat to species that, as adults, range widely in the wooded uplands, contributing an important energy link between aquatic and terrestrial ecosystems (deMaynadier and Hunter 1995). In an analysis of 106 vernal pools in Massachusetts, Stone (1992) found that the most important characteristic distinguishing sites utilized by obligate vernal pool breeders was the percentage of forest within a 152 m radius of the pool. A critical threshold analysis by Homan et al. (2004) determined that wood frogs are more sensitive to habitat loss near the pond than are spotted salamanders (Ambystoma maculatum). This could be due to the relative importance of winter habitat. Regosin et al. (2005) found that adult wood frogs tended to move toward the breeding pond during the fall, and wintered at the highest density near the pond.

While data are emerging on the effects of forestry on stream-breeding amphibians, the impact of logging practices on the amphibian fauna of other aquatic systems, such as vernal pools, is still mostly lacking (deMaynadier and Hunter 1995). Experimental manipulation of upland buffer width is necessary to determine how such
management practices may protect amphibian populations. To determine how much upland immediately adjacent to vernal pools is necessary to adequately protect amphibian populations, I experimentally manipulated forest buffer width, and tested whether this had any effect on 1) relative adult and metamorph abundance, 2) relative adult survival, and 3) post-breeding adult and emigrating metamorph size. I hypothesized that a smaller buffer would result in lower adult wood frog abundance and size than a larger buffer because of reduced habitat availability. I predicted that survival would be lower at buffer sites than reference sites due to a potential increase in the number of predators in the clearcut habitat. Based on previous research (e.g., Hermann et al. 2005; Mattfeldt 2004) I expected hydroperiod to have the greatest effect on metamorph production, regardless of buffer width treatment.

**Methods**

**Study Site**

This study was conducted on property in central Maine owned and managed by International Paper/Sustainable Forest Technologies, totaling 120,646 ha (289,552 acres). This land has an abundance of vernal pools as well as access roads. Forests were mixed hemlock (*Tsuga canadensis*) and hardwood (*Fagus grandifolia*, *Acer saccharum*, *Betula alleghaniensis*) in the lower elevations with increasing domination by balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) at higher elevations and along riparian areas. This study was conducted exclusively within hemlock-northern hardwood forest.
Study Organisms

Wood frogs (*Rana sylvatica*) breed in fish-free, seasonally-inundated wetlands (e.g., vernal pools) beginning in early April in Maine (Hunter et al. 1999). The breeding event typically lasts two weeks or less. Eggs are laid in globular clusters and attached to vegetation or sticks about 10 cm below the water surface. Most of the egg masses in a pool are communally clumped. Larvae hatch approximately three weeks after breeding begins, and metamorphose between late May and mid-August in Maine (Hunter et al. 1999). Adult wood frogs spend the non-breeding portion of the summer in woodlands surrounding the breeding pool, and during winter they hibernate under logs, leaf litter, or rocks (Hunter et al. 1999). Females reach sexual maturity at three years of age and males at two (Bellis 1961).

Buffer Width Manipulations

To test the hypothesis that wood frog populations are influenced by forest buffer width surrounding vernal pools, I encircled 12 breeding pools using drift fences in conjunction with pitfall traps. Over 100 pools in the study area were originally identified using NWI maps. Potentially suitable wetlands were selected based on several criteria. Vernal pools selected were initially surrounded by relatively undisturbed forest (logging > 60 years ago) within at least a 1,000 m radius around the pool. These wetlands were of similar size (about 0.2 ha), which is typical of vernal pools in the region (Gibbs 1993). I also selected pools with hydroperiods of 5 to 6 months post ice-out to buffer the effects of unusually dry years (i.e., to ensure that pools were inundated long enough to allow wood frogs time to metamorphose, but short enough to prevent colonization by predatory fish). Finally, I selected pools with similar species composition and wood frog and spotted

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salamander egg mass numbers based on an egg mass survey conducted in April/May 2003. In summary, the surrounding landscape, within-pool characteristics, and species composition of study site vernal pools were standardized to the fullest degree possible.

Between September 2003 and March 2004, International Paper Inc. clearcut (removal of all trees down to 5 cm dbh) forest at different distances from the vernal pool to create buffer zones. Buffers of 30 m, 100 m, and >1000 m (uncut, reference site) were established at four pools per buffer treatment. Buffers were created by clearcutting a 100 m wide concentric band around the forest buffer zone (Figure 1). The widths chosen were based on current BMP recommendations and suggestions in the literature (Dodd 1996; Semlitsch 1998; Givens 2001; Richter et al. 2001; Calhoun and deMaynadier 2004). Buffer treatments were implemented in a completely randomized design. I dropped one reference site vernal pool from the study due to excessive ice formation and extremely delayed thawing. I used a Trimble Pathfinder Pro XR GPS unit to map each pool, buffer, and clearcut perimeter.

**Amphibian Collection**

From July through October 2003, vernal pools were enclosed by drift fences made of silt fencing 91cm in height and buried 8 - 10cm. Fences were positioned at least 5 m back from the high water mark to reduce the chance of flooding. Pitfall traps made from two stacked 9.5 liter metal cans were placed as pairs on opposite sides of the fences at 10 m intervals (Pechmann et al. 1989; Semlitsch et al. 1996; Dodd and Cade 1998). These cans were deep enough to prevent amphibian species from climbing or jumping out. To minimize the potential desiccating effects of the sun a small amount of leaves and a moist sponge were maintained in pitfall traps.
Drift fences were sampled from ice-out (April) through first terrestrial frost and the onset of hibernation (November) in 2004 and 2005 to quantify the number of adult and metamorph (young-of-year) wood frogs at each site the first and second year after the implementation of buffer zone treatments. This allowed me to compare the relative effects of buffer size on wood frog populations.

Pitfalls were checked daily beginning at 7:00am. For each individual captured entering the pool (immigrating), I recorded date, trap ID, species (other species utilized these pools and I collected data as part of a broader study), and sex (for adults). Sex was determined by the presence or absence of nuptial pads. For each individual captured exiting the pool (emigrating), I recorded date, trap ID, species, gender, snout-urostyle length (SUL) to the nearest mm using a ruler, and mass to the nearest 0.5 g using a hand-held Pesola spring scale. I assumed that all adults entering or exiting pools were breeding adults. I measured SUL (not mass) of emigrating metamorph wood frogs.

All emigrating adult wood frogs were marked by toe-clipping in order to determine relative survival among buffer width treatments. I used wetland-specific toe-clips in order to distinguish animals between pools (either 1 or 2 toes removed). I also toe-clipped emigrating metamorph wood frogs, as this study is part of a long-term project. After processing, individuals were released on the opposite side of the fence. Toe-clipping is one of the easiest and least expensive ways to mark anurans, and is typically permanent in adults (Donnelly et al. 1994; Schlaepfer 1998). However, it remains unclear to what extent mobility and overall survivorship are affected by this technique (Hero 1989; Schlaepfer 1998). McCarthy and Parris (2004) re-analysed available toe-clip data using Bayesian statistics and found that the effect of toe clipping
on the return rate of amphibians increases with the number of toes removed. By removing only 1-2 toes, I hoped to minimize negative impacts on amphibian mobility and survival (McCarthy and Parris 2004).

Wood frog egg mass surveys were conducted at each pool approximately 1 week after the breeding event in both 2004 and 2005. Vernal pool depth was measured throughout the spring/summer using permanent depth gauges in order to determine hydroperiod length, defined as the number of weeks a pool contained water from ice-out to drying.

**Data Analysis**

Adult and metamorph abundance data were log_{10}-transformed to homogenize variances and normalize data prior to analysis. I used analysis of variance (ANOVA) to test for differences between buffer width (treatment), year, sex (only for adults), and hydroperiod (only for metamorphs) on the abundance of adult and metamorph wood frogs. I used a two-tailed Pearson correlation to test the relationship between the number of emigrating metamorphs and 1) the number of immigrating females, and 2) the number of egg masses.

Adult recapture data were square root transformed to homogenize variances and normalize data prior to analysis. I used ANOVA to test for differences between buffer width and sex on the proportion of recaptured adults from the total marked in 2004 (PRM), and on the proportion of recaptured adults from the total captured in 2005 (PRT).

I used adult mass and metamorph SUL as estimates of body size. I calculated the mean wood frog mass and SUL for each vernal pool (separate for males and females). I tested for differences between buffer width (treatment) and year on the body size of adult
and metamorph wood frogs using ANOVA. If ANOVAs were significant, I ran a Tukey post-hoc multiple comparison test to determine pairwise differences between treatments at an experiment-wide error rate of \( p < 0.05 \). All analyses were conducted using SPSS (Windows, Release 14.0.1. 2005. Chicago: SPSS Inc.).

Skeletochronology is now widely used to determine age in amphibians. The lines of arrested growth, laid down in the long bones during periods of unfavorable conditions (e.g., winter), allow accurate calculation of the number of years an animal has lived (Marnell 1998). This technique would have been ideal to use for the current project, but financial constraints prevented it. Rather, I used size as an estimate of age for adult wood frogs because many poikilotherms continue to grow throughout their lifetime, and thus growth measurements become a measure of their age (but see Hota 1994 and Lauck 2005b). Therefore, to examine the effects of buffer width on adult wood frog size, and to estimate age of adult wood frogs, I established size categories for males and females based on adult mass (Table 1).

**Results**

**Abundance**

I captured a total of 2006 immigrating adult wood frogs in 2004 and 1320 in 2005. There was a male-biased sex ratio of 1.6 (males:females) for the two years combined (Figure 2). The number of adult frogs captured was not affected by treatment, year, or sex (Table 2).

Although the number of adult females was significantly correlated with number of egg masses (\( p < 0.001 \)), emigrating metamorph abundance was not significantly correlated with either the number of immigrating females (\( p = 0.202 \)) or the number of
egg masses (p = 0.521). I determined the number of emigrating metamorphs produced per immigrating female (Table 3). Although the reference sites in 2005 had the largest overall number of metamorphs per female, there was a great deal of variability among the pools. Furthermore, reference sites had the lowest production in 2004, where only one metamorph was produced from all reference sites. Early drying of several pools in 2004 resulted in a metamorph recruitment of zero; whereas one pool in 2005 accounted for over 70% of the total metamorph production of both years combined (Figure 3).

Metamorph production was highly variable between years and among pools, and was not significantly affected by year, buffer width treatment, or hydroperiod (Table 4). Vernal pool hydroperiods ranged from 1-31 weeks (mean = 19); hydroperiod was not affected by year or treatment (Table 5).

**Adult Survival**

The number of recaptured adult wood frogs was less in the 30 m buffer treatments than the reference and 100 m buffer treatments, whereas, the number of unmarked adults measured in 2005 was highest at 30 m buffer sites (Figure 4). The proportion of recaptured adult wood frogs in 2005 from those marked in 2004 (PRM) was not significantly affected by treatment or sex (Table 6). There was high variability for females in the 100 m buffer sites and males in the 30 m buffer sites (Figure 5). Female recapture rates were much lower in the 30 m buffer sites (Figure 5), but not significantly different from the other treatments.

The proportion of recaptured adults from the total captured in 2005 (PRT) was significantly affected by treatment, but not sex (Table 7). There was a significantly greater PRT from the reference sites than the 30 m buffer sites (Tukey post-hoc p =
0.034); difference in recapture rates were not significant between the reference and 100 m buffer sites (Tukey post-hoc p = 0.748); nor the 100 m buffer and 30 m buffer sites (Tukey post-hoc p = 0.101). Approximately 33% of the frogs caught in 2005 from reference sites were recaptured individuals, compared to only 7% from the 30 m buffer sites (Figure 6). Patterns of recapture among treatments were similar for males and females.

Size

Male and female adult wood frogs were analyzed separately. Adult size was not significantly affected by year or treatment (Table 8; Figure 7). However, treatment effects approached significance for both males (p = 0.055) and females (p = 0.057). For both sexes, frogs from reference sites were larger than those from buffer treatment sites, particularly the 30 m buffer treatment (though not significant).

Figures 8 and 9 illustrate the number of emigrating adult wood frogs in each size class in 2004 and 2005. In 2005 there was a greater number of emigrating adults in the 30 m buffer sites than the reference and 100 m buffer sites. A higher proportion of these frogs (those from the 30 m buffer sites) were comprised of smaller individuals than at the 100 m buffer and reference sites. These patterns are similar for both males and females.

Figures 10 and 11 show the size distribution of marked (those measured in 2004) and recaptured (measured in 2005) female and male wood frogs, respectively. For both sexes there were relatively similar size distributions among the three treatments in 2004. However, the 30 m buffer sites have fewer total recaptured frogs than the 100 m buffer and reference sites, in addition to fewer larger individuals. This pattern is the same for both males and females.
Metamorph size was highly variable among pools, and was not significantly affected by year or buffer width treatment (Table 9). Although not significantly different, metamorph wood frogs from reference sites were on average smaller than those from treatment sites.

**Discussion**

The objective of this chapter was to examine the effects of forest buffer width on wood frog abundance, survival, and size. I determined that small buffers surrounding vernal pools have negative impacts on adult wood frog survival and size, and the potential to influence local population dynamics.

A lack of significant difference of immigrating adult abundance between years suggests that the size of the adult breeding populations did not differ greatly during the two years sampled. There was high variability in the immigrating adult abundance for both males and females at all three buffer treatments (Figure 2). Berven (1990) found that breeding populations of wood frogs, number of eggs deposited, and premetamorphic survival varied widely among ponds and the seven years of his study period. He determined that the variation in adult numbers was largely due to variation in juvenile production, and the variation in number of individuals surviving to become adults was due to annual variation in premetamorphic survival (Berven 1990). It is possible that the numbers of immigrating adult wood frogs in the 100 m buffer sites were lower than the reference and 30 m buffer sites because of differences in juvenile recruitment of past years.

There were relatively similar numbers of emigrating adult wood frogs (post-breeding) from all three treatments in 2004. However, the total number of recaptured
frogs, the proportion of recaptured female wood frogs from those marked in 2004 (PRM), and the proportion of recaptured adult frogs from the total caught in 2005 (PRT) were lower in the 30 m buffer sites than the 100 m buffer and reference sites. A low PRM suggests fewer adult frogs returned to breed in 2005 at sites with smaller buffers, i.e., small buffers result in reduced survival. A low PRT suggests that there were more first-time breeders at the 30 m buffer sites than the reference sites. This is supported by the higher number of unmarked (non-recapture) adults in the 30 m buffer sites than the reference and 100 m buffer sites (Figure 6). Given the relatively similar number of immigrating and emigrating adults among the three treatments, and the low recapture rates at the 30 m buffer sites, it is possible that vernal pools with small forest buffers may result in higher adult wood frog mortality. Variability in PRT was high for both males and females from the reference sites, and for males at the 100 m buffer sites. However, variability in PRT was much lower for males and females from the 30 m buffer sites, suggesting uniformly strong treatment effects.

Because wood frogs exhibit high breeding site fidelity (Berven 1990), it is unlikely that reduced recapture rates at 30 m buffers were caused by frogs breeding elsewhere (but see Petranka et al. 2004). Likewise, in Chapter II, I demonstrate that clearcuts do not prevent adult wood frogs from migrating to breeding pools. It is likely that reduced survival was due to unsuitable habitat conditions in the edge or surrounding clearcut either during the non-breeding active season or the winter hibernation period. Possibilities for this include: higher rates of desiccation caused by increased temperature fluctuations and wind exposure (as compared to buffer); lower resource availability; or
greater predator abundance (e.g., snakes); higher mortalities of frogs that overwinter in clearcut.

Rothermel and Luhrig (2005) demonstrated that the clearcut habitat was unsuitable for juvenile mole salamanders (*Ambystoma talpoideum*). Juveniles inhabiting recent clearcuts (via enclosures) had greater mortality rates than those inhabiting uncut forest (Rothermel and Luhrig 2005). Clearcuts in the current study were generally inhospitable habitat, though permeable to adult dispersal (see Chapter II). Based on movement data (see Chapter II), it is likely that the clearcut habitat at buffer treatment sites was previously occupied by adult wood frogs prior to canopy removal. Reduced habitat availability likely forced wood frogs to seek alternative habitat by either remaining within the buffer or dispersing to the forest beyond the clearcut.

If frogs dispersed through the clearcut they could be subject to increased predation rates. Amphibians comprise a large part of the diet of snakes common to the project area (e.g., *Thamnophis sirtalis, Thamnophis sauritus, Diadophis punctatus*). As poikilotherms, snakes respond positively to habitat modification that reduces canopy cover. For example, total adult snake abundance was significantly lower in hardwood than cut-over hardwood treatments during equal trapping periods in Maryland (McLeod and Gates 1998). Additionally, two studies in Georgia and Texas determined that reptile abundance (Moseley et al. 2003) and species richness (Goldstein et al. 2005) was greater in burned and clearcut treatments, respectively, compared to forested reference sites. Although documenting snake abundance was beyond the scope of my project, I frequently observed snakes in clearcut areas.
Wood frogs hibernate under moist forest floor debris from October to late March (DeGraaf and Yamasaki 2001). It may be advantageous for male wood frogs to hibernate close to the breeding pool, as this would enable them to arrive at the breeding pool earlier during a period of explosive spring breeding (Zweifel 1989). Regosin et al. (2003) estimated that male wood frogs were 4.9 times more likely than females to overwinter < 65 m from their breeding pool. However, it is likely that if adult frogs overwintered in clearcut or buffer edge habitat, they would risk an increased probability of fatality. The buffer and reference sites had less daily temperature fluctuation, and presumably less wind, than clearcuts (Babbitt and Freidenfelds unpublished data). Costanzo et al. (1991) experimentally froze wood frogs to -2.5°C under five distinct cooling regimes to investigate the effect of cooling rate on survival. Frogs survived freezing when cooled at slower rates, but mortality resulted at higher rates. Surviving frogs in the latter groups (higher rates) required longer periods to recover, and transient injury to the neuromuscular system was evident (Costanzo et al. 1991). They concluded that slow cooling may be critical to the freeze tolerance of wood frogs. Overall, larger buffers can better safeguard against extreme winter temperatures than smaller buffers; overwintering in clearcuts may result in higher mortality rates.

Regosin et al. (2003, 2005) reported winter densities of wood frogs in Massachusetts as 0-6.3 per 100 m² and 0.6-0.9 per 100 m², respectively. The area of the 100 m buffer is more than 3.5 times larger than the area of the 30 m buffer (approximately 12,600 m² and 44,800 m², respectively). Equal numbers of frogs within each buffer would result in vastly different densities. It is unclear what impact increased winter densities would have on wood frog fitness and local population dynamics.
A decrease in upland habitat immediately surrounding the breeding pool resulted in reduced adult wood frog body size for both males and females. Wood frog population age structure (based on size categories) was relatively similar at all three treatments in 2004 and at the reference and 100 m buffer sites in 2005. For both males and females, lower mean body mass at the 30 m buffer sites was due to a much higher number of smaller, and presumably younger, frogs in 2005 (Figures 8 and 9). This is further evidence of the increase in first-time breeders at 30 m buffer sites. It is possible that these size patterns correspond to high or low larval productivity of past years, and are unrelated to buffer width. Alternatively, smaller younger, first-time breeders at the 30 m buffer treatment may represent dispersal from adjacent sites that are productive. Permeability of 100 m wide clearcuts, but lower adult survival may result in a shift in age structure at vernal pools with 30 m buffers, such that individuals are recruited into the local breeding population in their first year but suffer higher adult mortality. Longer-term research is needed to determine if this is the case.

The benefits of large body size in amphibians are well documented. Wood frog clutch size positively increases with female body size, larger males are more successful in male-male competition for females, and males show a preference for large females (Berven 1981; Berven 1990; Berven and Grudzien 1990). Additionally, larger frogs have a smaller relative surface area that reduces the risk of dehydration, and may be able to forage and disperse for longer periods and over longer distances than smaller frogs (Lauck 2005). Goater (1994) and Scott (1994) found that a 10% increase in amphibian body size could result in approximately 4% and 80% increases in individual survival and fecundity, respectively. Therefore, it is probable that an increase in first-time breeders at
the 30 m buffer sites, because they are smaller, will negatively affect population
dynamics through reduced fecundity and survival.

Due to early pool drying in 2004, metamorph production at the three reference
sites was comprised of only one individual (SUL = 16 mm). It is possible that buffer
treatment effects on both metamorph size and abundance are confounded by density-
dependent effects and other factors such as food availability. Wilbur (1976) found that at
high densities, two changes occur in the distribution of amphibian body sizes: skewness
increases, and the mean decreases. As a result, only a few individuals are able to reach
the size required for metamorphosis. The remainder of the population grows slowly and
succumbs to predation or other sources of mortality before they reach the minimum size
that both larval density and food level had a significant effect on size at metamorphosis
for wood frogs. At low densities and high food levels individuals metamorphosed at a
significantly larger size than those individuals reared at low food levels and high
densities (Berven and Chadra 1988).

The average size at metamorphosis is positively related to adult body size for
North American ranids such as wood frogs (Werner 1986). Semlitsch et al. (1988)
concluded that earlier metamorphosis led to larger size at first reproduction for
Ambystoma talpoideum. Also, larger juveniles at metamorphosis led to larger adults at
first reproduction for both sexes and younger age at first reproduction in females
(Semlitsch et al. 1988). Metamorphosing at large size is beneficial to wood frogs because
they are likely to be larger as adults than smaller metamorphosing individuals, the
benefits of which were discussed above. However, site to site and year to year variability makes detecting treatment effects on metamorph size difficult.

Metamorph production appears to be a poor indicator of the effects of forest buffer width on vernal pool-breeding amphibians. Metamorph abundance was highly variable among pools and years, and was not affected by hydroperiod. Pools that dried before metamorphosis was complete resulted in zero metamorph recruitment, which should have caused significant hydroperiod affects. However, predation and density-dependent competition may have had a stronger influence on metamorph production than buffer width treatment or hydroperiod. In both 2004 and 2006 (Babbitt, unpublished data), one vernal pool had extremely high wood frog larval densities in June, yet very few larvae successfully metamorphosed (N < 10). Another pool exhibited a drastic decrease in metamorph production in 2005 (N = 3) compared to 2004 (N = 619), even though there were similar hydroperiod lengths for the two years. One possible explanation for this is the overwintering of green frog (Rana clamitans) larvae, which may compete for food resources with wood frog larvae.

Vernal pool hydroperiod is critical in controlling the development of wood frog larvae through metamorphosis into juveniles. Hydroperiod, measured as the number of weeks a pool contained water from ice-out to drying, was not affected by buffer width treatment. It is more likely, then, that hydroperiod is influenced by pool-specific factors not measured in this study. Soil type, drainage, basin depth, water table height, and amount of surrounding vegetation can affect the length of time a pool remains wet. Forest buffers of at least 30 m appear to have little impact on vernal pool hydrology.
Given the results of the current study it is possible that, over time, the high proportion of smaller adult frogs, and low recapture rates, would result in reduced fecundity and survival at the 30 m buffer sites. Therefore, significant alteration of population dynamics at vernal pools with small buffers is a real likelihood, especially given the high yearly variability in metamorph recruitment. These findings are supported by wood frog movement data (see Chapter II), which suggest that 30 m forest buffers are inadequate to provide suitable upland habitat for adult wood frogs, particularly females.

Vernal pools in Maine are a vital component of forest communities, and necessary for the long-term persistence of several amphibian species. Forest managers that aim to balance timber harvesting activities with forest community biodiversity and environmental health should consider implementing vernal pool buffers to protect pools from physical damage and reduce the impacts of clearcutting on amphibians. Given the inherent dynamic nature of amphibian populations, continued research on the impacts of buffer width on vernal pool wood frog populations is necessary to provide the data needed to guide management decisions regarding upland habitat adjacent to vernal pools.
Figure 1. Schematic of experimental design for forest buffer treatments at 11 vernal pools in Maine.
Figure 2. Mean (± 2 SE) immigrating adult wood frog abundance from three buffer width treatments at 11 vernal pools in Maine.
Figure 3. Number of emigrating metamorph wood frogs from three buffer width treatments at 11 vernal pools in Maine during 2004 and 2005.
Figure 4. Number of emigrating adult wood frogs from three buffer width treatments at 11 vernal pools in Maine. Bars represent frogs marked in 2004, recaptured in 2005, and unmarked (non-recaptured) in 2005.
Figure 5. Mean (± 2 SE) proportion of recaptured adult wood frogs in 2005 from those marked in 2004 (PRM) from three buffer width treatments at 11 vernal pools in Maine.
Figure 6. Mean (± 2 SE) proportion of recaptured adult wood frogs - those marked in 2004 - from the total caught in 2005 (PRT) from three buffer width treatments at 11 vernal pools in Maine.
Figure 7. Mean (± 2 SE) mass of adult wood frogs from three buffer width treatments at 11 vernal pools in Maine.
Figure 8. Number of emigrating female wood frogs in each of 5 mass categories during 2004 and 2005 from three buffer width treatments at 11 vernal pools in Maine.
Figure 9. Number of emigrating male wood frogs in each of 4 mass categories during 2004 and 2005 from three buffer width treatments at 11 vernal pools in Maine.
Figure 10. Comparison between the number of emigrating female wood frogs marked in 2004 and recaptured in 2005 in each of 5 mass (g) categories from three buffer width treatments at 11 vernal pools in Maine.
Figure 11. Comparison between the number of emigrating male wood frogs marked in 2004 and recaptured in 2005 in each of 4 mass (g) categories from three buffer width treatments at 11 vernal pools in Maine.
Figure 12. Mean (± 2 SE) metamorph wood frog snout-urostyle length from three buffer width treatments at 11 vernal pools in 2004 and 2005 (the 2004 reference sample is comprised of one individual).
Table 1. Mass categories for male and female adult wood frogs measured from three buffer width treatments at 11 vernal pools in Maine.

<table>
<thead>
<tr>
<th>Mass Category</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5 - 7.9</td>
</tr>
<tr>
<td>2</td>
<td>8 - 10.9</td>
</tr>
<tr>
<td>3</td>
<td>11 - 13.9</td>
</tr>
<tr>
<td>4</td>
<td>14 - 16.9</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 17</td>
</tr>
<tr>
<td>Males</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4 - 6.9</td>
</tr>
<tr>
<td>2</td>
<td>7 - 9.9</td>
</tr>
<tr>
<td>3</td>
<td>10 - 12.9</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 13</td>
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Table 2. Results of ANOVA of immigrating adult wood frog abundance for three buffer width treatments during 2004 and 2005 at 11 vernal pools in Maine.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
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<th>F</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Year</td>
<td>1</td>
<td>0.086</td>
<td>0.407</td>
<td>0.528</td>
</tr>
<tr>
<td>Treatment</td>
<td>2</td>
<td>0.260</td>
<td>1.235</td>
<td>0.304</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>0.496</td>
<td>2.357</td>
<td>0.135</td>
</tr>
<tr>
<td>Year × Treatment</td>
<td>2</td>
<td>0.035</td>
<td>0.165</td>
<td>0.849</td>
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<td>Year × Sex</td>
<td>1</td>
<td>0.245</td>
<td>1.164</td>
<td>0.289</td>
</tr>
<tr>
<td>Treatment × Sex</td>
<td>2</td>
<td>0.033</td>
<td>0.156</td>
<td>0.857</td>
</tr>
<tr>
<td>Year × Treatment × Sex</td>
<td>2</td>
<td>0.004</td>
<td>0.020</td>
<td>0.980</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>0.210</td>
<td></td>
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</tr>
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</table>
Table 3. Mean (± SD) number of wood frog metamorphs/female from three buffer width treatments in 2004 and 2005 at 11 vernal pools in Maine.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Reference</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>100 m Buffer</td>
<td>3.0 ± 3.9</td>
</tr>
<tr>
<td></td>
<td>30 m Buffer</td>
<td>9.3 ± 13.6</td>
</tr>
<tr>
<td>2005</td>
<td>Reference</td>
<td>43.9 ± 73.2</td>
</tr>
<tr>
<td></td>
<td>100 m Buffer</td>
<td>7.5 ± 14.5</td>
</tr>
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<td></td>
<td>30 m Buffer</td>
<td>2.4 ± 4.0</td>
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Table 4. Results of ANOVA of emigrating metamorph wood frog abundance for three buffer width treatments during 2004 and 2005 at 11 vernal pools in Maine.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
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<th>F</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Year</td>
<td>1</td>
<td>0.380</td>
<td>0.487</td>
<td>0.558</td>
</tr>
<tr>
<td>Treatment</td>
<td>2</td>
<td>1.904</td>
<td>2.443</td>
<td>0.290</td>
</tr>
<tr>
<td>Hydroperiod</td>
<td>12</td>
<td>0.954</td>
<td>1.224</td>
<td>0.535</td>
</tr>
<tr>
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<tr>
<td>Treatment x Hydroperiod</td>
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<td>3.824</td>
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</tr>
<tr>
<td>Error</td>
<td>2</td>
<td>0.779</td>
<td></td>
<td></td>
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Table 5. Results of ANOVA of vernal pool hydroperiod (weeks) for three buffer width treatments in 2004 and 2005 at 11 vernal pools in Maine.

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<th>P</th>
</tr>
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<td>Year</td>
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<td>22.083</td>
<td>0.196</td>
<td>0.664</td>
</tr>
<tr>
<td>Treatment</td>
<td>2</td>
<td>1.718</td>
<td>0.015</td>
<td>0.985</td>
</tr>
<tr>
<td>Year × Treatment</td>
<td>2</td>
<td>87.560</td>
<td>0.778</td>
<td>0.476</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>112.567</td>
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</tbody>
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Table 6. Results of ANOVA of proportion of recaptured adult wood frogs in 2005 that were marked in 2004 (PRM) from three buffer width treatments at 11 vernal pools in Maine.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
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<td>0.081</td>
<td>1.278</td>
<td>0.306</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>0.012</td>
<td>0.187</td>
<td>0.671</td>
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<tr>
<td>Treatment × Sex</td>
<td>2</td>
<td>0.161</td>
<td>2.561</td>
<td>0.108</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>0.063</td>
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</tr>
</tbody>
</table>
Table 7. Results of ANOVA of proportion of recaptured adult wood frogs (those marked in 2004) from the total caught in 2005 (PRT) from three buffer width treatments at 11 vernal pools in Maine.

<table>
<thead>
<tr>
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<th>df</th>
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<th>F</th>
<th>P</th>
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</thead>
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<td>0.173</td>
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<td>Sex</td>
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<td>0.107</td>
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<td>0.119</td>
</tr>
<tr>
<td>Treatment x Sex</td>
<td>2</td>
<td>0.029</td>
<td>0.745</td>
<td>0.491</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>0.039</td>
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</tbody>
</table>
Table 8. Results of ANOVA of adult wood frog mass (g) for three buffer width treatments in 2004 and 2005 at 11 vernal pools in Maine.

<table>
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<th>P</th>
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<td>Female</td>
<td>Year</td>
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<td>0.050</td>
<td>0.039</td>
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<td>Treatment</td>
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<td>4.455</td>
<td>3.445</td>
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<td>Year × Treatment</td>
<td>2</td>
<td>0.228</td>
<td>0.177</td>
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</tr>
<tr>
<td></td>
<td>Error</td>
<td>16</td>
<td>1.293</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>Year</td>
<td>1</td>
<td>2.927</td>
<td>3.611</td>
<td>0.076</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>2</td>
<td>2.829</td>
<td>3.490</td>
<td>0.055</td>
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<tr>
<td></td>
<td>Year × Treatment</td>
<td>2</td>
<td>0.103</td>
<td>0.127</td>
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<td>Error</td>
<td>16</td>
<td>0.811</td>
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<td></td>
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</table>
Table 9. Results of ANOVA of metamorph wood frog SUL (mm) for three buffer width treatments in 2004 and 2005 at 11 vernal pools in Maine.

<table>
<thead>
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<tbody>
<tr>
<td>Year</td>
<td>1</td>
<td>8.865</td>
<td>4.293</td>
<td>0.059</td>
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<tr>
<td>Treatment</td>
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<td>Year x Treatment</td>
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<td>Error</td>
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CHAPTER II

THE EFFECTS OF FOREST BUFFER SIZE ON ADULT WOOD FROG POST-BREEDING MOVEMENT

Introduction

Vernal pools are obligate breeding sites for several species of amphibians such as wood frogs, (*Rana sylavatica*), spotted salamanders (*Ambystoma maculatum*), and blue-spotted salamanders (*A. jeffersonianum*). However, amphibians that are an integral component of vernal pool communities spend more time in contiguous terrestrial habitats than in the aquatic breeding habitats (Berven 1990; Hunter et al. 1999). Vernal pool-breeding amphibians must move from terrestrial habitats over land to lay eggs, and therefore need a matrix of upland that is permeable to movement. Thus, upland habitat land-use changes (e.g., clearcutting) can have significant effects on amphibian populations.

Most studies of the effects of forest management on amphibians have focused on terrestrial salamanders, or amphibian species not associated with vernal pools. Many of these studies examined the impact of clearcutting (or other timber harvesting methods) on amphibian species richness, diversity, and life history traits (Chazal and Niewiarowski 1998; Dupuis et al. 1995; Gray and Smith 2005; Hanlin et al. 2000; Lauck 2005). For example, Knapp et al. (2003) found significant negative effects of timber harvesting on the abundance of terrestrial salamanders. However, there are few published reports on
the effects of clearcutting on vernal pool-breeding amphibian dispersal through forested landscapes, or the functional use of upland buffers.

Intensive forest management reduces or removes amphibian microhabitat produced by leaf litter and coarse woody debris (McLeod and Gates 1998; Semlitsch 2000), and disrupts amphibian migration routes immediately surrounding the pool (deMaynadier and Hunter 1995). Clearcutting eliminates shade, increases surface temperature, disrupts soil structure, and reduces soil moisture making such areas inhospitable or less suitable for many amphibian species (Semlitsch 2000). Rothermel and Luhring (2005) found canopy removal resulting from clearcuts greatly increased the risk of mortality due to desiccation for juvenile mole salamanders (*A. talpoideum*).

DeMaynadier and Hunter (1999) observed significantly fewer adult and juvenile wood frogs and spotted salamanders in recent clearcuts (2–11 yr old) than in mature (70–90 yr old) closed-canopy forest habitats.

Because vernal pools are common throughout northern New England forested landscapes, there is a high probability of timber harvesting activities impacting vernal pools, as well as pool-dependant organisms. A recent approach to vernal pool-breeding amphibian conservation involves the maintenance of suitable terrestrial habitat surrounding pools (forest buffers). Calhoun and deMaynadier (2004) developed Habitat Management Guidelines (HMGs), specifically for vernal pool wildlife, in which they recommend conserving vernal pools and adjacent forested habitat during harvest operations. Faccio (2003) determined a life zone encompassing 95% of *A. maculatum* and *A. jeffersonianum* populations would extend 157 m from a pool’s edge. The amount of forested upland needed to protect wood frog populations remains unknown.
Wood frog dispersal occurs in the juvenile stage and is a key factor in wetland recolonization (Berven and Grudzien 1990). However, little is known about adult wood frog post-breeding migration and upland habitat use. T. Rittenhouse (personal communication) and R. Baldwin (personal communication) describe maximum wood frogs movements of approximately 400 m and 340 m, respectively. To date, there have been no published reports of adult wood frog movement measured using radio-telemetry. The aim of this study was to determine if adult wood frogs could disperse through clearcuts, and if buffer width had any effect on wood frog movement. Gibbs (1998) found paved roads to be a barrier to amphibian movement, yet suggests that some woodland amphibians will cross substantial areas of open land to reach breeding pools, if significant physical barriers such as roads do not block their passage. I predicted that recent clearcut habitats would be inhospitable. It is unclear whether clearcuts are permeable to adult wood frogs since no previous studies have answered this question. However, if clearcuts are permeable, I expect movements will be longer in the buffer treatments compared to the reference sites because frogs may have to move farther to get to suitable habitat outside the vernal pool buffer zone.

**Methods**

**Study Site**

This study was conducted on property in central Maine owned and managed by International Paper/Sustainable Forest Technologies, totaling 120,646 ha (289,552 acres). This land has an abundance of vernal pools as well as access roads. Forests were mixed hemlock- (*Tsuga canadensis*) hardwood (*Fagus grandifolia, Acer saccharum, Betula alleghaniensis*) in the lower elevations with increasing domination by balsam fir (*Abies*...)
balsamea) and red spruce (Picea rubens) at higher elevations and along riparian areas. This study was conducted exclusively within hemlock-northern hardwood forest.

Study Organisms

Wood frogs (Rana sylvatica) breed in fish-free, seasonally-inundated wetlands (e.g., vernal pools) beginning in early April in Maine (Hunter et al. 1999). The breeding event typically lasts two weeks or less. Eggs are laid in globular clusters and attached to vegetation or sticks about 10 cm below the water surface. Most of the egg masses in a pool are communally clumped. Larvae hatch approximately three weeks after breeding begins, and metamorphose between late May and mid-August in Maine (Hunter et al. 1999). Adult wood frogs spend the non-breeding portion of the summer in woodlands surrounding the breeding pool, and during winter they hibernate under logs, leaf litter, or rocks (Hunter et al. 1999). Females reach sexual maturity at three years of age and males at two (Bellis 1961).

Buffer Width Manipulations

To test the hypothesis that wood frog populations are influenced by forest buffer width surrounding vernal pools, I encircled 12 breeding pools using drift fences in conjunction with pitfall traps. Potentially suitable wetlands were selected based on several criteria. Vernal pools selected were initially surrounded by relatively undisturbed forest (logging > 60 years ago) within at least a 1,000 m radius around the pool. These wetlands were of similar size (about 0.2 ha), which is typical of vernal pools in the region (Gibbs 1993). I also selected pools with hydroperiods of 5 to 6 months post ice-out to buffer the effects of unusually dry years. That is, to ensure that pools were inundated long

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enough to allow wood frogs time to metamorphose, but short enough to prevent colonization by predatory fish. Finally, I selected pools with similar species composition and wood frog and spotted salamander (for use in another study) egg mass numbers based on an egg mass survey conducted in April/May 2003. In summary, the surrounding landscape, within-pool characteristics, and species composition of study site vernal pools were standardized to the fullest degree possible.

Between September 2003 and March 2004, the International Paper logging corporation clearcut (removal of all trees down to 5 cm dbh) forest at different distances from the vernal pool to create buffer zones. Buffers of 30 m, 100 m, and >1000 m (uncut, reference site) were established at four pools per buffer treatment. Buffers were created by clearcutting a 100 m wide concentric band around the forest buffer zone (Figure 1). The widths chosen were based on current BMP recommendations and suggestions in the literature (Dodd 1996; Semlitsch 1998; Givens 2001; Richter et al. 2001; Calhoun and deMaynadier 2004). Buffers treatments were implemented in a completely randomized design. I dropped one reference site vernal pool from the study due to excessive ice formation and extremely delayed thawing. I used a Trimble Pathfinder Pro XR GPS unit to map each pool, buffer, and clearcut perimeter.

**Movement**

I collected adult wood frogs for radio-tracking as they emigrated from breeding vernal pools using pitfall traps in conjunction with drift fences. I used a BD-2 transmitter (Holohil Systems), with a battery life of 5 weeks and total weight of 0.95 g. Transmitters did not exceed 10% of the frogs’ body mass (to keep the effects of the transmitter belt on frog behavior to a minimum). Transmitters were attached to wood frogs using Teflon
tubing to make a harness (Bartelt and Peterson 2000). The harness was positioned on the waist of the frog by sliding it over the extended hind legs. Harnesses weighed less than 0.001 g. The cotton thread used to hold the tubing together was susceptible to moist conditions and deteriorated over time, allowing unrecovered radios to fall off frogs (Waye 2001). Transmitter harnesses were attached in the field, and frogs were handled as little as possible.

I located each animal every other day from May (capture) - August 2004 and April – July 2005 using an Advanced Telemetry Systems Challenger 2000 receiver and a hand-held three-element Yagi antenna. When individuals were located, I determined their position by direct overhead localization (Madison 1997), marked the location with labeled flags, recorded the location using a Trimble Pathfinder Pro XR GPS, and subsequently plotted the location on a GIS map of the site. Additionally, I recorded the frogs' location as one of three habitat types: buffer, clearcut, or forest (wooded area beyond clearcut).

Frogs were checked for skin abrasions each week and recaptured every month so that new transmitters could be refitted. If minor abrasions were present, a topical antibiotic/antiseptic (e.g., Bactine®) was applied to the skin. If severe abrasions were present, the transmitter was removed and the animal released in order to prevent unnecessary fatality (N = 6).

Data Analysis

Animals tracked less than 10 days were excluded from analyses (N = 5). I used GIS maps of each site to calculate the area of each habitat type for availability/utilization analysis. The approximate maximum adult wood frog migration distance of 480 m
reported by Calhoun and deMaynadier (2004) was used to estimate the outer forest boundary, and determine the forest habitat available to wood frogs. All radio-tracked frogs stayed within this distance from the vernal pool. I used Chi-square goodness-of-fit to test null hypotheses that individual habitat use (buffer, clearcut, or forest beyond clearcut) was in proportion to availability (Byers et al. 1984; White and Garrott 1990). If a significant difference was found between utilization and availability, then 95% Bonferroni confidence intervals were computed to determine if clearcut habitats were used more or less frequently than expected. The interval used was:

\[ p_i - z_{a/2k}[\left(1 - p_i\right)/n]^{0.5} \leq p_i \leq p_i + z_{a/2k}[\left(1 - p_i\right)/n]^{0.5}\]

where \( p_i \) is the proportion of locations in habitat \( i \), \( z_{a/2k} \) is the upper standard normal variate corresponding to a probability tail area of \( a/2 \) (with \( a = 0.05, z_{a/2k} = 2.394 \)), \( k \) is the number of categories, and \( n \) is equal to total use.

Using the ruler function in GIS, I measured the maximum linear distance moved by each frog from the breeding pool. I used linear regression to model the relationship between maximum distance moved and number of days tracked (Figure 13). Because there was a positive (R square = 0.087 for females; R square = 0.681 for males) and significant (\( p = 0.002 \) for males) linear relationship between distance and number of days tracked, I weighted the maximum dispersal distance by number of days tracked for all further analyses.

Data was tested for normality prior to analysis; no transformation was necessary. I used analysis of variance (ANOVA) to test for differences between buffer width (treatment), year, and sex on the maximum dispersal distance from the breeding pool by adult wood frogs, and used a Tukey post-hoc multiple comparison test to determine
pairwise differences between treatments at an experiment-wide error rate of $p < 0.05$. All analyses were conducted using SPSS (Windows, Release 14.0.1. 2005. Chicago: SPSS Inc.).

**Results**

Due to body mass restrictions, there was an unequal sample size of radio-tracked male (11) and female (22) wood frogs. I tracked 10 frogs from reference sites (7 females; 3 males), 12 from 100 m buffer sites (6 females; 6 males), and 11 from 30 m buffer sites (9 females; 2 males). Ten of the 23 radio-tracked adults dispersed through clearcuts into the surrounding forest; seven from the 30 m buffer and three from the 100 m buffer sites. Only one of the ten to disperse that far was a male (from a 100 m buffer site). Table 10 summarizes the proportion of locations in each habitat type for the 10 frogs which migrated through the clearcut. Both treatments had the lowest mean proportion of locations recorded in the clearcut habitat (Table 10). Figure 14 illustrates the number of frogs found in each habitat type at their last recorded location. Twenty of 23 frogs from the two buffer treatments exhibited significant habitat utilization preference, and the majority ($N = 11$) avoided (i.e., did not settle in) clearcuts (Table 11).

The mean number of days tracked was 41 (range 15 – 112). Six of 33 frogs tracked longer than 10 days moved no further than 12 m from the breeding pool (Table 12). Four emigrated from the pool and then returned several days later. The mean maximum distance moved was 121 m (range 0 – 350 m) for males and females combined. Female wood frogs moved on average 92 m farther than males (Table 13; Figure 15). This pattern was seen in all three treatments, but was most apparent at the 30
m buffer sites, where all males remained within the pool (N = 2), and females moved on average 200 m from the pool.

Wood frogs from the 100 m buffer sites moved significantly farther in 2004 than those in 2005 (Table 14; Figure 16). There were no differences in distance moved between years for frogs tracked at the 30 m buffer and reference sites. Adult wood frog dispersal distance responses in each treatment for the two years, and again in both sexes for the two year study period were variable, resulting in significant year by treatment and year by sex interactions. The lack of dispersal for males from the 30 m buffer sites resulted in a significant sex by treatment interaction. Frogs in the 30 m buffer sites moved farther on average than those in the 100 m buffer sites (Tukey post-hoc p < 0.001), which moved farther than those in the reference sites (Tukey post-hoc p < 0.001).

Discussion

The results of this study demonstrate that 100 m wide clearcuts are generally inhospitable, yet permeable habitat to adult wood frogs. Surface temperatures within the experimental clearcut were significantly higher than both the buffer and forested reference sites (Babbitt and Freidenfelds unpublished data). Because low soil moisture content, high ambient temperature, and wind cause dehydration in amphibians (Dupuis et al. 1995), even-aged forest management results in unsuitable amphibian habitat, and has the potential to reduce amphibian survival due to increased rates of desiccation (Rothermel and Luhring 2005). Frogs from both buffer treatments spent the least amount of time (measured as number of fixes) in the clearcut habitat. This is most likely due to the more extreme environmental conditions found there compared to within the buffer and surrounding forest, suggesting that adult wood frogs successfully avoid areas of
unsuitable habitat. DeMaynadier and Hunter (1998, 1999) report similar findings for juvenile and adult wood frog abundance and dispersal at clearcut-mature forest edges in Maine.

Adult wood frogs are extremely faithful to their breeding pools (but see Petranka et al. 2004). Homan et al. (2004) propose that this site fidelity might inhibit frogs from switching from an upland area with reduced suitable habitat to one with more suitable habitat. Although most frogs did not settle in clearcut habitat, nearly half of the total number of animals radio-tracked (at treatment sites) readily migrated through clearcuts (which to adults, prior to cutting, may have encompassed portions of their home range) to reach intact forest. Most frogs did not spend more than 6 days within clearcuts. Wood frog movement through clearcuts was typically over short time periods (2-4 days). When in clearcuts, frogs used moist areas (e.g., pools/puddles, water-filled tip-up mounds). Thus, although unsuitable long-term habitat, recent clearcuts appear to be highly permeable for adult wood frogs. However, the size at which an open area (e.g., clearcut) becomes a barrier to adult wood frog dispersal remains unknown, but appears to be more than 100 m.

Buffer width treatment had a significant effect on adult wood frog dispersal. Wood frogs at the reference sites moved on average 92 m from the breeding pool, whereas frogs at the 100 m and 30 m buffer sites dispersed significantly farther (127 m and 187 m, respectively). For the 30 m buffer treatment sites, 92 m from the pool represents area within the clearcut. Given that clearcuts are unsuitable habitat, wood frogs at the buffer treatment sites could either remain within the buffer zone, or move beyond the clearcut to the surrounding intact forest. A greater proportion of frogs at the
100 m buffer sites remained within the buffer compared to crossing the clearcut, whereas the opposite occurred at the 30 m buffer sites (Figure 14). This suggests that because smaller buffer zones provide less upland, vernal pool-breeding amphibians are forced to migrate farther in search of more suitable habitat.

Dispersal distances measured at the reference sites are assumed to be average migration distances for the species in a forested environment, given no habitat disturbance. Using distance data from the reference sites, I determined that a buffer zone encompassing the majority [95% confidence limits = mean ± 4.67 (t-distribution; \( \alpha = 0.05, df = 9 \) \times standard deviation/\( \sqrt{n} \)] of the wood frog population would have to include the terrestrial habitat 130 m from pool edge (Semlitsch 1998). According to this calculation, buffer zones 100 m and 30 m wide protect approximately 73% and 22% of the population, respectively. Therefore, while 100 m of intact forest surrounding vernal pools may protect the majority of adult wood frogs in a breeding population, a forest buffer width of 30 m is inadequate to provide suitable spring/summer upland foraging habitat. This is particularly true for females.

In all three treatments, female wood frogs dispersed farther on average from the breeding pool than males. Regosin et al. (2003; 2005) determined that male wood frogs overwinter closer to the vernal pool than females. These findings suggest that female wood frogs utilize different habitat during the non-breeding season than males. The significant difference between mean maximum distance moved between males and females in the current study may have critical implications for forest management. Habitat loss that disproportionately impacts females would increase the risk of local
extinction. This is particularly true for small populations with high variability in recruitment between years, which is common for wood frogs (Regosin et al. 2003).

Wood frogs are strongly influenced by both the amount of forest adjacent to the breeding pool and the percent forest cover. In New Hampshire, Mattfeldt (2004) found that the number of wood frog egg masses was positively related to the area of continuous forest within 300 m of the breeding vernal pool. Homan et al. (2004) investigated whether wood frogs exhibit thresholds in their probability of occupancy as surrounding forest habitat is lost. Thresholds occurred only when forest cover was measured within 300 m of the pond edge. In most cases where significant thresholds were found, they fell between 10% and 30% cover. Their analyses suggest that wood frogs are more sensitive to habitat loss near the pond than are spotted salamanders. Porej et al. (2004) examined the association between the amount of forest within a “core zone” (defined as terrestrial habitats used by the local breeding populations that are biologically necessary for the maintenance of amphibian diversity) and the presence of pond-breeding wood frogs in natural wetlands within agricultural landscapes of Ohio. The probability of presence was positively associated with the amount of forest within the core zone and the amount of forest within the zone extending from 200 to 1000 m from the site. Average percent forest cover was higher in sites where wood frogs were present than sites where they were not recorded.

Hermann et al. (2005) found that wood frogs did not occur or were at extremely low abundances in wetlands surrounded by less than 60% cover, despite the fact that wood frog abundance was not significantly influenced by forest cover. Guerry and Hunter (2002) observed that wood frogs were positively associated with forest area, and
as the area of forest in the upland increased and when a pond was adjacent to the forest, there tended to be more forest-associated and aquatic species in the pond. These studies highlight the importance of maintaining an area of closed-canopy forest beyond disturbed habitat (e.g., clearcuts) in order to allow suitable refuge for adult and metamorph amphibians. This is especially vital to preserve juvenile dispersal between vernal pools.

Madison (1997) found the net distance from the nearest pond edge to the overwintering site for eight radio-tracked spotted salamanders (*Ambystoma maculatum*) to be 118 m (range = 15 – 210 m). Mean distance moved from release point to last location for 16 radio-tracked spotted salamanders and blue-spotted salamanders (*A. jeffersonianum*) in Vermont was 112 m (range = 11 – 405 m), with no difference between the species (Faccio 2003). Semlitsch (1998) reviewed ambystomatid movement literature and concluded that a buffer zone of 164 m would encompass the majority of a population. Given similar life-history requirements between wood frogs and several *Ambystoma* species, it is not surprising that adequate buffer zone widths would be comparable. By implementing forest buffers, it may be possible to manage for vernal pool-breeding amphibians as a group, rather than focusing on each species individually.

Forest disturbance (e.g., clearcutting) results in the formation of unsuitable amphibian habitat patches. Fortunately, forest regeneration begins shortly after timber harvesting, and can add significant new plant growth within a few growing seasons (e.g., two to three years). The amount of time needed before amphibians utilize re-grown areas of timber management (i.e., unsuitable habitat becomes suitable) remains unknown.

Wetland delineations typically include little or no upland area. Therefore, anthropogenic modifications of habitat beyond the delineated wetland “edge” have been
viewed as permissible, possibly resulting in the destruction of critical habitat surrounding some wetlands (Gibbons 2003). Forest buffers that only protect a small percentage of the amphibian population can have substantial negative impacts on population dynamics and could result in local extinctions. Results from the current study demonstrate the importance of maintaining areas of forest immediately adjacent to the vernal pool edge. Additionally, larger buffers provide more upland habitat and protect a greater proportion of local wood frog populations. Finally, a portion of undisturbed, closed-canopy habitat should be maintained around the disturbed, unsuitable habitat in order to preserve viable pool-breeding amphibian populations.
Figure 13. Relationship between maximum distance moved from breeding vernal pool and number of days radio-tracked for adult wood frogs at 11 vernal pools in Maine.
Figure 14. Number of wood frogs found in each of three habitat types at their last recorded location (i.e., farthest each frog moved from vernal pool) from two buffer width treatments at 11 vernal pools in Maine.
Figure 15. Mean (± 2 SE) maximum distance moved from breeding vernal pools by adult wood frogs (N = 33) from three buffer width treatments in Maine. Data is combined for 2004 and 2005, and weighted by number of days tracked.
Figure 16. Mean (± 2 SE) maximum distance moved from breeding vernal pools by adult wood frogs in 2004 and 2005 from three buffer width treatments in Maine. Data is combined for males and females, and weighted by number of days tracked.
Table 10. Mean proportion (%) of wood frog locations in three habitat types from three buffer width treatments at vernal pools in Maine. Data used was for frogs that successfully crossed clearcut habitat (N = 10).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Habitat</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
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<td>100 m</td>
<td>Buffer</td>
<td>43 ± 32</td>
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</tr>
<tr>
<td></td>
<td>Clearcut</td>
<td>5 ± 8</td>
<td>0 - 14</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>52 ± 26</td>
<td>22 - 71</td>
</tr>
<tr>
<td>30 m</td>
<td>Buffer</td>
<td>18 ± 15</td>
<td>0 - 42</td>
</tr>
<tr>
<td></td>
<td>Clearcut</td>
<td>11 ± 14</td>
<td>0 - 33</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>71 ± 21</td>
<td>47 - 100</td>
</tr>
</tbody>
</table>

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Table 11. Conclusion on preference and avoidance of clearcut habitat for 23 radio-tracked wood frogs from two buffer width treatments in central Maine. A value of 'None' refers to data lacking to reject the null hypothesis.

<table>
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</tr>
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<td>AA</td>
<td>124.1505</td>
<td>2</td>
<td>&lt; 0.001</td>
<td>Avoid</td>
</tr>
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<td>113.2360</td>
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<td>&lt; 0.001</td>
<td>Prefer</td>
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<td>J</td>
<td>0.7669</td>
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Table 12. Inventory, fate, and movement data of 38 wood frogs radio-tracked from three buffer width treatments at vernal pools in Maine (L – lost animal; LB – animal lost belt; M – mortality; R – removed belt; RS – removed belt due to sores; T – transmitter battery died).

<table>
<thead>
<tr>
<th>Year</th>
<th>Pool</th>
<th>Treatment</th>
<th>Sex</th>
<th>Initial mass (g)</th>
<th>Maximum distance (m)</th>
<th>Days tracked</th>
<th>Fate</th>
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<tbody>
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<td>74</td>
<td>RS</td>
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<td>30 m</td>
<td>F</td>
<td>NA</td>
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<td>3</td>
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<tr>
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<td>25</td>
<td>T</td>
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</table>
Table 13. Maximum distance moved, in meters, (weighted by number of days tracked) for adult wood frogs at three buffer width treatments at vernal pools in Maine.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sex</th>
<th>N</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
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<td>7</td>
<td>99.2 ± 57.4</td>
<td>0 - 185.2</td>
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<td></td>
<td>Male</td>
<td>3</td>
<td>78 ± 57.3</td>
<td>0 - 126.6</td>
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<tr>
<td>100 m Buffer</td>
<td>Female</td>
<td>6</td>
<td>143.6 ± 97.2</td>
<td>10.7 - 297.7</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>6</td>
<td>118.3 ± 86</td>
<td>5.5 - 215.1</td>
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<tr>
<td>30 m Buffer</td>
<td>Female</td>
<td>9</td>
<td>215.4 ± 93.2</td>
<td>35.4 - 349.6</td>
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<tr>
<td></td>
<td>Male</td>
<td>2</td>
<td>0 ± 0</td>
<td>0 - 0</td>
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Table 14. Results of the ANOVA of the effects of buffer width, year, sex, and their interaction on maximum wood frog distance (weighted by number of days tracked) moved from the breeding vernal pool (N = 33).

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<td>Error</td>
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<td>5476.954</td>
<td></td>
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</tr>
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</table>
LITERATURE CITED


Stone, J.S. 1992. Vernal pools in Massachusetts: aerial photographic identification, biological and physiographic characteristics, and state certification criteria. Master’s Thesis. University of Massachusetts, Amherst, MA, USA.


APPENDIX

University of New Hampshire Institutional Animal Care and Use Committee (IACUC)
Approval for Use of Vertebrate Animals in Research
June 1, 2004

Babbitt, Kimberly J
Natural Resources
James Hall
Durham, NH 03824

IACUC #: 020601
Approval Date: 06/26/2002
Review Level: C

Project: Experimental testing of buffer requirements for amphibians inhabiting vernal pools in a forested landscape

The Institutional Animal Care and Use Committee (IACUC) reviewed and approved the protocol submitted for this study under Category C on Page 4 of the Application for Review of Vertebrate Animal Use in Research or Instruction - the research potentially involves minor short-term pain, discomfort or distress which will be treated with appropriate anesthetics/analgesics or other assessments.

Approval is granted for a period of three years from the approval date above. Continued approval throughout the three year period is contingent upon completion of annual reports on the use of animals. At the end of the three year approval period you may submit a new application and request for extension to continue this study. Requests for extension must be filed prior to the expiration of the original approval.

Please Note:
1. All cage, pen, or other animal identification records must include your IACUC # listed above.
2. Use of animals in research and instruction is approved contingent upon participation in the UNH Occupational Health Program for persons handling animals. Participation is mandatory for all principal investigators and their affiliated personnel, employees of the University and students alike. A Medical History Questionnaire accompanies this approval; please copy and distribute to all listed project staff who have not completed this form already. Completed questionnaires should be sent to Dr. Gladi Porsche, UNH Health Services.

If you have any questions, please contact either Van Gould at 862-4629 or Julie Simpson at 862-2003.

For the IACUC,

Roger E. Wells, D.V.M.
Vice Chair

cc: File
June 30, 2005

Babbitt, Kimberly J
Natural Resources, Nesmith 206
Durham, NH 03824

IACUC #: 050604
Approval Date: 06/29/2005
Review Level: C
Project: Experimental Testing of Buffer Requirements for Amphibians Inhabiting Vernal Pools in a Forested Landscape

The Institutional Animal Care and Use Committee (IACUC) reviewed and approved the protocol submitted for this study under Category C on Page 4 of the Application for Review of Vertebrate Animal Use in Research or Instruction - the research potentially involves minor short-term pain, discomfort or distress which will be treated with appropriate anesthetics/analgesics or other assessments. The IACUC made the following comments on this protocol:

1. The Committee suggested that the investigator might consider using surgical glue/tissue cement instead of sutures.
2. In the future, the investigator should include references for any citations included in the protocol.

Approval is granted for a period of three years from the approval date above. Continued approval throughout the three year period is contingent upon completion of annual reports on the use of animals. At the end of the three year approval period you may submit a new application and request for extension to continue this project. Requests for extension must be filed prior to the expiration of the original approval.

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If you have any questions, please contact either Van Gould at 862-4629 or Julie Simpson at 862-2003.

For the IACUC,

Roger E. Wells, D.V.M.
Vice Chair

Research Conduct and Compliance Services, Office of Sponsored Research, Service Building, 51 College Road, Durham, NH 03824-3585 * Fax: 603-862-3564

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