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CONSERVING WETLANDS FOR HUMANS AND AMPHIBIANS: A MULTIDISCIPLINARY APPROACH TO UNDERSTANDING THE SOCIAL AND ECOLOGICAL EFFECTIVENESS OF NEW ENGLAND'S WETLAND POLICIES

BY

JESSICA S. VEYSEY POWELL

BA, Dartmouth College, 2000

MS, University of New Hampshire, 2006

DISSERTATION

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy

in

Natural Resources and Environmental Studies

December, 2014

This dissertation has been examined and approved in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Natural Resources and Environmental Studies by:

Dissertation Director, Kimberly J. Babbitt,
Professor of Wildlife and Conservation Biology

Mark J. Ducey,
Professor of Natural Resources and the Environment

Charles A. French,
Extension Program Team Leader for Community and Economic Development

David M. Konisky,
Associate Professor of Public Policy

Thomas D. Lee,
Associate Professor of Natural Resources and the Environment

Thomas G. Safford,
Associate Professor of Sociology

On 20 November 2014

Original approval signatures are on file with the University of New Hampshire Graduate School.

DEDICATION

To my grandmothers, whose life circumstances and culture kept them from pursuing higher education.

And to my nieces and nephew. Hopefully born at the right time. May your world be full of salamanders and frogs, should you choose to study them.

ACKNOWLEDGMENTS

First, I would like to thank Dr. Kim Babbitt who served as both my doctoral and master's advisor. She has been unfailing in her support, finding creative ways to keep me funded and encouraging me to pursue social-science research, though neither she nor I knew much social science at the start of my doctorate. I learned much from her, especially about scientific writing, critical thinking, and asserting power in the academic world. This dissertation and my growth as a scientist are a direct result of her confidence in me. I would also like to thank my committee members, who each provided key advice at different times. Dr. Mark Ducey was ever patient while answering my many statistical questions and helped me keep perspective about the rapidly evolving field of statistics. Dr. Tom Safford and Dr. David Konisky provided critical counsel on the design, analysis, and writing of my case-study project. Quite possibly, without their sage and timely advice, I might still be floundering, nowhere near ready to defend this dissertation. Dr. Tom Lee and Dr. Charlie French have been consistently encouraging and, in particular, asked insightful questions about study design and relevance during the early stages of this work.

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ABSTRACT

CONSERVING WETLANDS FOR HUMANS AND AMPHIBIANS:

A MULTIDISCIPLINARY APPROACH TO UNDERSTANDING THE SOCIAL AND ECOLOGICAL EFFECTIVENESS OF NEW ENGLAND'S WETLAND POLICIES

by

Jessica S. Veysey Powell

University of New Hampshire, December 2014

Freshwater wetland ecosystems are a valuable resource, but current policies fail to prevent their continuing destruction. Policy-makers increasingly use decentralized wetland-buffer programs to address such policy failings, but scant research has evaluated whether these programs are both ecologically and socially effective. In the following dissertation, I address this gap using two complementary projects.

For the first project, I assessed whether forested buffers are an effective tool for maintaining viable populations of pool-breeding amphibians. Such species spend their early life stages in vernal pools, which are small, highly productive wetlands, but use the surrounding forest during juvenile and adult life-stages. Though buffers are often prescribed for managing these species, buffer utility has never been experimentally tested. For this project, I used data from a landscape-scale experiment to determine whether wider buffers more efficiently mitigate the effects of forest disturbance on breeding-adult populations of spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Lithobates sylvaticus*), two amphibian species that

breed in vernal pools throughout eastern North America. This experiment was conducted at 11 natural vernal pools in an industrial forest in east-central Maine. Each pool was randomly assigned to one of three treatments (i.e., reference, 100m buffer, 30m buffer). Clearcutting was used to create experimental buffers. All spotted salamanders and wood frogs breeding in these pools over the six study years were captured, counted, sexed, and sized. I used generalized linear mixed effects regression to assess the relative impacts of buffer treatment and pool hydroperiod on breeding-adult population size, composition, and biomass.

I found that clearcutting resulted in negative impacts to breeding-adult populations, but that buffer width was an important mitigating factor in the extent of these impacts. Specifically, narrower (30m) buffers were associated with altered salamander sex ratios, and for both species, diminished body size, condition, and biomass and fewer recaptures. In the wider (100m) buffer treatment, I detected negative effects on salamander sex ratios and abundance, and the biomass of both species. However, the 100m-treatment effects were largely limited to pools that were also stressed hydrologically. The observed negative effects potentially signal reduced local-population resiliency, which could scale up to regional-population and community-level effects, especially if other stressors were introduced to the system. Several, though not all, of the negative effects started to recover as the cuts regenerated, however, suggesting a temporally-finite window of reduced resiliency. Overall, these results provide the first experimental evidence showing that buffers that are only 30m wide may be insufficient for maintaining resilient local populations of pool-breeding amphibians.

Whereas for my first project, I focused on the value of buffers for wildlife in a forestry setting, for my second project I examined decentralized wetland-buffer programs in exurban towns. In New England, many municipalities have local wetland-permit policies and land-use

decision-making is largely devolved to municipal boards. While some evidence suggests that local wetland programs minimize development in and near wetlands, it does not explain why towns with similar programs sometimes have very different wetland-protection outcomes, if stakeholders support local wetland programs, or whether social outcomes feedback to influence ecological outcomes. I used case-study analysis to determine the specific factors driving, and the potential for interactions between, the ecological and social effectiveness (EE and SE) of municipal wetland-permitting programs in four southern New England towns. To assess EE, I used regression techniques to quantify spatial impacts to wetland ecosystems on 50 construction site plans per town. To determine SE, I conducted and qualitatively coded 45 key-informant interviews.

I found that EE and SE both varied considerably across the four towns, despite broadly similar wetland-policies and demographic profiles. EE was largely a function of SE and policy details. In turn, SE was driven by multiple interacting factors, with no single prescription fitting all towns. Nevertheless, I did identify eight principal SE drivers that strongly shaped, facilitated, or were used to express SE. These included: having a conservation-based town identity, being able to communicate about wetland permitting, property-rights ethics, town organizational structure, education, wealth, public participation, and local politics. The case-studies show that local buffer programs can effectively protect wetlands if the necessary social factors are aligned. When social factors do not align, however, stakeholder malcontent can weaken EE and destabilize social relations. To help safeguard against such negative fallout, I provide a set of recommendations intended to enhance the SE and EE of local wetland programs.

My research results, when combined and synthesized with previous research, ultimately indicate that buffers are critical for wetland-ecosystem integrity, but that wider buffers are

needed than those currently used in developed landscapes. Equally important, however, the synthesized evidence suggests that buffers alone are an insufficient tool for protecting wetland ecosystems. Rather an effective wetland-management strategy must nurture the social dynamics associated with wetland-program implementation and integrate buffer policies with landscape-scale conservation planning.

INTRODUCTION

Over 8.7 million species inhabit Earth (Mora et al. 2011). Humans are just one of these species, but with a current population of 7.3 billion and projected growth to 9.6 billion by 2050 (UN 2013; USCB 2014), we exert tremendous impact on global ecosystems. We use land for growing food, building homes and infrastructure, storing waste, harvesting and mining fuel and manufacturing materials, and recreating. In the process, we release harmful chemicals into the environment, move species between biomes, and fragment open spaces. The cumulative impact of human growth is destabilization of our planet's regulatory systems and extinction of other species, many of which contribute to the conditions which facilitate human life both at present and throughout our evolution. Currently, human-induced extinction rates are estimated to be 1000 times greater than background extinction levels (Pimm et al. 2014). If we hope to staunch this tide of destruction, it is imperative that we develop ways to manage ecosystems for the coexistence and benefit of both humans and other species.

In this dissertation, I explore potential management strategies for freshwater wetlands, forests, and amphibians: two ecosystems and an animal group that are experiencing strain due to human use and encroachment, but which provide humans numerous beneficial services. Freshwater wetlands cover < 3% of the earth's surface (Zedler and Kercher 2005), but supply habitat for at least 100,000 different animal species (Ramsar 2001). Wetlands help control floods, sequester carbon and pollutants, and provide humans with fresh drinking water, food, fiber, and transportation and recreation pathways (Whiting and Chanton 2001; Ramsar 2013). Forests are far more widespread, covering about 28% of the earth's surface, but provide many similar ecosystem services, including carbon sequestration; water-cycle regulation; food and fiber

provision; erosion control; recreation opportunities; and timber for biofuel, building supplies, and paper production (Shvidenko et al. 2005). Stress on both ecosystems is rising as human population and per capita consumption drive increasing forest and wetland conversion to meet agriculture and development demands and intensified harvesting of forest and wetland products (Ramsar 2001; Rodriguez et al. 2005; Shvidenko et al. 2005). Wetlands are also frequently altered during land-conversion activities because they often constitute a transition zone between open water and terrestrial ecosystems and can thus be difficult to recognize (Stine 2008). As for amphibians, there are over 7300 species on Earth, spread across six continents (AmphibiaWeb 2014). Amphibians also provide diverse ecosystem services, including food, drugs, pest control, and modulation of nutrient cycles and trophic interactions (Crump 2010; Hocking and Babbitt 2014). Many amphibian species utilize, and are exposed to habitat disturbance and potential pollutants in, both wetlands and forest. Because of their complex habitat needs and semi-permeable skin, amphibians can serve as sentinel species that indicate and forewarn ecosystem disruptions (e.g., Blaustein 1994; Welsh and Ollivier 1998; Townsend and Driscoll 2013). Globally, amphibians are experiencing rapid declines, with 36 documented species extinctions, signaling on-going ecosystem perturbations (Crump 2010; Pimm et al. 2014).

My research was based in New England, which is an excellent place to study wetlands, forests, and amphibians, because all three are still relatively abundant in the region, but are increasingly subject to constraints from development, agriculture, and energy production (Jeon et al. 2012; Colocousis 2013; Donahue et al. 2014). Moreover, forestry remains a critical component of the economy in the three northern New England states (NEFA 2013), while wetland regulations are hotly contested in much of southern New England (e.g., Shelby 2008; Calhoun et al. 2014). Further, for over 15 years, policy-makers and users from this region have

expressed frustration at how little data is available to inform policy decisions about where and how to allow development and forestry in proximity to wetlands and the habitat needs of wetland-dependent wildlife (Veysey Powell unpub. data). By examining alternative management strategies in advance of major declines, I aimed to both provide baseline data on ecosystem function and species dynamics in a relatively naturalistic setting and produce policy recommendations that will help to avert future declines.

My dissertation research is comprised of two complementary projects. In the first project, I used data from a landscape-scale experiment to assess whether vegetated buffers (i.e., relatively undisturbed strips of land adjacent to wetlands) are an effective tool for maintaining viable populations of wetland-dependent amphibians, and if so, how wide those buffers should be. Buffers are used extensively as a wetland-management tool in forestry and construction, but their utility for protecting amphibians that breed in ephemeral wetlands has never been experimentally evaluated. This project was conducted in an industrial forest in east-central Maine and used clearcutting to disturb forested amphibian habitat near wetlands and create variably sized buffers. I analyzed whether wider buffers were more efficient at mitigating cutting effects on amphibian communities. I specifically looked at the interactive effects of cutting and buffer width on breeding-adult demography for two relatively common amphibian species: the spotted salamander (*Ambystoma maculatum*) and wood frog (*Lithobates sylvaticus*). In chapter 1, I describe how cutting and buffer width influenced breeding-adult abundance, sex ratios, and recapture proportions. In chapter 2, I describe the experimental effects on breeding-adult body condition and biomass. The results from this project have and will continue to inform forestry best management policies in mixed temperate forests. I also used the results to design and interpret my second project.

For the second project, I used case-study analysis to assess the geographic and social implications of municipal wetland-policy decisions. While forestry planning is largely driven by individual landowners, much of the responsibility for planning development in proximity to wetlands is decentralized to municipal boards. Decentralized governance can enhance social satisfaction with decision processes and is thought to improve ecological outcomes, compared to state or federal governance (Lubell et al. 2005). Very little research has investigated whether decentralized governance actually improves environmental outcomes, however (Leach and Pelkey 2001; Meyer and Konisky 2007b). In this project, I evaluated whether devolving wetland decision-power to the local level is ecologically and socially sound and identified the specific factors fueling wetland loss and wetland-policy effectiveness in exurban New England. I selected four exurban towns, two from north-central Massachusetts and two from south-central New Hampshire to use as case studies. All four towns had a local wetland-permit policy which relied on vegetated buffers to protect wetlands. I compared the ecological effectiveness of each town's wetland program by quantifying spatial impacts to wetland ecosystems on permitted construction site plans. In defining ecological effectiveness, I relied heavily on the results of my first project and assumed that wider buffers led to better overall ecological outcomes. To determine social effectiveness (i.e., the extent to which stakeholders accept and support wetland programs) and assess how it relates to ecological effectiveness, I conducted and qualitatively analyzed 45 key-informant interviews. In chapter 3, I present the results of my cross-case analysis.

Finally, in chapter 4, I take a holistic look at my dissertation research. I evaluate the overall significance and limitations of the work, explore potential extensions of the research, and then return to the question of whether vegetated buffers are an effective tool for protecting wetland communities. To answer this question, I synthesize results from the experimental and

case-study projects, and contextualize these results within the broader literature on amphibian, forest, and wetland conservation.

In the end, it is important to me that my research be highly applied and contribute to policy decisions that meet the needs of both humans and the ecological communities we inhabit. To increase the practical utility of my research, I include policy recommendations within each chapter. These recommendations are intended to guide the use of wetland buffers, enhance the effectiveness of local wetland programs, and maximize public investments in wetland management.

CHAPTER 1

AN EXPERIMENTAL TEST OF BUFFER UTILITY AS A TECHNIQUE FOR MANAGING POOL-BREEDING AMPHIBIANS

Abstract

Vegetated buffers are used extensively to manage wetland-dependent wildlife. Despite widespread application, buffer utility has not been experimentally validated for most wetland-dependent species. To address this gap, we conducted a six-year, landscape-scale experiment, testing how buffers of different widths affect the demographic structure of two amphibian species at 11 ephemeral pools in a working forest of the northeastern U.S[1]. We randomly assigned each pool to one of three treatments (i.e., reference, 100m buffer, 30m buffer) and used clearcutting to create experimental buffers. We captured all spotted salamanders and wood frogs breeding in each pool and examined the relative impacts of buffer treatment and hydroperiod on breeding population size and composition. Clearcutting was associated with negative impacts to breeding-adult populations. The negative effects of cutting increased as forest-buffer width decreased and were strongest for salamanders and when other stressors were present (e.g., when water availability was low). This study demonstrates that buffers help mitigate the impacts of terrestrial habitat disturbance on wetland-dependent amphibians, but that buffer width and pool hydroperiod play a critical role in that process. We provide the first experimental evidence showing that buffers that are only 30m wide may be insufficient for maintaining resilient local populations of pool-breeding amphibians.

[1] The experimental results presented in my dissertation are but one piece of a much larger project to which many individuals contributed. In this chapter, I use plural pronouns to indicate work which was accomplished through the efforts of multiple people, myself included.

Introduction

Vegetated buffers have been used extensively for several decades to protect wetlands across a variety of landscapes. Buffers were originally designed to filter water pollutants and maintain water quality (Lee et al. 2004; Lovell and Sullivan 2006). In this context, 15-30 m-wide buffers are often sufficient to remove nitrogen, phosphorus, and sediment from runoff before it enters wetlands (Castelle et al. 1994; Broadmeadow 2004; Mayer et al. 2007). Over the last two decades, as interest in biodiversity and ecosystem function proliferated, policy-makers increasingly relied on buffers to conserve wetland-dependent wildlife (Castelle et al. 1994; Lee et al. 2004; Lovell and Sullivan 2006). Lacking political support and wildlife-specific data, they assumed 15-30 m-wide water quality buffers would benefit wildlife (Castelle et al. 1994; Chase et al. 1997; Goates et al. 2007). Such narrow buffers may be insufficient for maintaining viable populations of many wetland-dependent species, however, because these species regularly use habitat that extends farther from wetlands than typical water-quality buffers (Harper et al. 2008; Marczak et al. 2010; Stoffyn-Egli and Willison 2011).

This may be especially true for amphibians that breed in ephemeral pools. The semi-annual drying cycle of ephemeral pools prevents establishment of predatory fish populations, making these pools extremely productive amphibian habitat. During the non-breeding season, these amphibians range across the surrounding landscape, using additional wetlands and uplands for foraging, shelter, estivation, and hibernation (Semlitsch 1998; Faccio 2003; Baldwin et al. 2006a), sometimes migrating hundreds of meters into terrestrial habitat (Trenham and Shaffer 2005; Veysey et al. 2009; Freidenfelds et al. 2011). Land-uses that alter the habitat quality of breeding pools and/or adjacent uplands can potentially have strong negative effects on local and regional population persistence.

Historically, ephemeral pools received little policy protection in the United States (U.S.). Federal protection ostensibly falls under the Clean Water Act, but is tenuous given recent Supreme Court decisions and has never officially included a buffer (Adler et al. 2007). Some states, counties, and municipalities supplement federal law by implementing more stringent local policies. However, only 15 of 50 states have substantial wetland programs, most of which do not include protection, let alone buffers, for ephemeral pools (Thomas 2008). Four of six New England states provide a regulatory buffer for ephemeral pools (mean ± SD: 23 ± 29 m; range: 0 – 76 m), but these buffers typically only apply to a subset of pools and project types (310 CMR 10a [2009]; 06-096 CMR Ch. 335 [2009]; Code Vt. R. 12 004 056 [2010]; Conn. Regs §22a-39 [1988]; (RIDEM 2010) and are substantially narrower than the 164-290-m buffers that scientists recommend, based on amphibian migration data (e.g., Semlitsch and Bodie 2003).

Previous observational and modeling studies conclude that regulatory buffers in the U.S. are inadequate for protecting populations of ephemeral-pool-breeding amphibians (Semlitsch and Bodie 2003; Gamble et al. 2006; Harper et al. 2008). In most of these studies, however, buffer effects were never explicitly tested, but rather estimated from species' migration distances in undisturbed habitat. Thus, very little is actually known about how the demographics and behavior of ephemeral-pool-breeding amphibians differ in unbuffered and buffered systems, and what optimal buffer widths are for different species. Overall, experimental confirmation of the need for wider buffers is severely lacking. Though some policy-makers express interest in expanding buffers to accommodate wildlife habitat needs (Peterson and Anderson 2009; Bauer et al. 2010a; Freeman et al. 2012), they hesitate to support policy changes without solid, experimental evidence demonstrating the utility of buffers for wildlife (Heinen and Mehta 2000; Schulte et al. 2006).

To address this need, we conducted a six-year, landscape-scale experiment and examined how buffers of different widths affect the population viability of two amphibian species at ephemeral pools in an industrial forest of the northeastern U.S. We studied spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Lithobates sylvaticus*) because they use similar macrohabitat, but differ in microhabitat preferences and key demographic traits, and may thus require different conservation strategies. In particular, spotted salamanders utilize small-mammal burrows extensively as refugia (Madison 1997; Faccio 2003), can live up to 32 years in the wild (mean adult age in one northern population was 8.8 years; Flageole and Leclair 1992a; b), and usually breed multiple times in their lives (Savage and Zamudio 2005). By contrast, wood frogs seek refuge in other wetlands during the summer (Baldwin et al. 2006a), overwinter in leaf litter (Blanchard 1933; Baldwin et al. 2006a), have a maximum lifespan of 5-6 years (Redmer and Trauth 2005; Berven 2009), and typically breed only once after reaching sexual maturity (Berven 1990; 2009), but are more fecund than spotted salamanders (Harper et al. 2008). We hypothesized that: 1) for both species, breeding-population size and buffer width would be positively correlated; 2) negative demographic impacts to both species would recover with time, as disturbed forest around buffers regenerated; but 3) wood frogs, being more fecund, would recover faster than spotted salamanders.

Methods

Study Site

We conducted this research in an industrial forest, owned by International Paper/ Sustainable Forest Technologies, in east-central Maine, U.S. (45º0’52”N, 44º48”32”N;

68º28’11”W, 67º53’10”W). The forest is predominantly eastern hemlock (*Tsuga canadensis*) and northern hardwood *(Fagus grandifolia*, *Acer saccharum*, *Betula alleghaniensis*) at lower elevations, and balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) at higher elevations. Moderate hills, wetlands (including numerous ephemeral pools), and dirt logging roads are common. In 2002, we identified 300 ephemeral pools in this landscape and chose 40 of similar size (i.e., 0.1–0.3 ha) and adjacent forest (i.e., uncut within 1000 m) for in-depth inspection. In spring 2003, we surveyed egg masses at these 40 pools and identified 35 with breeding populations of both wood frogs and spotted salamanders and hydroperiods of at least five months post-ice out. We randomly chose 12 of the 35 pools for this study. In spring 2004, we learned that one of the 12 pools had a permanent inflow and removed that pool from the study.

Buffer Creation

We randomly assigned each of the remaining 11 pools to one of three treatments: reference (i.e., uncut; N=3), 100m buffer (N=4), or 30m buffer (N=4). From September 2003 to March 2004, the landowner used clearcutting to create experimental buffers at the 100m and 30m treatment pools. The cutting removed all merchantable trees ≥ 5 cm diameter at breast height and slash, though a small quantity of woody debris remained. After cutting, pools in the two buffer treatments had, respectively, a 100-m or 30-m-wide upland buffer encircling the pool and a 100-m-wide concentric clearcut around the buffer (Fig. 1.1). We selected buffer widths typical of those in existing laws, Best Management Practices, and the literature (e.g., M.G.L. c.131§ 40; Semlitsch 1998; Calhoun 2002).

Amphibian Sampling

During summer and fall 2003, we encircled each of the 11 pools with a drift fence/pit fall trap array (Willson and Gibbons 2010). We used plastic silt fencing that was 91 cm tall and buried 8-10 cm deep and positioned fences 5 m upgradient of each pool's high water mark to minimize flooding risk. We buried pairs of 5.7 liter aluminum cans on opposite sides of the drift fence at 10 m intervals (Willson and Gibbons 2010). To prevent amphibian desiccation, we placed a moistened sponge in the bottom of each trap.

From 2004 through 2009, we opened traps in the spring after ice-out and closed traps when a pool was dry for at least seven consecutive days or, in the fall, when amphibians were no longer active due to hard frosts. We uprooted sections of the fence during the winter to allow movement of non-focal species. We checked pitfall traps daily during periods of high amphibian activity (i.e., April-May and July-September) and every one to five days during periods of less amphibian activity (i.e., June and late fall). Due to poor road conditions, we could not access one 30m pool in 2009. However, our statistical technique is robust to missing data (Pinheiro and Bates 2000), allowing us to use the other five years of data from this pool.

We captured and counted all amphibians entering and exiting the pools and sexed all adult amphibians exiting pools. We assumed all non-gravid adult spotted salamanders and wood frogs leaving a pool had bred in that pool and marked each with a pool-specific toe-clip (Ferner 2010). From 2005 to 2009, we counted the number of recaptured individuals at each pool. After processing each animal, we released it on the opposite side of the fence from the point of capture. If an individual returned to a pool in the same year that it was toe-clipped, we only included its initial visit in our analyses.

Hydroperiod Sampling

We calculated hydroperiod for each pool in each year as the number of days a pool held water between ice-out (i.e., < 75% of the pool was covered in ice) and the day the pool dried completely. To facilitate statistical analyses, we assigned a hydroperiod end date of October 28th to pools that did not dry in a given year. We chose this end date because we still had evidence of persistent water in these pools on this date, but it was sufficiently late in the year that most amphibians at our study pools were inactive.

Statistical Analyses

To assess the relative impacts of forestry treatment and hydroperiod on the size and composition of spotted salamander and wood frog breeding populations, we developed generalized linear mixed effects regression models using the "glme" function in the correlatedData library of S-Plus 8.0 (Insightful Corporation, Seattle, WA, USA 2007) and the "glmer" function in the lme4 library (Bates et al. 2011) of R 2.13.0 (R Core Team 2011). We modeled both the sex ratio and proportion of recaptured adults for each species using mixed-effects logistic regression with a logit link. We defined sex ratio as: Number of breeding males / (Number of breeding males + Number of breeding females). We defined the proportion of recaptured adults as: Number of recaptured breeding adults / (Number of recaptured breeding adults + Number of new-captured breeding adults). We modeled total breeding adult abundance for each species with mixed-effects Poisson regression, using a log link.

We treated year and pool ID as crossed random effects (Pinheiro and Bates 2000) in all models. We modeled the variance-covariance structure for each regression to account for inter-year correlation at individual pools and heterogeneous variance across groups. We used

likelihood ratio tests to optimize each regression's variance-covariance structure. We accounted for intra-pool correlation in the salamander abundance model using a first-order auto-regressive process with year as the time variable. We did not need to define a correlation structure for any other model. We specified the variance structure for all models except the proportion-of-recaptured-salamander model. For salamander sex ratio, we assigned different variances to each study year. For salamander abundance, we allowed the variance to increase exponentially as a function of mean-pool hydroperiod (i.e., the mean hydroperiod for each pool across the six study years). For the proportion-of-recaptured-frogs model, we assigned different variances to each treatment. For frog sex ratio, we allowed the variance to increase, within each study year separately, as a power function of the model's fitted values. For frog abundance, we allowed the variance to increase, within each treatment separately, as a power function of the standard deviation of pool hydroperiod (as calculated for each pool across the six study years; sd.hydro). In their final forms, all models satisfied the assumptions of Poisson or logistic regression.

Our predictor variables were: buffer treatment, mean-pool hydroperiod, sd.hydro, an interaction between treatment and mean-pool hydroperiod, and a pair of numeric dummy variables representing an interaction between treatment and study year. We used the first dummy variable (dv.cut) to distinguish whether a pool was subjected to clearcutting or not. We used the second dummy variable (dv.30m) to indicate marginal impacts to the 30m treatment pools. We used ANOVAs to determine the overall significance of each fixed effect and t/z tests (for S-plus and R models, respectively) to test the significance of the different treatment levels (α = 0.05). We used treatment contrasts to compare the reference treatment to each respective cut treatment. We applied a sequential Bonferroni procedure to adjust α-levels during a post hoc comparison between the 100m and 30m treatments for the proportion-of-recaptured-frogs model.

Based on an apriori decision, when the hydroperiod interaction was not significant, we dropped this interaction from the model and refit the model for the remaining fixed effects. Ultimately, we only included the hydroperiod interaction in the salamander abundance model. We also dropped dv.30m from the proportion-of-recaptured-frogs model because dv.30m and treatment were confounded, with both predictors effectively canceling each other out. We retained treatment instead of dv.30m because a reduced model with treatment provided a better fit than one with dv.30m. However, the reduced dv.30m model suggested that the proportion of recaptured frogs in the 30m treatment decreased during the study.

Results

From 2004 to 2009, we captured 3624 breeding spotted salamanders, including 2811 (78%) new-captures and 812 (22%) recaptures, and 1518 (42%) females and 2099 (58%) males. Similarly, we caught 6521 breeding wood frogs, including 5478 (84%) new-captures, 1014 (16%) recaptures, 2427 (37%) females, and 4072 (63%) males. Breeding adult abundance, especially for wood frogs, was highly variable within and across pools and years (Table 1.1, Fig. 1.2). For example, at one reference pool, annual breeding wood frog abundance ranged from 70 to 568, with a mean of 214 frogs, while at a different reference pool, breeding wood frog abundance ranged from 54 to 161, with a mean of 95. Hydroperiod also varied widely in this forest-ephemeral pool ecosystem. One semi-permanent pool never completely dried during the six-year study. By contrast, mean hydroperiod at another pool was about four months, but varied by as much as 49 days.

Spotted Salamanders

Breeding-salamander sex ratio increased in both cut treatments during the study, though the rate was slightly greater in the 100m versus 30m treatment (Table 1.2; Fig. 1.3). For example, at 100m pools, we predicted approximately equal numbers of each sex in 2004, but 2.3 males per female in 2009. Similarly at 30m pools, we predicted approximately 1.3 males per female in 2004, but 2 males per female in 2009. At reference pools, by comparison, we predicted 1.1 males per female, on average. The male-biased sex ratios were driven by a decrease in the number of females, and to some extent, an increase in the number of males, at both cut treatments.

The proportion of recaptured salamanders was lower in the 30m versus reference treatment right after the cut, but increased with time, so that by 2008 (i.e., five years post-cut), recapture proportions at 30m pools were predicted to be only slightly less than those at reference pools (Fig. 1.4). For example, in the 30m treatment, the ratio of recaptured to new-captured adults was predicted to be 1:7 in 2005, but 1:3.3 in 2008. Comparatively and on average, we predicted approximately 1 recapture: 3 new-captures at the reference pools. These trends were largely driven by male and female new-capture abundance, which tended to be higher in the 30m treatment during the first three years of the study, but similar in the two treatments by the study's end. Few salamanders were recaptured in any treatment in 2009, however. In fact, we recaptured no females from the 30m treatment in 2009. (We could only trap at three of the four 30m pools in 2009, however).

At short hydroperiod pools, we found fewer breeding spotted salamanders in the 100m treatment than the reference treatment (Fig. 1.5). For instance, if pool mean hydroperiod were 45 days (the minimum mean hydroperiod observed), the number of breeding salamanders at a 100m pool was predicted to be only about 12% of the abundance at a reference pool. However,

abundance increased with mean hydroperiod at the 100m pools, such that for each additional day a pool held water, the number of breeding adults was predicted to increase by about 3%.

Wood Frogs

The proportion of recaptured adults in the 30m treatment was predicted to be, on average and for the duration of the study, 62% of that in the 100m treatment (though we found no difference in recapture proportion between the reference and either cut treatment; Fig. 1.6). This was largely because male and female recaptures were scarce in the 30m treatment. In fact, no females were recaptured at 30m pools in 2008. Buffer treatment was not a significant predictor of breeding wood frog abundance or sex ratio, but we did find more breeding wood frogs at pools with longer hydroperiods (Fig. 1.7). For each additional day a pool held water, abundance was predicted to increase by a factor of 0.7%.

Discussion

This is the first landscape-scale experiment to explicitly test whether vegetated buffers are an effective tool for managing ephemeral-pool-breeding amphibians and to compare the variable impacts of different buffer widths on amphibian demography. We found buffer width, time since cut, and pool hydroperiod were all important factors in determining breeding-adult response to clearcutting of terrestrial habitat around ephemeral pools. Contrary to our hypotheses, breeding-population size and buffer width were not positively correlated; only one of four negative demographic responses recovered during the six-year study; and wood frogs, where impacted, did not did recover faster than spotted salamanders. However, we did find that recaptured adults were least abundant in the narrow (30m) buffer treatment, salamander sex

ratios were skewed in both buffer treatments, and that the effects of buffer width on salamander abundance were mediated by pool hydroperiod. Our objective with this landscape-scale experiment was to describe population-level patterns of species response to buffered disturbance. Though we did not test for mechanisms driving these patterns, we explore potential mechanisms in the following discussion.

Spotted salamanders

Sex ratio

The sex ratio of breeding salamanders was significantly altered by buffer treatment. Whereas the sexes were present at references pools in near equal proportions, males were more than twice as abundant as females in both buffer treatments by the study's end. Though spotted salamander breeding populations are typically male-biased (Woodward 1982; Savage and Zamudio 2005; Homan et al. 2007), in our study, sharply biased ratios only occurred at pools where clearcuts disturbed non-breeding habitat. The decline in female abundance which principally propelled the male-biased sex ratios at the buffer treatments suggests that cutting reduced terrestrial habitat quality, leading females to delay maturity, breed less frequently, or experience increased mortality.

Clear cutting can negatively impact habitat quality in multiple ways. Desiccation (Rothermel and Luhring 2005; Tilghman et al. 2012) and predation (Enge and Marion 1986; Todd et al. 2008) can be higher, while prey (Addison and Barber 1997; Willett 2001; Riffell et al. 2011) and shelter (Enge and Marion 1986; deMaynadier and Hunter Jr. 1995) availability can be lower, in clearcut versus intact forest. Salamanders may spend less time foraging in cuts, limiting growth, reproduction, and survival (deMaynadier and Hunter Jr. 1995; Johnston and Frid 2002).

Clearcuts can also reduce habitat quality through edge effects (deMaynadier and Hunter 1998; Renken et al. 2004) or if salamanders preferentially occupy remnant forests, causing crowding and resource scarcity (Regosin et al. 2003a; Regosin et al. 2004; Patrick et al. 2008a). Though spotted salamanders can spend long periods in clearcuts (Veysey et al. 2009), they prefer forest (deMaynadier and Hunter 1998; Renken et al. 2004) and can evacuate cuts into adjacent forest (Semlitsch et al. 2009a), setting the stage for density-dependent fitness effects. Cuts may disproportionately impact females because females invest more in reproduction and thus have greater energetic needs (Finkler et al. 2003; Graeter et al. 2008; Finkler 2013). Alternatively, cuts may prompt females to switch breeding pools (Petranka et al. 2004). Females may be more likely to switch pools because they tend to migrate further and encounter alternative breeding sites more frequently than males (Patrick et al. 2008a).

Increasing a population's proportion of males can alter mating behavior, with potentially negative consequences for individual fitness and genetic diversity. Spotted salamanders converge on ephemeral pools to breed each spring (Husting 1965; Arnold 1976). Inter-male competition for females is intense and males physically pursue available females (Arnold 1976). Increasing the proportion of males can intensify inter-male competition, such that many males fail to mate or contribute their genes to the population (Arnold 1976; Tennessen and Zamudio 2003). Females exposed to male aggression may experience increased stress, which can translate to impaired immunity and body condition, thereby decreasing future fitness (Sztatecsny et al. 2006; Grayson et al. 2012). A shortage of females also constrains potential reproductive output and thus population growth (Verrell and Krenz 1998; Cotton and Wedekind 2009).

Recapture Proportion

The proportion of recaptured salamanders in the 30m treatment was reduced just after the cut, but returned nearly to reference levels by the study's end. An initial influx and subsequent decline of new-captures at 30m pools propelled this trend. New-captures were either immigrants or adults native to a study pool who previously refrained from breeding. The new-capture influx indicates that more non-breeders or, more likely immigrants, used 30m pools than reference pools, during the first few years post-cut. We suggest two explanations for this pattern. First, cutting may have increased mortality among established adults or caused them to emigrate to other pools, freeing habitat for immigrants. Second, cutting may have altered salamander orientation or habitat-selection cues, thereby increasing immigrant detection and/or selection of 30m pools (Miller 2001). For instance, it may have been easier for immigrants to detect wind-borne olfactory cues across the narrow buffer and clearcut of the 30m pools than across a similar distance of forest at the reference pools.

The subsequent drop in new-captures in the 30m treatment, combined with declining recapture numbers, means the initial influx of new-captures failed to transition to a stable population of resident breeding adults and that immigration to 30m pools decreased. Such patterns suggest habitat quality in and around 30m pools declined with time. Deteriorating habitat quality could lead to lower growth rates, delaying reproductive maturity (Berven 1990; Semlitsch et al. 2009b) and thus recapture rates among resident adults. Alternatively, reduced habitat quality could lead to lower survival (Rothermel and Semlitsch 2002; Rothermel and Luhring 2005; Harper et al. 2008) or cause individuals to switch breeding pools. Ultimately, the influx of new-captures did not convert to recaptures, indicating that the 30m treatment acted as a sink for numerous adult salamanders.

Abundance

Hydroperiod mediated the impact of buffer treatment on breeding-salamander abundance. Compared to reference pools, short-hydroperiod 100m pools had small breeding populations, while long-hydroperiod 100m pools had large populations. Short hydroperiods typically support smaller populations (Babbitt et al. 2003; Egan and Paton 2004; Baldwin et al. 2006b), because fewer metamorphs are produced (Shoop 1974; Semlitsch 1987b; Pechmann et al. 1989) and surviving metamorphs can be small and disease-prone (Gervasi and Foufopoulos 2008; Hector and Nakagawa 2012). In resource-rich terrestrial habitats (i.e., at reference pools), such stunted metamorphs may exhibit compensatory or 'catch-up' growth, minimizing impacts to population size (Morey and Reznick 2001; Mangel and Munch 2005; Hector and Nakagawa 2012); but this may not be possible in resource-poor terrestrial habitats.

The small populations at short hydroperiod, 100m pools provide further evidence that clearcutting created a resource-poor terrestrial habitat, whose negative impacts were not fully offset by the 100m buffer. As stated previously, clearcuts can be a harsh environment and cause edge effects and possibly overcrowding in adjacent buffers. These habitat changes could reduce breeding populations if: salamanders emigrate to other breeding pools, experience elevated mortality, delay maturity, or invest less energy in reproduction. In the last case, population fecundity could suffer if females breed less frequently or produce smaller clutches. These negative effects may be masked at long hydroperiod pools where metamorphs are more robust and do not need surplus 'catch-up' resources (Semlitsch 1987a; Brodman 1996).

We cannot easily explain why salamander abundance at long hydroperiod pools was higher in the 100m versus reference treatment or why we found a hydroperiod effect at 100m, but not 30m, pools. In the former case, abundance was also more variable at 100m pools,

possibly indicating less consistent resource availability in the 100m treatment. In the latter case, we suggest three possible reasons. First, the cut zone in the 100m treatment (i.e., 100-200m from the pool) may be a more vital source of 'catch-up' resources, due to its location or larger area, than the cut zone at 30m pools (i.e., 30-130m). Second, resource competition may force stunted metamorphs to settle for sub-optimal, clearcut habitat (Regosin et al. 2004), but because the clearcut is farther from the 100m pools, migration costs may be higher and metamorphs may have greater energetic deficits upon reaching the cut. Conversely, because of its greater size, salamanders may be less likely to leave the 100m buffer, leading to overcrowding and the associated risks of disease transmission, predation, and malnourishment.

Wood frogs

Recapture Proportion

The proportion of recaptured wood frogs was lowest in the 30m treatment, suggesting inferior habitat quality around 30m pools for at least the first six years post-cut. Habitat switching and/or high mortality of mature individuals could explain the lack of recaptured adults. Wood frogs in the southeastern U.S. are known to change breeding pools in response to habitat disturbance (Petranka et al. 2004). At our 30m pools, multiple radio-tagged wood frogs migrated through the clearcut to intact forest (Freidenfelds et al. 2011). Such frogs may have continued moving until they encountered an alternative breeding pool. It is also possible that mortality was elevated at the 30m pools due to both direct and indirect cutting effects (e.g., crushed by a skidder [(Knapp et al. 2003; Penman 2008)], overcrowding in the buffer (Harper and Semlitsch 2007; Patrick et al. 2008b)], predation (Graeter et al. 2008)]).

Recapture rates were depressed at 30m, but not 100m, pools. Land out to 130m from a pool supports large numbers of, and is important winter habitat for, adult wood frogs, but densities decline markedly after 130m (Regosin et al. 2005; Rittenhouse and Semlitsch 2007). Thus it is plausible that cutting affected more critical terrestrial habitat for mature frogs at 30m versus 100m pools. Additionally, adult wood frogs experience negative density dependence when terrestrial habitat is limited (Berven 2009) and juveniles crowd into suitable habitat, even if it increases mortality (Harper and Semlitsch 2007; Patrick et al. 2008b). Therefore, it is also possible that overcrowding negatively impacted frog populations, with greater effects at the smaller, 30m buffer where less habitat was available adjacent to pools.

Ultimately, the 30m-treatment recapture shortage could have negative population-level consequences. Though adult abundance did not differ across treatments during our study, adult wood frogs were smaller at 30m pools (Veysey Powell and Babbitt *in prep*), suggesting a shift in population structure towards younger and/or slower-growing individuals. Compared to recaptures, new-captured adults tend to be younger and smaller (Berven 1981), less competitive when mating (Berven 1981; Howard and Kluge 1985), and to produce smaller eggs (Berven 1988) and less competitive larvae (Berven 2009). Less competitive larvae are generally smaller at metamorphosis (Berven 1990; 2009), which can feedback to reinforce small adult size and clutch volumes and lead to delayed sexual maturation and increased risk of mortality prior to first reproduction (Berven 1982; Morrison and Hero 2003). As a result, fecundity may decline, leaving a population vulnerable to future perturbations (Morrison and Hero 2003).

Sex Ratio and Abundance

Wood frog sex ratio and abundance were not significantly impacted by buffer treatment. We were intrigued that sex ratios did not differ between the 30m and reference treatments because previous research suggested females might disproportionately suffer mortality during winter cutting at 30m pools (Regosin et al. 2003b; Regosin et al. 2005). By contrast, our results suggest that both sexes experienced similar levels of cutting-induced mortality and/or behavioral changes, allowing for stable relative abundances. Indeed, >25% of adults from both sexes could have been directly impacted by harvesting in the 30 – 130m zone at the 30m pools (Regosin et al. 2003b; Regosin et al. 2005; Rittenhouse and Semlitsch 2007). Additionally, radiotracking data indicate modified migratory behavior in the 30m treatment, with each sex adopting a different strategy for seeking viable habitat (Freidenfelds et al. 2011). While males may have responded to cutting by hunkering down in the buffer, females tended to move quickly through the cut into undisturbed forest (Freidenfelds et al. 2011). These strategies appear adaptive when compared to reference-pool behavior, where mean emigration distances were 72 ± 28 m and 95 ± 16 m, for males and females, respectively, locating both sexes squarely in what would be the clearcut were they at 30m pools (Freidenfelds et al. 2011). Overall, the number of males seeking refuge in the buffer may have been matched by females sheltering in the forest beyond the cut, resulting in similar sex ratios at the 30m and reference treatments.

Breeding-frog abundance, while unaffected by treatment, was correlated with mean-pool hydroperiod. This is consistent with previous work showing that wood frogs are more abundant where ephemeral pools hold water long enough for larvae to develop completely (Egan and Paton 2004; Baldwin et al. 2006b; Veysey et al. 2011). What distinguishes our study is that hydroperiod was a dominant predictor of wood frog abundance despite the major disturbance of

clearcutting. This result reaffirms the importance of metamorph production for wood frog population size (Berven 1990; 1995; 2009). Metamorph production is foremost a function of hydroperiod (Pechmann et al. 1991; Berven 1995) and the most direct link between hydroperiod and adult abundance. In ephemeral-pool ecosystems, hydroperiod, metamorph production, and adult populations vary widely from year to year (Pechmann et al. 1991; Berven 1995). Even without habitat disturbance, wood frog populations have high natural extinction probabilities and depend on boom metamorph production years for persistence (Harper et al. 2008). Habitat disturbance likely amplifies this dependence on metamorphs and, ultimately, hydroperiod.

Interspecies Comparison

Population models indicate that spotted salamanders are sensitive to habitat degradation and loss within 165m of breeding pools (Harper et al. 2008). The multiple negative demographic effects we observed in the 30m and 100m treatments suggest clearcutting reduced habitat quality, if not quantity, for spotted salamanders, especially females. Moreover, poor retention of new-captured salamanders at 30m pools suggests this treatment was a reproductive sink that provided less quality habitat than the 100m treatment. Our results provide experimental evidence to support the model-based conclusions by Harper et al. (2008) that the area out to 100 m from breeding pools is vital for spotted-salamander population stability.

By comparison, population models show that wood frogs are sensitive to immigration rates and habitat loss (Harper et al. 2008). Recaptured wood frogs were scarce at 30m pools, but breeding abundance did not differ between treatments, suggesting immigrants crossed cuts to replenish populations and that both 30m and 100m buffers helped mitigate the negative effects of clearcuts. Radiotracking research confirms wood frogs could cross our cuts (Freidenfelds et al.

2011). The persistent scarcity of recaptures in the 30m treatment, however, suggests negative habitat impacts, not entirely offset by immigration, that could inflate local extinction probabilities (Harper et al. 2008). Extinction probability also increases with stochastic variability and permanence of habitat alteration (Harper et al. 2008). Our system is highly variable due to inter-annual differences in precipitation and temperature, which jointly drive fluctuating hydroperiods and amphibian productivity.

Despite this variability, clearcuts regenerate. We thus expect wood-frog recapture proportions to recover and extinction probabilities to decrease as forests at 30m pools regrow. The precise recovery timeframe is unclear, however. In fact, the alternative recaptured-frog model, which included the yearX30m buffer interaction (i.e., included dv.30m instead of the main treatment effect), suggested a declining proportion of recaptured frogs over our six-year study. Other studies in east-central Maine found reduced wood-frog abundance in clearcuts during the first six years post-cut (Popescu et al. 2012) and reduced landscape permeability among juveniles for 10-20 years post-cut (Popescu and Hunter Jr. 2011). Our combined results suggest more than 6 years of regeneration are needed for clearcuts to develop the moist micro-climates and structured leaf litter necessary to support thriving wood-frog populations.

Management Implications

This is the first study to explicitly test whether forested buffers are effective for maintaining adult populations of ephemeral-pool-breeding amphibians. Previous research shows that amphibian abundance generally declines in response to forest cutting (Renken et al. 2004; Semlitsch et al. 2009b; Tilghman et al. 2012), even in the relatively moist northeastern U.S.

(Popescu et al. 2012). Our study demonstrates that buffers help mitigate the impacts of clearcutting, but that buffer width plays a critical role in that process.

Spotted-salamander and wood-frog breeding populations responded negatively to clearcutting in the 30m treatment, suggesting 30m buffers may be insufficient for maintaining resilient populations of both species. This was true despite great ecosystem variability, which complicates statistical detection of treatment effects. Though abundance was not directly affected, the sex-ratio and recapture impacts suggest increased vulnerability of 30m populations to additional stressors (e.g., climate change, disease; Semlitsch 2000; Blaustein and Kiesecker 2002). Moreover, 30m pools appeared to act as sink habitat for immigrants of both species for the first six years post-cut. With 100m buffers, cutting negatively affected salamander sex ratio and abundance, but not recapture proportion, suggesting population processes and habitat quality were less impaired than with 30m buffers. Similarly, no wood-frog metrics were impacted in the 100m treatment. Lagged demographic effects are possible in both cut treatments (Harper et al. 2008), but unexpected, given forest regeneration. We examined amphibian response to variable buffer sizes, given a static clearcut width, but we recognize that optimal buffer width may vary with clearcut size. Testing other clearcut configurations was beyond our study's scope, however.

Notwithstanding the major disturbance caused by our clearcuts, hydroperiod was a key driver in this ecosystem. Mean-pool hydroperiod was the only significant predictor of wood-frog abundance. Salamander abundance was best predicted by an interaction between hydroperiod and buffer treatment. Our results reaffirm that hydroperiod must be factored into these species' management plans. To maintain viable populations of both species, land-use planners should prioritize conservation of ephemeral pools with medium to long hydroperiods (i.e., > 4 months),

a recommendation supported by previous research (Babbitt et al. 2003; Egan and Paton 2004; Veysey et al. 2011).

Overall, our study provides solid experimental evidence that 30m-wide water-quality buffers, which are assumed to provide wetland-dependent-wildlife habitat, are not sufficient to maintain resilient local populations of spotted salamanders and wood frogs, species representative of ephemeral-pool-breeding amphibians in the eastern U.S. Populations in the 100m treatment were relatively more resilient, indicating that 100m buffers may provide adequate habitat in some contexts. Despite the negative impacts from clearcutting that we observed at individual pools, inter-pool gene flow was high in this forest for both species (Coster 2013; Coster et al. *in review*). The broader implications of our results are thus landscape-dependent. We conducted our study in a relatively moist, working forest in the northeastern U.S. where the clearcut return interval is several decades (Seymour et al. 2002). Notwithstanding timber harvest, the forest and wetland habitats that these species prefer are generally abundant in this landscape, facilitating dispersal to recolonize or rescue local populations affected by cutting (Coster 2013; Coster et al. *in review*). However, inter-pool dispersal may be impeded and 100m buffers may inadequately protect local population resiliency, in landscapes where: cutting is more extensive; water is less plentiful; site preparation reduces habitat quality; the return interval is shorter; or other stressors interact synergistically with forest cutting. This may be especially true in exurban and suburban landscapes where, unlike forestry, development permanently alters habitat suitability (Windmiller et al. 2008; Gabrielsen et al. 2013; Cline and Hunter 2014).

Table 1.1. Mean and variability of predictor and outcome variables at 11 natural ephemeral pools in east-central Maine, USA.

	Mean ± SE	**Range**	
Mean hydroperiod (days)	125.96 ± 5.98	44.83 - 197.00[d]	
SD hydroperiod (days)[a]	31.81 ± 1.58	6.32 - 48.76	

	Spotted Salamander		**Wood Frog**	
	Mean ± SE	**Range**	**Mean ± SE**	**Range**
Total abundance	55.78 ± 7.01	0 - 242	100.68 ± 10.11	7 - 568
Proportion recaptured[b]	0.24 ± 0.02	0 - 0.63	0.17 ± 0.02	0 - 0.67
Sex ratio[c]	0.58 ± 0.02	0.10 - 1.00	0.61 ± 0.02	0.14 - 0.88

[a] Standard deviation of the pool hydroperiod.

[b] Proportion recaptured = number of recaptured breeding adults / (number of recaptured breeding adults + number of new-captured breeding adults).

[c] Sex ratio = number of breeding males / (number of breeding males + number of breeding females).

[d] Some pools did not dry in some years. To facilitate analyses, we assigned such pools a late-fall hydroperiod end date. Mean hydroperiod was calculated using the capped end dates.

Table 1.2. Generalized linear mixed regression results, showing the relative impact of forestry treatment, hydroperiod, and study year on demographic characteristics of breeding spotted salamander and wood frog populations at 11 ephemeral pools in east-central Maine, USA.

Population Metric	Predictor[a]	F value$_{(df)}$	t value$_{(df)}$	Coefficient ± SE
Spotted Salamander				
Total Abundance	treatment(100m)[b]*mean.hydro[c]	$5.65_{(2,56)}^{*}$	$3.33_{(56)}^{*}$	0.03 ± 0.009
	treatment(100m)	$4.16_{(2,56)}^{*}$	$-2.79_{(56)}^{*}$	-3.38 ± 1.212
	intercept	$12.81_{(1,56)}^{**}$	$3.58_{(56)}^{**}$	3.88 ± 1.084
Proportion Recaptured	treatment(30m)[d]	$13.74_{(2)}^{*g}$	-2.58^{*g}	-1.27 ± 0.490
	dv.30m[e]	$10.12_{(1)}^{*}$	3.22^{*}	0.30 ± 0.093
Sex Ratio	dv.cut[f]	$28.46_{(1,57)}^{***}$	$5.34_{(57)}^{***}$	0.18 ± 0.034
	dv.30m	$3.10_{(1,57)}^{\cdot}$	$-1.76_{(57)}^{\cdot}$	-0.09 ± 0.051
Wood Frog				
Total Abundance	mean.hydro	$6.17_{(1,58)}^{*}$	$2.48_{(58)}^{*}$	0.01 ± 0.003
	intercept	$31.03_{(1,58)}^{***}$	$5.57_{(58)}^{***}$	3.35 ± 0.601
Proportion Recaptured	treatment(100m vs. 30m)	$9.53_{(2,48)}^{**}$	$4.36_{(48)}^{**}$	0.81 ± 0.185
	intercept	$8.65_{(1,48)}^{*}$	$-2.94_{(48)}^{*}$	-1.39 ± 0.474
Sex Ratio		ns[h]		

[a] All models included the following predictors: treatment, mean.hydro, standard deviation of the pool hydroperiod (days), dv.cut, dv.30m, and an interaction between treatment and mean.hydro. Based on an a priori decision, we dropped the interaction from the model when the interaction was not significant. Only significant fixed-effects results are shown.

[b] Categorical variable, coded 0 = reference treatment and 1 = 100m treatment.

[c] Mean.hydro = mean pool hydroperiod in days.

[d] Categorical variable, coded 0 = reference treatment and 1 = 30m treatment.

e Dv.30m = dummy variable representing the marginal impact of the 30m treatment over the six years of the study.

[f] Dv.cut = dummy variable representing the difference between the reference treatment and the two cut treatments, over the six years of the study.

[g] We analyzed the proportion of recaptured salamander model in R 2.13. For this model, we thus used X^2 values to assess overall significance of each variable and z values to compare between individual levels of categorical predictors.

[h] None of the independent variables were significant predictors of wood frog sex ratio.

*** $p < 0.0001$; ** $p < 0.001$; * $p < 0.05$; $^{\cdot}$ $0.05 \leq p < 0.1$

Figure 1.1. Experimental design implemented at 11 natural ephemeral pools in east-central Maine, USA. Undisturbed buffers of either 100m (left; n = 4) or 30m (right; n = 4) were left adjacent to pools and 100m wide clear cuts were created around the buffers. Forest beyond the clear cut was undisturbed. No cutting occurred at reference pools (not shown; n = 3).

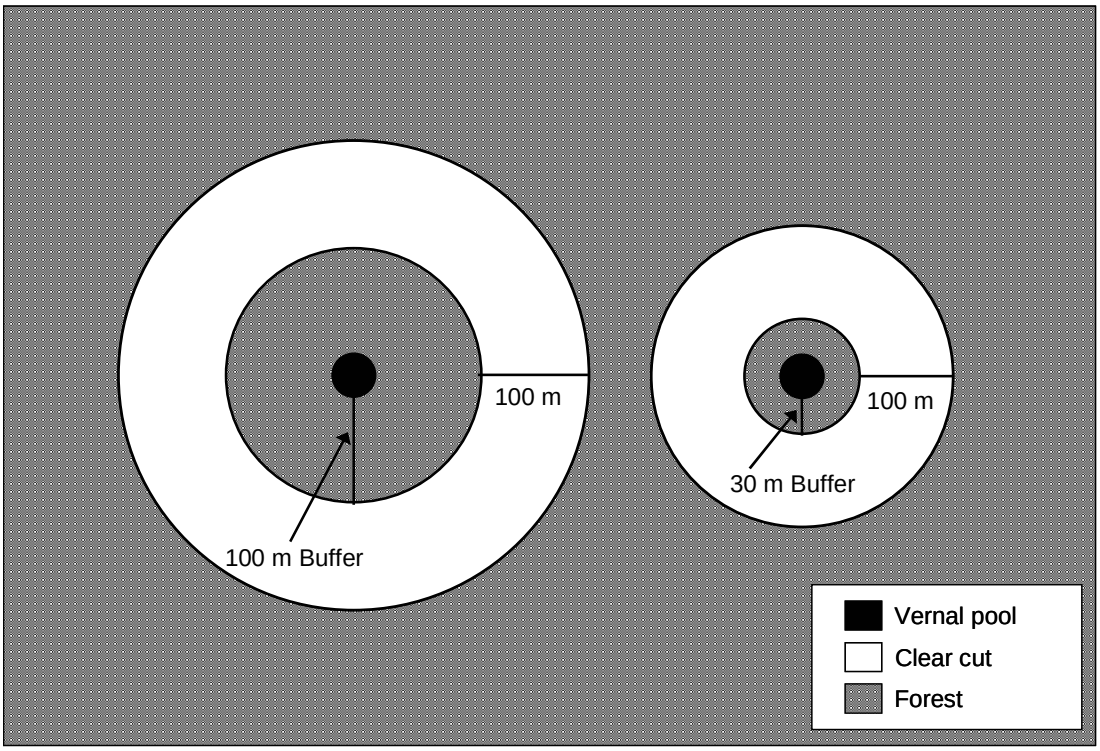


Figure 1.2. Breeding spotted salamander and wood frog abundance at 11 natural ephemeral pools in east-central Maine, USA, across the six study years. Each pool is labeled with an identifying number and the applied forestry treatment. Experimental forestry treatments were: reference (uncut), 100m undisturbed buffer, 30m undisturbed buffer.

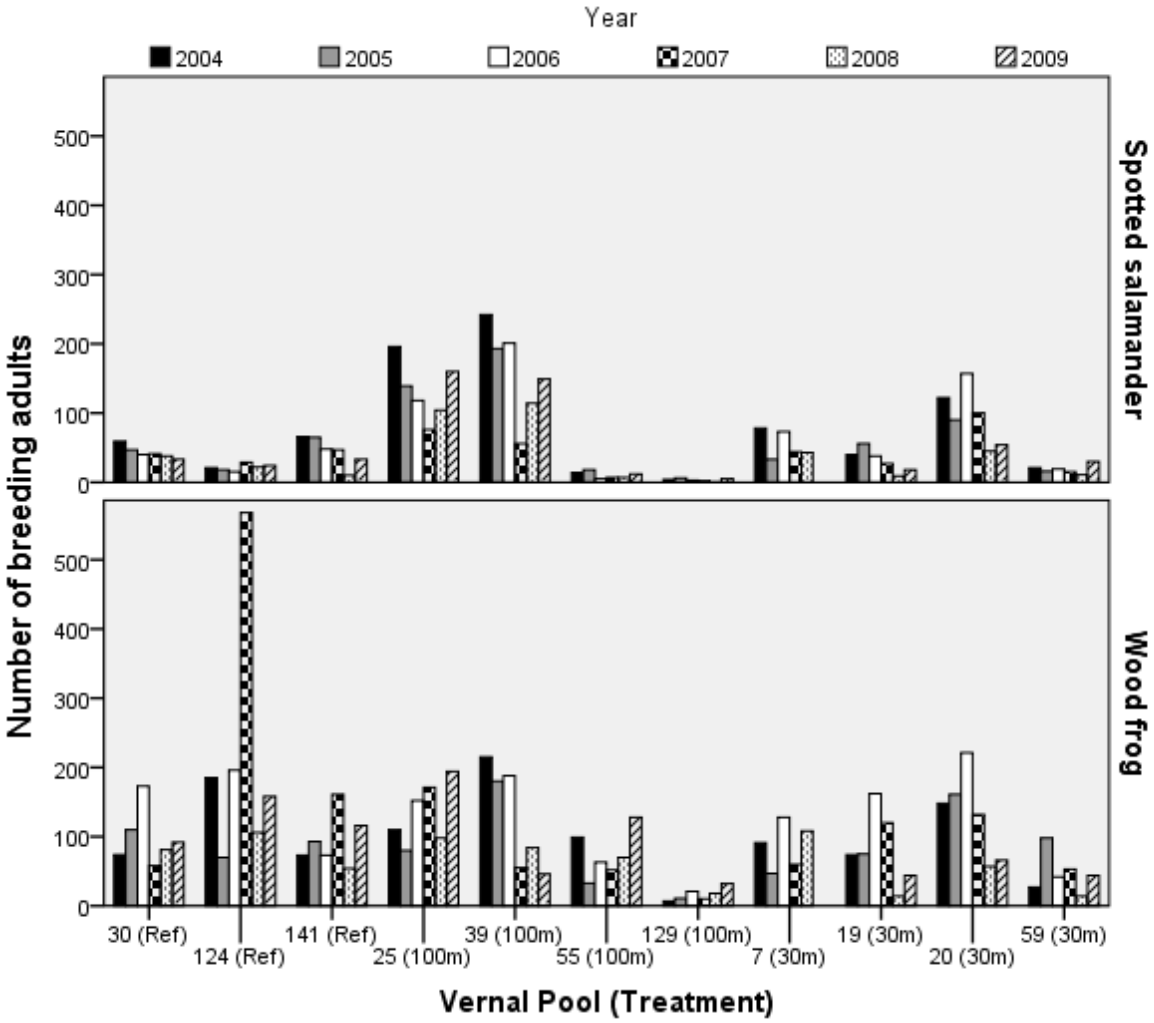


Figure 1.3. Mean (±1SE) sex ratio of breeding spotted salamanders by forestry treatment and study year at 11 natural ephemeral pools in east-central Maine, USA. Treatment were: reference (uncut), 100m undisturbed buffer, 30m undisturbed buffer.

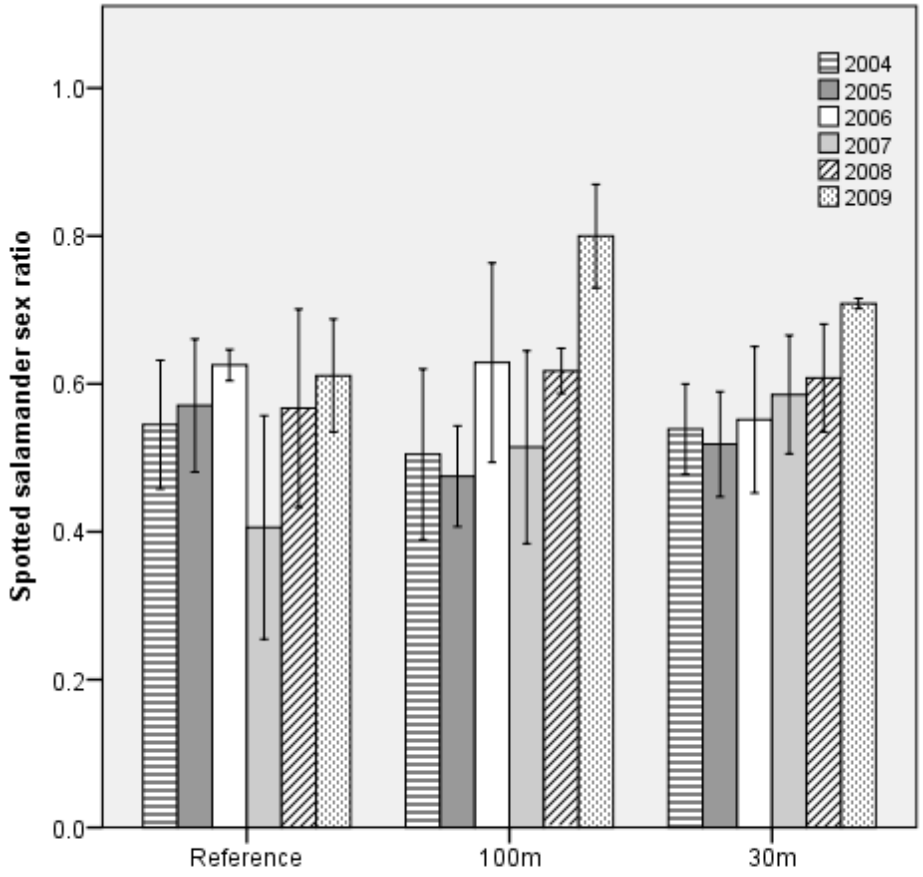


Figure 1.4. Predicted mean proportion of recaptured breeding spotted salamanders by forestry treatment and study year, including random between-year variability, at 11 natural ephemeral pools in east-central Maine, USA. Treatment were: reference (uncut), 100m undisturbed buffer, 30m undisturbed buffer.

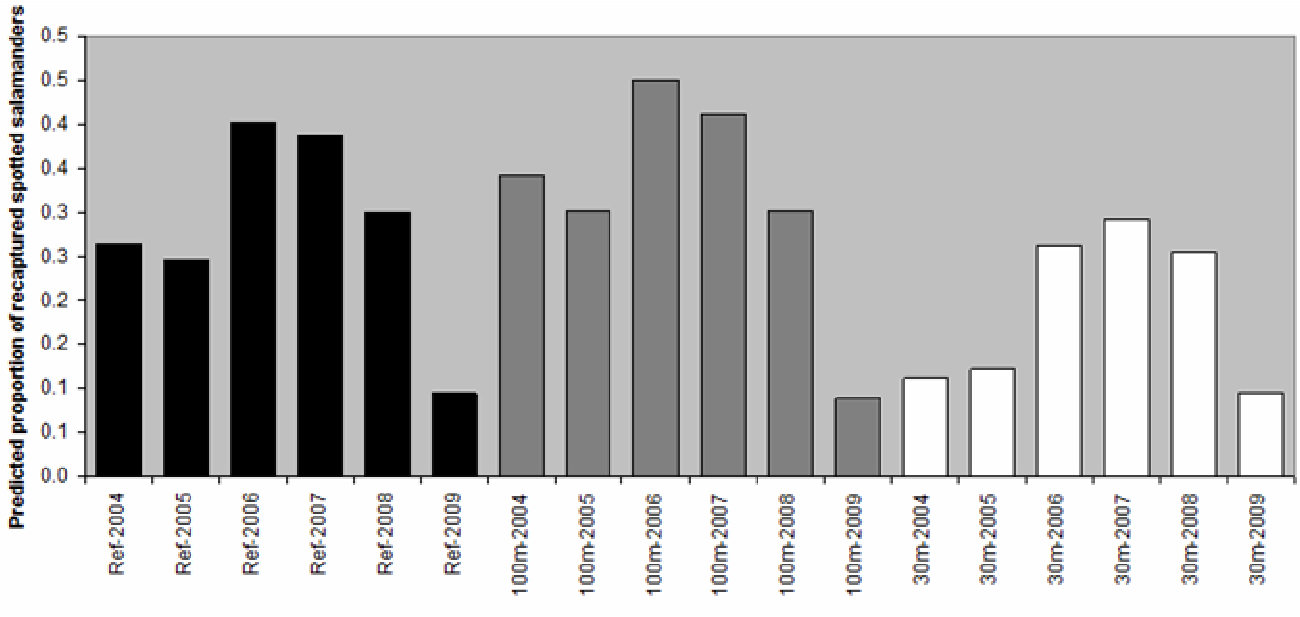


Figure 1.5. Number of breeding spotted salamanders by experimental forestry treatment, at 11 natural ephemeral pools in east-central Maine, USA. Treatments were: reference (uncut), 100m undisturbed buffer, 30m undisturbed buffer.

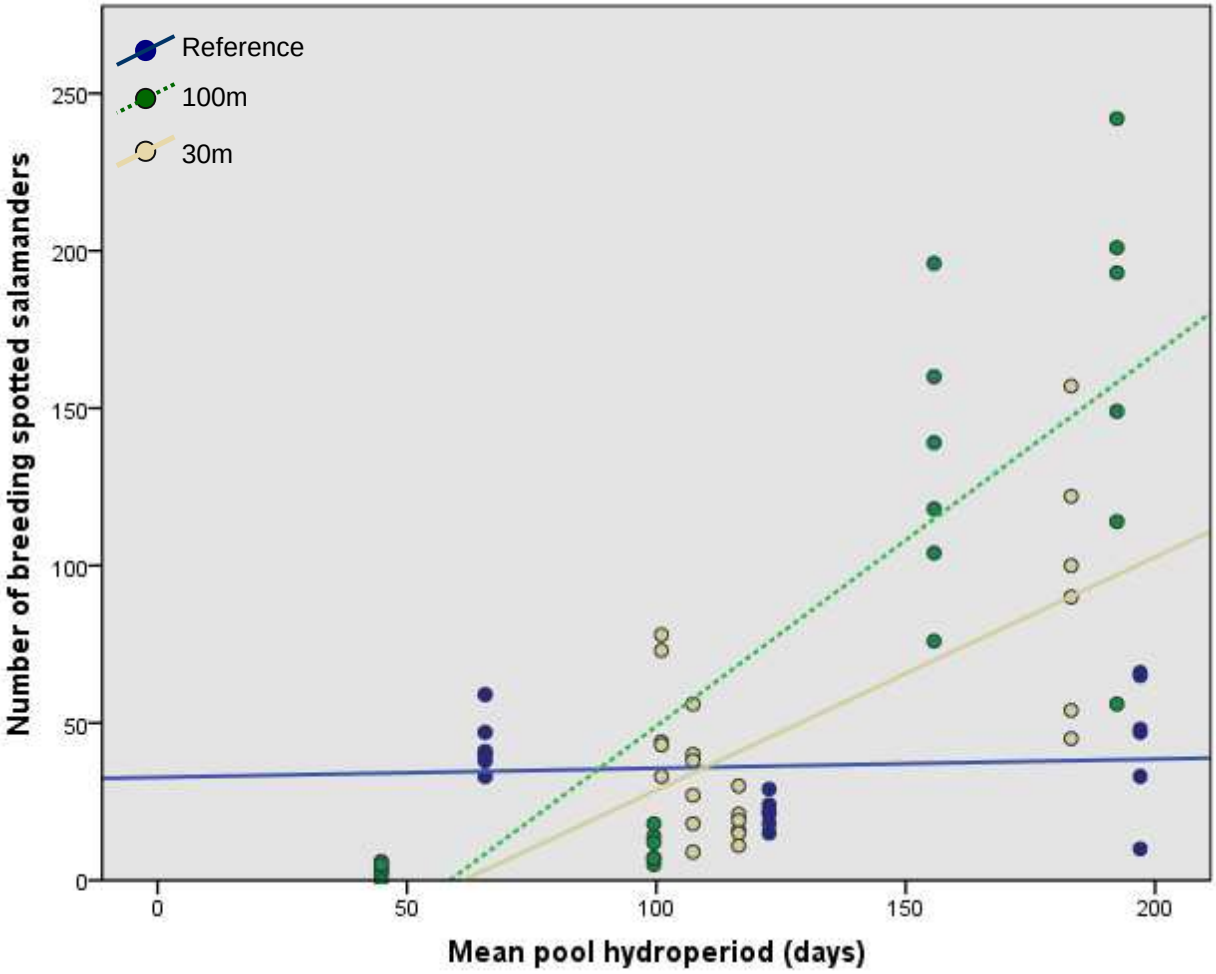


Figure 1.6. Mean (±1SE) proportion of recaptured breeding wood frogs across three experimental forestry treatments at 11 ephemeral pools in east-central Maine, USA. Treatments were: reference (uncut); 100m undisturbed buffer; 30m undisturbed buffer.

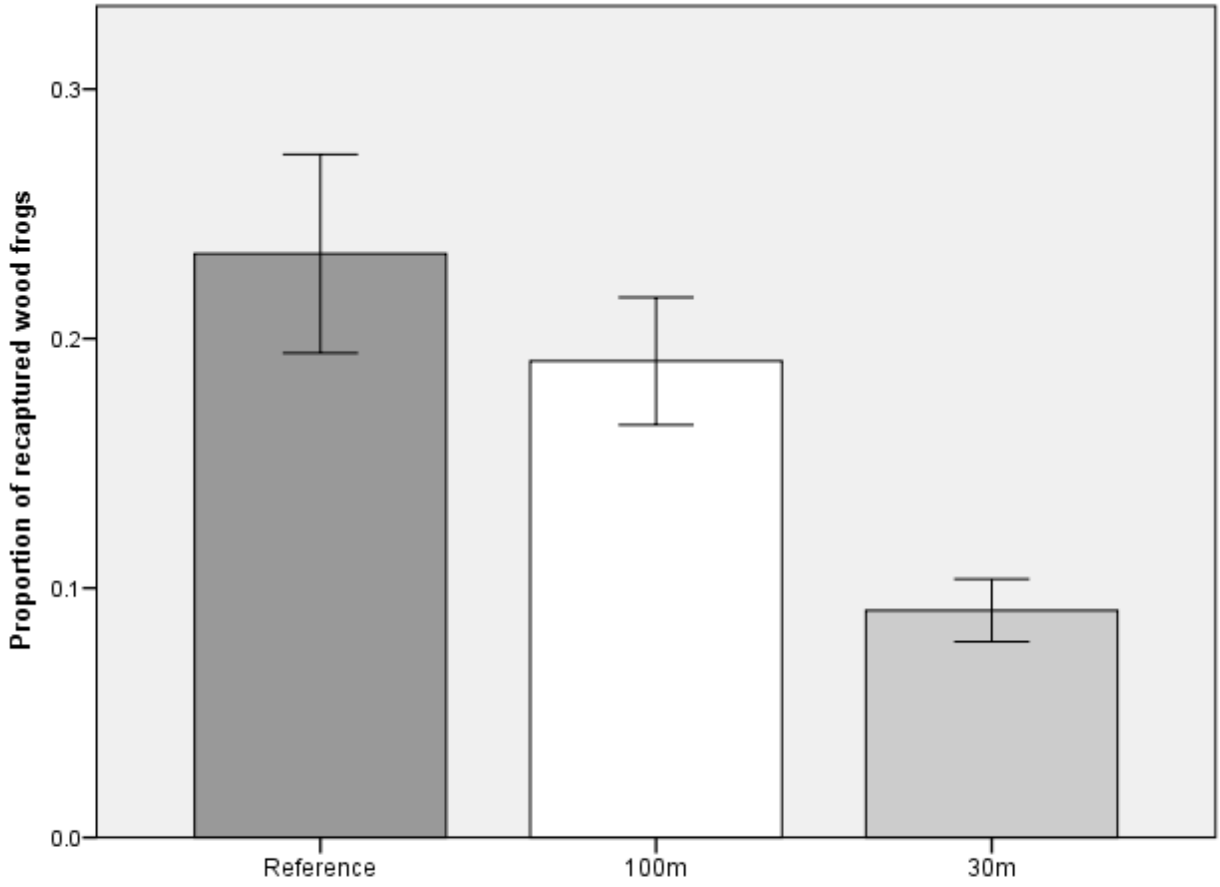
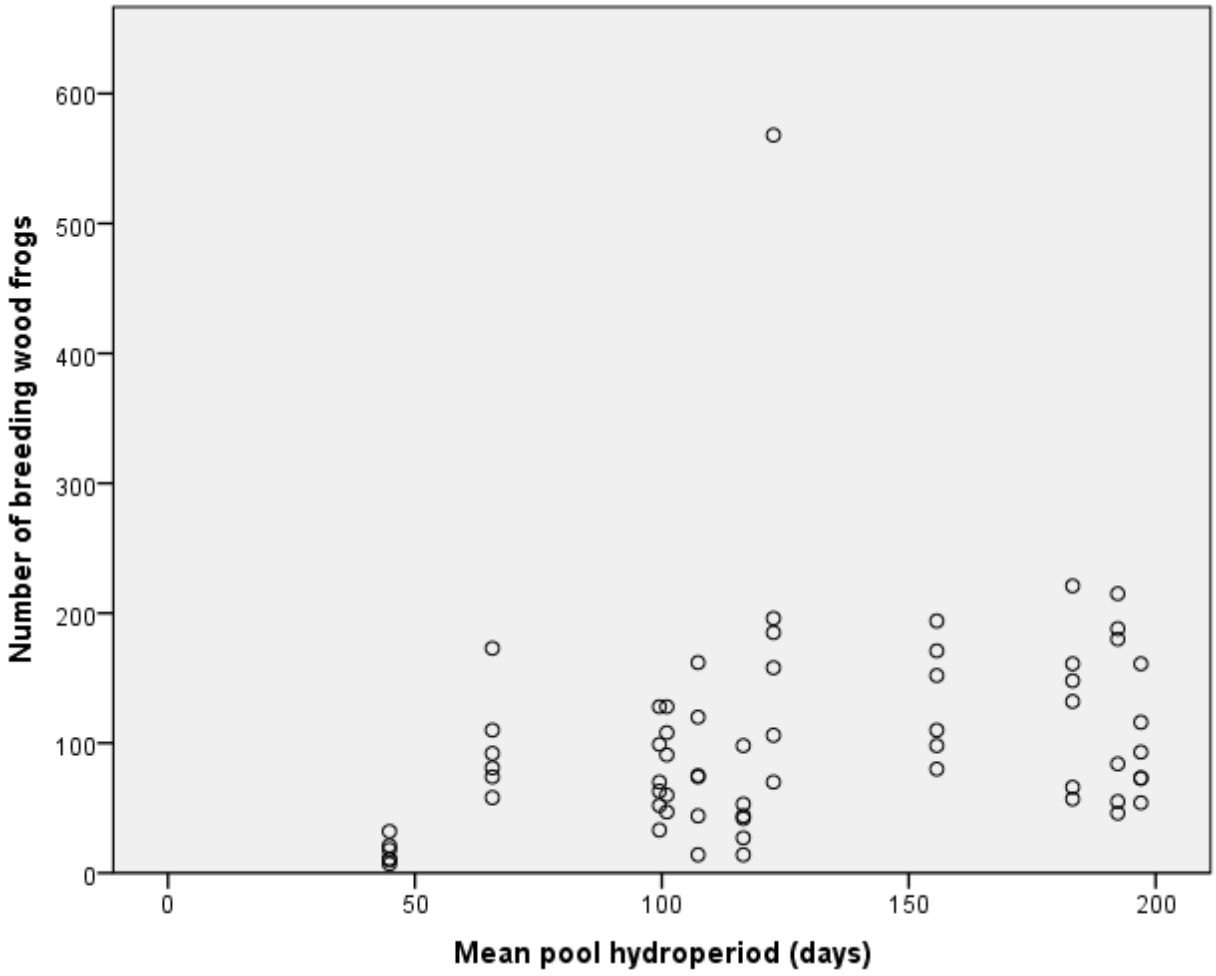


Figure 1.7. Number of breeding wood frogs at 11 natural ephemeral pools in east-central Maine, USA, in relation to mean pool hydroperiod (days).



CHAPTER 2

DESPITE BUFFERS, EXPERIMENTAL FOREST CLEARCUTS IMPACT AMPHIBIAN BODY SIZE AND BIOMASS

Abstract

Forest buffers are a primary tool used to protect wetland-dependent wildlife. Though implemented widely, buffer efficacy is untested for most amphibian species. Consequently, it remains unclear whether buffers are sufficient for maintaining viable amphibian populations and if so, how wide buffers should be. I present evidence from a six-year, landscape-scale experiment testing the interactive impacts of forest clearcutting and buffer width on body size and condition and population biomass of breeding adults for two amphibian species at 11 natural vernal pools in the northeastern United States[1]. To my knowledge, this is the first experiment to evaluate buffer efficacy for pool-breeding amphibians. We randomly assigned each pool to one of three treatments (i.e., reference, 100m buffer, 30m buffer) and used clearcutting to create experimental buffers. We captured all spotted salamanders and wood frogs breeding in each pool and used linear-mixed-effects regression to assess the relative effects of buffer treatment and pool hydroperiod on size, condition, and biomass. Clearcuts resulted in strong negative impacts to amphibian size, condition, and biomass, but wider buffers helped mitigate the magnitude and duration of these effects. Hydroperiod was an important mediating factor: in the 100m treatment, cutting only affected pools that were also stressed hydrologically. Overall, spotted salamanders

[1] The experimental results presented in my dissertation are but one piece of a much larger project to which many individuals contributed. In this chapter, I use plural pronouns to indicate work which was accomplished through the efforts of multiple people, myself included.

and female wood frogs were impacted more strongly than male wood frogs. These results highlight the importance of individualized metrics like body size and condition, which can reveal sublethal effects and illuminate potential mechanisms by which habitat disturbance impacts wildlife populations. As such, individualized metrics provide critical insights that complement species occurrence and abundance-based population assessments.

Introduction

Globally, forest ecosystems are experiencing intensifying stress as growing human populations demand more developed and agricultural land and larger volumes of forest products (Irland 1999; FAO 2012). Whether owners develop, harvest, or conserve their forests is a complex decision driven by global economic trends (Friedland et al. 2004; FAO 2012). Over the last two decades, increasing awareness that forests provide critical ecosystem services catalyzed interest in sustainable management programs that allow forest owners to harvest timber while maintaining ecosystem functions and biodiversity (Seymour et al. 2006; Klenner et al. 2009; Peterson and Anderson 2009). Developing sustainable forest-management plans can be difficult even for common species, however, given our sometimes rudimentary understanding of the complex interactions between forest components and ability to predict species' responses to disturbance (Peterson and Monserud 2002).

Amphibians can be particularly challenging to accommodate given their complex life cycles and diverse habitat needs (deMaynadier and Houlahan 2008). In temperate forests, many amphibian species occupy wetlands during their egg and larval stages, but migrate hundreds of meters into adjacent forest as juveniles and adults (e.g., Semlitsch and Bodie 2003; Veysey et al. 2009; Freidenfelds et al. 2011). Forest harvesting can alter both the wetland and upland habitat

of these species, with potentially negative consequences for population persistence (deMaynadier and Houlahan 2008). In general, timber harvesting, especially clearcuts, is locally associated with reduced abundance and survival of numerous amphibian species across various forest types (e.g., Renken et al. 2004; Rittenhouse et al. 2009; Tilghman et al. 2012). Responding to such scientific evidence, public pressure, economic incentive, and personal ecological ethic, some forest managers in temperate ecosystems have indicated willingness to integrate amphibian habitat needs into forest management plans (Beese et al. 2005; Bunnell 2005; GFGS 2009).

Forested buffers are a primary tool used to protect amphibians in such plans. Though buffers are implemented widely, their efficacy is untested for most amphibian species. Thus, it remains unclear whether buffers are sufficient for maintaining viable amphibian populations in working forests and if so, how wide buffers should be. Most studies that recommend amphibian buffers are based on observational data from unbuffered landscapes (e.g., Crawford and Semlitsch 2007; Harper et al. 2008; Ficetola et al. 2009). After reviewing the movement characteristics of 32 species across such landscapes, Semlitsch and Bodie (2003) suggested that a 290-m life zone, centered like a buffer around a wetland, is necessary to protect the core habitat of most wetland-dependent amphibian species. Scientists and conservation planners frequently reference the need for a protective 290-m life zone, but policy-makers are slow to embrace such large constraints on land use (Lee et al. 2004; Bauer et al. 2010a; Hart and Calhoun 2010). Compared to development and intensive agriculture, however, forestry can be a temporary disturbance. Because forests typically regenerate for several decades post-cut, habitat conditions are dynamic and amphibians may be able to persist even if buffers considerably smaller than 290 m are used (Rittenhouse et al. 2008; Hart and Calhoun 2010; Tilghman et al. 2012).

Only a handful of studies have intentionally tested the impacts of buffer-mediated forest cutting on amphibians, however, and these have limited inference. Most were restricted to stream-side habitats (e.g., Vesely and McComb 2002; Perkins and Hunter 2006), used narrow buffers (i.e., <35 m; e.g., Johnston and Frid 2002; Pollett et al. 2010; Hawkes and Gregory 2012), and were conducted in northwestern North America. For some, forestry impacts were confounded by other management treatments or time of harvest (Cole et al. 1997; Hannon et al. 2002). Some focused solely or partly on terrestrial species (Hawkes and Gregory 2012) or only sampled in or extremely close to streams (Dupuis and Steventon 1999; Olson and Rugger 2007). Such studies have limited applicability for amphibians that breed in lentic habitats, especially since post-breeding migrations for such species often extend far beyond 35 m.

To strengthen the scientific basis for making decisions about buffer width, we present evidence from a six-year, landscape-scale experiment testing the interactive impacts of clearcutting and buffer width on breeding-adult demography for two amphibian species at natural vernal pools in an industrial forest in the northeastern United States. To our knowledge, this is the first experiment to evaluate buffer efficacy for pool-breeding amphibians. In Veysey Powell and Babbitt (*in review*), we show that narrow buffers result in reduced recaptures of mature spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Lithobates sylvaticus*) and altered sex ratios for spotted salamanders. Here, we assess how body size and condition and population biomass vary in response to buffer width for breeding adults of both species. Amphibian body size and condition are correlated with and can be proxies for multiple fitness measures including fecundity (Semlitsch 1985; Berven 1988), survival (Spotila 1972; Berven 1990), endurance (John-Alder and Morin 1990; Beck and Congdon 2000), and immunity (Lochmiller and Deerenberg 2000; McMurry et al. 2009). Biomass measures productivity and indexes energetic

contributions of amphibian populations to aquatic and terrestrial components of forest ecosystems (Regester et al. 2006; Deichmann et al. 2008). Understanding how buffer width relates to body size and condition can provide important insights into the indirect pathways by which forestry affects amphibian populations (Welsh et al. 2008). Similarly, knowing how adult biomass changes in response to buffer width can help clarify how cutting influences ecosystem energy flows. Previous research suggests that forest cutting is associated with reduced amphibian size and body condition, but studies examining such indirect forestry effects are relatively rare, were not conducted in buffered landscapes, and produced results that were inconsistent across species and age classes (e.g., Chazal and Niewiarowski 1998; Karraker and Welsh 2006; Patrick et al. 2006). Nonetheless, because narrow buffers provide less forest habitat than wide buffers, we predicted that breeding populations would be dominated by smaller individuals and lower overall biomass in narrow versus wider buffers.

Methods

Study Site

We conducted this research in an industrial forest in Penobscot and Washington counties, Maine, USA (45º0’52”N, 44º48”32”N; 68º28’11”W, 67º53’10”W). Northern hardwoods *(Fagus grandifolia*, *Acer saccharum*, *Betula alleghaniensis*) and eastern hemlock (*Tsuga canadensis*) characterized the forest at lower elevations, while balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) were prevalent at higher elevations. Wetlands, moderate hills, and dirt logging roads were common landscape features. In 2002, we located 300 vernal pools in this forest. With pool size (i.e., 0.1-0.3 ha) and forest condition (i.e., uncut within 1000m) as selection criteria, we

narrowed the list of potential study pools from 300 to 40. In 2003, we counted amphibian egg masses and tracked hydroperiod at the 40 pools and identified 35 that were inundated, but ice-free, for at least five months, with breeding populations of both spotted salamanders and wood frogs. To finalize study-site selection, we randomly chose 12 of the 35 pools. In spring 2004, we learned that one of the 12 pools had a permanent inflow and removed that pool from the study.

Buffer Creation

Between fall 2003 and spring 2004, the landowner created experimental buffers by clearcutting forest around the study pools. We randomly assigned each of the 11 pools to one of three treatments: reference (i.e., uncut; N=3), 100m buffer (N=4), or 30m buffer (N=4). Pools in the two buffer treatments had, respectively, a 100-m or 30-m-wide upland buffer encircling the pool and a 100-m-wide concentric clearcut around the buffer (Fig. 2.1). We chose buffers from those recommended by extant Best Management Practices, laws, and literature (M.G.L. c.131§ 40; Semlitsch 1998; Calhoun 2002). Clearcutting removed all merchantable trees ≥ 5 cm diameter at breast height and slash, though a minimal amount of woody debris was left post-cut.

Amphibian Sampling

In summer and fall 2003, we surrounded each of the 11 pools with a drift fence / pit fall trap array (Willson and Gibbons 2010), placing fences 5 m above the high water line to minimize flooding. Drift fences were 91-cm tall plastic silt fence, with the bottom edge buried 8-10 cm deep. Pitfall traps were 5.7 liter aluminum cans buried in pairs on opposite sides of the drift fence and spaced about 10 m apart (Willson and Gibbons 2010). We put moistened sponges at the bottom of each trap to prevent amphibian desiccation.

From 2004 to 2009, we opened traps in the spring after ice-out and closed traps when a pool was dry for at least seven consecutive days or in the fall when hard frosts curbed amphibian movement. During the winter, we pulled up sections of drift fence to allow movement of other wildlife species. We checked pitfall traps daily during periods of frequent amphibian movement (i.e., April-May and July-September) and every one to five days during periods when amphibians were less active (i.e., June and October-early November). For 2009, we did not open traps at one 30m pool because the pool was inaccessible. Our analysis is robust to this missing data, however (Pinheiro and Bates 2000).

Using the pitfall traps, we captured, counted, and sexed all adult spotted salamanders and wood frogs exiting the pools. For each individual, we also measured snout-vent or snout-urostyle length (hereafter SVL) and mass. To distinguish recaptures from new-captures and minimize the chances of counting the same individual more than once a year, we marked all exiting adults with a pool-specific toe-clip (Ferner 2010). For any individual that returned to a pool the same year it was toe-clipped, we only analyzed data from its first visit. Post-processing, we released each animal on the opposite side of the fence from which we captured it.

Hydroperiod Sampling

We measured hydroperiod for each pool in each year as the number of days the pool held water between ice-out (i.e., < 75% of the pool was covered in ice) and the day the pool dried completely. To facilitate analyses, we assigned a hydroperiod end date of October 28th to pools that did not dry in a given year. We used this date because these pools still held water on this date, but it was late enough in the year that most amphibians at our study pools were inactive.

Statistical Analyses

To test the relative impacts of buffer treatment and hydroperiod on several measures of breeding-amphibian body condition and biomass, we conducted linear mixed effects regressions (LME) using the "lme" function in S-Plus 8.0 (Insightful Corporation, Seattle, WA, USA). Our predictor variables were: buffer treatment, mean-pool hydroperiod (i.e., the mean hydroperiod for each pool across the six study years), standard deviation of pool hydroperiod (calculated for each pool across the six study years), an interaction between treatment and mean-pool hydroperiod, and a pair of numeric dummy variables representing an interaction between treatment and study year. We used the first dummy variable (cut.year) to distinguish whether a pool was clearcut or not. We used the second dummy variable (30m.year) to indicate marginal impacts to 30m buffer pools.

We assessed body condition using three size metrics: SVL, mass, and a body-condition index (BCI). We used the BCI as a relative measure of energy reserves. We calculated the BCI as the residuals of an ordinary least-squares regression of mass on SVL. To obtain normal residuals for the BCI, we square-root transformed the mass and SVL data for salamanders and log-transformed mass and SVL for frogs. We calculated separate BCIs for each sex within each species. Residual-based condition indices are an appropriate tool for our study for the following reasons. First, by calculating separate BCIs for each sex within each species, we avoided the scaling issues that result when comparing BCIs across groups known to differ in size due to heterauxesis and allomorphosis (Peig and Green 2010). Second, after transformation, our data did not violate the critical, testable assumptions inherent to BCI analysis, namely: mass and SVL were linearly related, BCI was independent of SVL, and SVL is a reliable indicator of structural size (Green 2001; Schulte-Hostedde et al. 2005; Bancila et al. 2010). Finally, residual-based

condition indices outperform similar measures of condition and accurately parallel energy reserves in a variety of species (Ardia 2005; Schulte-Hostedde et al. 2005; Bancila et al. 2010).

We calculated biomass as the sum of the mass of all individuals, with separate biomasses calculated for each species and each sex at each wetland in each year. For each individual counted, but not weighed (N=328 and 748 [or 9% and 11%], for spotted salamanders and wood frogs, respectively), we assigned a mass equivalent to the imputed mean mass for its respective category. We could not determine the sex of 22 spotted salamanders and 27 wood frogs that we found dead in traps. We did not use dead individuals in the biomass analysis. To meet the assumptions of LME, we used ln(biomass + 0.5) as the y variable in all biomass analyses, except for recaptured male spotted salamanders, for which we used the untransformed biomass.

We performed separate regressions for each combination of capture status (i.e., new-capture or recapture) and sex, within each species, for a total of eight regression models per size metric. We treated year and pool ID as crossed random effects (Pinheiro and Bates 2000) in all models, except when the model would not converge with crossed effects, in which case we simplified the model to include either a random intercept for year or for wetland, whichever provided a better model fit, as determined by likelihood ratio tests (LRTs). Among the simplified models, we used year random intercepts for the SVL of new-captured and recaptured male wood frogs, the BCI of recaptured female wood frogs, and the BCI of male and female recaptured spotted salamanders. Similarly, we used wetland random intercepts for the BCI of new-captured male wood frogs. We also modeled the variance-covariance structure for each regression to account for heterogeneous variance across groups and correlation among individuals from the same wetland (Appendix 1). We used LRTs to optimize the variance-covariance structure of each model and F and t tests to determine the significance of each fixed effect ($\alpha = 0.05$). We

used treatment contrasts to compare the reference treatment to each respective cut treatment. Based on an a priori decision, when the hydroperiod interaction was not significant, we removed this interaction from the model and refit the model for the remaining fixed effects. In their final forms, all models satisfied the assumptions of LME.

Results

Over the six study years, the 11 vernal pools produced over 47 kg of breeding spotted salamanders and 64 kg of breeding wood frogs. This biomass represented 3624 breeding spotted salamanders and 6521 breeding wood frogs. Descriptive statistics are provided in Table 2.1 for size and body condition and in Table 2.2 for biomass.

Spotted Salamanders

In general, we found that spotted salamanders were smaller and had worse body condition at 30m, compared to reference, pools. For some, but not all, combinations of capture status, sex, and size metric, we observed partial recovery of the size metric at 30m pools over the six study years. We found less consistent relationships between treatment and biomass than between treatment and body size/condition.

Recaptured female salamanders were, throughout the study and on average, predicted to be 9.1 mm shorter at 30m versus reference pools (Table 2.3; Fig. 2.2). (Note: no females were recaptured at 30m pools in 2009). Similarly, in the first recapture year (i.e., 2005), the average recaptured female at the 30m pools was predicted to weigh 7 g less, and have worse body condition, than her reference-pool counterpart. However, mass and BCI were both predicted to recover to mean reference levels by about 9.5 years post-cut. Conversely, recaptured-female

body condition at the 100m pools worsened with time, so that by the study's end, 100m-pool BCI was predicted to be about two times lower than the mean reference BCI. BCI also decreased, in all treatments, with increasing hydroperiod duration and variability. Finally, recaptured female biomass was predicted to decrease by about 58% per year at 30m pools, but tended to increase by about 2.4% per each additional day of mean hydroperiod in all treatments.

New-captured female spotted salamanders were predicted to weigh, on average and for the duration of the study, 4.5 g less at 30m pools than at reference pools (Fig. 2.3). They also tended to have persistently worse body condition at 30m pools. During the first year post-cut, new-captured females were predicted to be, on average, 7.3 mm shorter in the 30m versus reference treatment. SVL at 30m pools was predicted to recover to mean reference levels by about 14 years post-cut. For new-captured female biomass, the 30m and reference treatments did not differ, but 100m-treatment biomass depended on mean pool hydroperiod. Short-hydroperiod pools were predicted to produce much lower biomass in the 100m, compared to the reference, treatment. For each additional day of mean hydroperiod, however, biomass at the 100m pools was predicted to increase by about 3.8%.

For recaptured male spotted salamanders, both SVL and BCI were lower at 30m pools than reference pools and failed to recover to reference levels. On average, recaptured males were predicted to be 9.8 mm shorter at 30m pools. During the first recapture year, recaptured males were also predicted to weigh, on average, about 4 g less at 30m versus reference pools. A marginally significant 30mXyear interaction suggests recaptured male mass would take about 11 years to recover to mean reference levels. Recaptured male body condition and biomass were also influenced by hydroperiod. For all treatments, body condition declined with increasing mean hydroperiod and pools with more variable hydroperiod tended to support lower total biomass.

For short-hydroperiod pools, we also found less biomass in the 100m versus the reference treatment, but the associated coefficient and standard error were quite large and should be cautiously interpreted. Nevertheless, for each additional day of mean hydroperiod, 100m biomass was predicted to increase by 2.5 g.

New-captured male spotted salamanders were predicted, on average, to be 6.8 mm shorter, weigh 3.2 g less, and have worse body condition, at 30m pools than at reference pools during the first year post-cut (Fig. 2.4). However, all three size metrics were predicted to recover with time at the 30m pools. The predicted recovery periods were, respectively: 8, 10, and 9 years, for SVL, mass, and BCI. Conversely, biomass at 30m pools was predicted to decrease by about 9% each year. Biomass at 100m pools depended on year and mean hydroperiod. During the first year post-cut, on average, less biomass was predicted at 100m versus reference pools. For each successive year, however, 100m biomass was predicted to increase by about 19%, so that by 3.5 years post-cut, similar amounts of biomass were predicted from typical 100m and reference pools. We also found that short-hydroperiod pools had much less biomass in the 100m versus reference treatment, but biomass increased at 100m pools by about 2.9% per additional day of mean hydroperiod. Finally, new-capture male body condition tended to worsen as mean hydroperiod increased.

Wood Frogs

For wood frog size and biomass generally, females and recaptured adults were more sensitive to buffer treatment than males and new-captured adults, respectively. Additionally, hydroperiod was a strong predictor across size metric, sex, and capture status.

For recaptured female wood frogs, BCI and biomass were predicted to be, on average, lower at 30m pools than at reference pools, and did not recover during the study (Figs. 2.5 & 2.6). Further, SVL was predicted to decrease by 1.32 mm/year at the 30m pools. At short-hydroperiod pools, biomass was lower in the 100m versus reference treatment, but for each additional day of mean hydroperiod, 100m biomass was predicted to increase by about 3%. Body condition worsened as hydroperiod variability increased. Finally, recaptured female mass was unrelated to treatment, year, or hydroperiod.

For new-captured female wood frogs, biomass in the 30m treatment was predicted to decrease by about 14% per year. Similar to recaptured females, new-captured female biomass at short-hydroperiod pools was lower in the 100m versus reference treatment, but 100m biomass was predicted to increase with each additional day of mean hydroperiod by about 1.4%. In both cut treatments, SVL and mass were predicted to increase post-cut, by 0.3 mm/year and 0.2 g/year, respectively. Finally, BCI was unrelated to treatment, year, or hydroperiod.

For recaptured male wood frogs, SVL and biomass were predicted to decrease at 30m pools by 0.9 mm/year and about 44% per year, respectively (Figs. 6 & 7). Similarly, as hydroperiod variability increased, SVL, mass, and BCI decreased, such that for each additional day of hydroperiod variability, frogs were predicted to be 0.04 mm shorter and weigh 0.03 g less. Conversely, for each additional day of mean hydroperiod, recaptured male biomass was predicted to increase by about 1.5%.

For new-captured male wood frogs, for every additional day of hydroperiod variability, body mass was predicted to decrease by 0.03 g, but for each additional day of mean hydroperiod duration, biomass was predicted to increase by about 1.5%. Both SVL and BCI of new-captured males were unrelated to treatment, year, or hydroperiod.

Discussion

This is the first landscape-scale experiment to test how buffer width affects the impacts of forest clearcutting on amphibian body size, condition, and biomass at natural vernal pools. As hypothesized, we generally found that amphibians were smaller, had lower energy reserves, and supported less biomass at pools with a narrow 30m buffer versus 100m-buffer or reference pools. The response at 100m pools was typically mediated by hydroperiod: short-hydroperiod pools had less biomass in the 100m versus reference treatment. Overall, spotted salamanders were more affected than wood frogs and recaptured adults were more sensitive than new-captured adults. Though some size and condition metrics started to recover during the first six years post-cut, other impacts persisted or worsened. Our study demonstrates that clearcutting is associated with strong sub-lethal effects on local amphibian populations. These effects potentially signal reduced population resilience, which could alter local and regional population and community dynamics. Wider buffers helped mitigate the magnitude and duration of these effects.

Size and Condition

Mechanisms

Food energy is allocated to one of four uses: maintenance, growth, reproduction, or storage. As ectotherms, amphibians have low maintenance costs and efficiently convert food to biomass (Pough 1980). Various factors can disrupt this efficiency, causing reallocation of energetic investments and reduced body size and condition. In clearcuts, high temperatures and low humidity (Chen et al. 1999; Harpole and Haas 1999; Rothermel and Luhring 2005) can elevate metabolic rates (Whitford and Hutchison 1967; Whitford 1973) and maintenance costs (Spotila 1972; Homyack et al. 2011), while inhibiting foraging (deMaynadier and Hunter Jr.

1995; Sieg 2010). Higher predation risk (Blomquist and Hunter 2007; Rittenhouse et al. 2009) or less prey in cuts or along cut edges could also limit food intake (Harper and Guynn Jr. 1999; Homyack et al. 2011). Such problems can compound if robust individuals claim prime buffer habitat, 'despotically' forcing stunted individuals into the cut (Fretwell 1972; Patrick et al. 2006; Welsh et al. 2008). Alternatively, individuals may avoid the cut by remaining in the buffer, causing overcrowding. This could limit food consumption and elevate maintenance costs, through increased competition for prey and shelter (Regosin et al. 2004; Patrick et al. 2008b; Berven 2009), predation risk (Rittenhouse et al. 2009), and the stress associated with competitive interactions and predator avoidance (Cooperman et al. 2004; Watson et al. 2004; Janin et al. 2011). With increased maintenance and reduced food intake, individuals would be forced to invest less in reproduction, growth, and/or storage. Negative feedback, whereby small adults produce small eggs (Berven 1988; Scott and Fore 1995), which become disadvantaged larvae (DuShane and Hutchinson 1944; Komoroski et al. 1998; Berven 2009), which metamorphose into stunted adults (Werner 1986; Semlitsch 1987a; Scott 1994), could reinforce this pattern. Alternatively, large or well-conditioned adults might be killed during cutting or emigrate to other pools (Petranka et al. 2004) leaving small, weak individuals behind.

Overall, reduced size and body condition suggest poor habitat quality in the 30m treatment (Stevenson and Woods 2006; Homyack 2010; Janin et al. 2011). By comparing SVL, mass, and condition, we can discern how habitat degradation altered energy allocation across treatments, species, sexes, and capture classes and start to elucidate mechanisms by which timber harvest influences amphibian populations. For recaptured spotted salamanders, SVL showed no recovery during the six study years, whereas female mass and condition were predicted to recover by about 9 years post-cut and male mass by about 11 years. Clearly, recaptured adults

did not invest in structural growth, but prioritized maintenance, reproduction, and, for females, storage. These recovery trajectories suggest recaptured salamander size and condition take 10+ years after a clearcut to either rebound or adjust to reduced habitat carrying capacity (Janin et al. 2011). Among new-captures, by contrast, the SVL of both sexes and male mass and body condition, were recovering by the experiment's end. New-captured salamanders include immigrants and residents who previously refrained from breeding. New-capture recovery trajectories suggest several possible conclusions. First, 30m-treatment habitat alterations were least severe for male new-captures. Second, large (long) immigrants perceived the 30m treatment as viable habitat only after several years of cut regeneration. Finally, resident new-capture salamanders adopted differing allocation strategies, with some breeding shortly after the cut, at the expense of structural growth; and others prioritizing growth by delaying breeding for several years post-cut.

Among recaptured wood frogs in the 30m treatment, mean SVL decreased over time, suggesting that frogs invested less energy in structural growth and/or mean age declined over the course of the study. Similarly, females had persistently poor body condition, indicating insufficient food in-take to amass fat reserves. However, buffer treatment did not influence either sex's mass or male body condition, suggesting recaptured frogs favored maintenance, reproduction, and (among males) fat storage, over growth. Previous research from unbuffered landscapes also found anuran growth constrained in clearcuts versus uncut forest (Neckel-Oliveira and Gascon 2006; Patrick et al. 2006; Todd and Rothermel 2006). In the current study, we differentiate between sexes and capture classes, demonstrating that both male and female recaptured frogs experience reduced growth in habitat disturbed by clearcutting, even when frogs can freely move between a 30m buffer, clearcut, and forest beyond the cut. By contrast, new-

captured frog size and condition did not differ across treatments, implying that immigrant frogs traversed cuts without significant energetic losses.

In general, spotted salamanders experienced stronger negative effects in the 30m treatment than wood frogs. We suggest three explanations for this inter-species difference. First, both species migrate on rainy nights when desiccation is unlikely (Shoop 1965; Baldwin et al. 2006a; Veysey et al. 2009), but wood frogs are more vagile (Guerry and Hunter 2002; Petranka et al. 2004; Smith and Green 2005) and may cross cuts more quickly (Veysey et al. 2009; Freidenfelds et al. 2011), spending fewer days exposed to severe clearcut conditions. Further, salamanders may be more likely to linger in clearcuts, because salamanders primarily shelter in underground burrows (Madison 1997; deMaynadier and Hunter 1998; Faccio 2003). In our cuts, stumps were mostly left in place and no mechanical site preparation occurred, such that burrow structure may have been largely preserved (Veysey et al. 2009). Because aboveground weather is more extreme in clearcuts than forests (Chen et al. 1999; Rothermel and Luhring 2005; Freidenfelds et al. 2011), salamanders in cuts may be trapped in burrows for extended periods, minimizing foraging, and thereby negatively impacting size and condition (Shoop 1974; Homyack et al. 2011). Wood frogs, however, frequently shelter in leaf litter (Heatwole 1961; Baldwin et al. 2006a). Since young clearcuts have less litter than forests (Enge and Marion 1986; Russell et al. 2002; Patrick et al. 2006), frogs likely minimized time in cuts, only entering to migrate through to distant forests (Freidenfelds et al. 2011). Finally, spotted salamanders may be more sensitive to terrestrial density dependence than wood frogs. Though both species may crowd into 30m buffers, the consequences may be more negative for salamanders for various reasons. For example, burrows are likely scarcer than leaf litter and salamanders may be forced to share burrows or remain unsheltered. Forced sharing may increase agonistic interactions,

causing greater stress (Cooperman et al. 2004) and physical trauma (Ducey and Ritsema 1988; Walls 1990). In turn, salamanders may limit foraging to avoid competitive interactions (Ducey and Ritsema 1988; Smyers et al. 2002) or expend more energy while foraging over a broader area (Janin et al. 2011). Small salamanders may also be forced into suboptimal edge or cut habitat by larger competitors (Regosin et al. 2003a; Patrick et al. 2006; Welsh et al. 2008), negatively reinforcing their stature.

Implications

Reduced size and body condition are linked to numerous individual traits that can scale up to detrimentally impact local and regional populations. We categorize individual traits into reproductive, performance, and survival effects. Among the reproductive impacts, small size is associated with decreased clutch mass and volume (Kaplan and Salthe 1979; Berven 1988), egg size (Kaplan and Salthe 1979; Berven 1988; Scott and Fore 1995), egg nutrition (Berven 1988), number of eggs (Woodward 1982; Berven and Gill 1983; Scott and Fore 1995), mating success (Berven 1981; Howard and Kluge 1985; Chandler and Zamudio 2008), and survival during breeding (Berven 1981); and increased time to maturity and, for salamanders, inter-breeding interval (Scott and Fore 1995; Janin et al. 2011). Poor body condition can alter mating behavior (Eggert and Guyetant 2003; Humfeld 2013), leading to lower reproductive success (Brepson et al. 2013; Humfeld 2013). Small size can limit performance through reduced stamina (Bennett et al. 1989; Goater et al. 1993; Beck and Congdon 2000), jump distance (Emerson 1978; John-Alder and Morin 1990), and migration distance (Ponsero and Joly 1998; Faccio 2003), which may inhibit an animal's ability to escape predators or access good-quality habitat. As for survival, small individuals tend to store fewer lipids (Scott 1994; Scott and Fore 1995; Scott et al. 2007)

and dehydrate faster (Spotila 1972; Newman and Dunham 1994), leading to lower survival, especially under severe weather conditions (Scott 1994; Rothermel and Semlitsch 2006; Garner et al. 2011). Body size also influences population spatial structure: small individuals may be competitively excluded from prime habitats (Regosin et al. 2003a; Patrick et al. 2006) or crowd around water sources (Bellis 1962).

Ultimately, individual effects can alter local and regional population dynamics. Small amphibians of poor body condition are vulnerable to extreme weather and other stressors (Spotila 1972; Begon et al. 1996; Reading 2007), can depress breeding population size through delayed maturity (Semlitsch et al. 1988; Berven and Grudzien 1990) or skipped breeding events (Gill 1985; Morrison and Hero 2003; Church et al. 2007), and may have low reproductive success (Kaplan and Salthe 1979; Berven 1988; Reading 2007). A population of vulnerable individuals is likely less resilient to disturbance and other stressors and may rely excessively on immigration or adult survival to persist (Johst and Brandl 1997; Taylor and Scott 1997; Harper et al. 2008). Reduced reproductive success may also translate to fewer or less robust dispersers (Bonte and De la Pena 2009; Benton and Bowler 2012), depressing gene flow and altering regional population dynamics. Where a local population siphons immigrants from the regional disperser pool and produces less viable dispersers, it may act as a regional sink. Though total breeding-adult abundance was not reduced, we did find that both species' breeding-population structure was altered, with fewer recaptured amphibians and female salamanders present at 30m pools, confirming that this treatment did indeed serve as sink habitat and that reproductive potential was diminished (Veysey Powell and Babbitt *in review*).

Biomass

Mechanisms

Analyzing how adult-amphibian biomass varied across treatments is key to understanding how clearcuts alter ecosystem flows and community interactions. Adult spotted salamanders and wood frogs are important predators of forest-floor invertebrates (Marshall and Buell 1955; Knox 1999; Degraaf and Yamasaki 2001) and efficiently convert invertebrate to amphibian biomass (Pough 1980; Davic and Welsh 2004). In turn, both species are a vital food source for decomposers and larger predators (deMaynadier and Hunter Jr. 1995; Knox 1999; Davic and Welsh 2004). Adults also provide high-quality food to vernal-pool communities via eggmass deposition or if adults perish while breeding (deMaynadier and Hunter Jr. 1995; Regester et al. 2006; Regester and Whiles 2006). Consequently, both species are an important conduit for the flow of forest nutrients and energy into vernal pools and link multiple trophic levels in both subsystems (Regester et al. 2006; Regester and Whiles 2006; Schriever et al. 2014). As long-lived, fossorial adults, spotted salamanders also enhance soil fertility and stabilize ecosystem fluxes (Davic and Welsh 2004). Despite these contributions, few studies have examined forestry impacts on amphibian biomass. Available studies show amphibian biomass is generally lower in recent cuts, but none included buffers in the study design (Enge and Marion 1986; Corn and Bury 1989; Aubry 2000); but see (deMaynadier and Hunter Jr. 1995).

In our experiment, clearcutting was associated with reduced amphibian biomass, but more strongly in the 30m than the 100m buffer treatment. In fact for both species, biomass at 30m pools declined over time, suggesting deteriorating habitat quality or a lagged response to cutting. For wood frogs, biomass and SVL declined in tandem at 30m pools, suggesting reduced structural growth as the reason for diminished biomass. For spotted salamanders, biomass fell

despite some recovery of individual size and condition and relatively stable breeding abundances (Veysey Powell and Babbitt *in review*), suggesting no single driver of salamander biomass loss.

At 100m pools, adult biomass production was mediated by hydroperiod, such that short-hydroperiod, 100m pools produced much less biomass than short-hydroperiod reference pools. For spotted salamanders, this pattern mirrored adult abundance (Veysey Powell and Babbitt *in review*), not size. For wood frogs, no particular driver was apparent, but only females were affected. It is unsurprising that biomass and hydroperiod were related, since hydroperiod is a determinative force in vernal-pool systems, influencing species distributions (Skelly et al. 1999; Babbitt et al. 2003; Baber et al. 2004), community composition (Snodgrass et al. 2000; Urban 2004; De Meester et al. 2005) and larval growth (Scott 1990; Rowe and Dunson 1995; Brodman 1996) and survival (Shoop 1974; Semlitsch 1987b; Taylor et al. 2006). It is well established that spotted salamander and wood frog abundance generally increase with vernal-pool hydroperiod (Egan and Paton 2004; Baldwin et al. 2006b; Veysey et al. 2011). If one considers only short-hydroperiod pools, however, the biomass difference between 100m and reference pools is striking. Apparently, cutting degraded habitat quality in the 100m treatment, but this only occurred, or was only apparent, if the population was also stressed hydrologically.

Implications

Adult biomass was reduced at 30m pools and short-hydroperiod 100m pools, limiting the amount of high-quality food available to amphibian predators and detrivores in and around these pools (deMaynadier and Hunter Jr. 1995; Regester and Whiles 2006). Lower biomass also likely means reduced nutrient and energy subsidies from forests into pools and modified food webs in both subsystems (Regester et al. 2006; Regester and Whiles 2006). Salamander biomass declines

may additionally serve to destabilize ecosystem processes, since their biomass is a long-term storage location for nutrients and energy (Davic and Welsh 2004). With less salamander biomass, resources may flow more quickly through food webs, resulting in more extreme population fluctuations at other trophic levels (deMaynadier and Hunter Jr. 1995; Davic and Welsh 2004).

Conclusions

Traditionally, researchers use species occurrence and abundance to assess disturbance impacts (Stevenson and Woods 2006; Welsh et al. 2008; Homyack 2010). While valuable, such metrics describe population responses, which may only be discernable after multiple breeding cycles (Todd and Rothermel 2006; Janin et al. 2011; MacCracken and Stebbings 2012). Individualized metrics, like body size and condition, may be more sensitive since population changes only accrue after enough individuals are affected. Individual metrics can forewarn lagged population responses, reveal sub-lethal effects that undermine population resilience, and illuminate mechanisms driving population responses (Stevenson and Woods 2006; Homyack 2010; Janin et al. 2011). Condition, in particular, is often used to index habitat quality since it represents individual fat reserves, which are a function of prey availability and the metabolic demands of a habitat (Stevenson and Woods 2006; Homyack 2010; Brodeur et al. 2011). By contrast, biomass is an infrequently used metric that extends abundance data and connects population changes to ecosystem processes (Gibbons et al. 2006; Deichmann et al. 2008).

The reduced body size and condition that we observed indicate clearcutting degraded amphibian habitat quality in the 30m treatment. In response, individuals shifted energy allocation away from structural growth and, in many cases, fat storage. Individual costs of energetic redistribution are substantial, but collective costs may be greater, and potentially include

constrained local reproductive output and altered regional population dynamics. Our biomass results also suggest that habitat quality declined at 30m pools, but further indicate synergistic effects of cutting and hydroperiod in the 100m treatment. More broadly, our biomass results imply that clearcuts altered food-web dynamics and ecosystems fluxes, within and between forests and vernal pools. Forest managers wishing to minimize amphibian size, condition, and biomass impacts should use buffers that are greater than 30 m wide and incorporate hydroperiod into management decisions. Where amphibian conservation is a primary objective and hydroperiod is short (i.e., < 4 months; (Babbitt et al. 2003; Egan and Paton 2004; Veysey et al. 2011), buffers wider than 100 m may be necessary. Where amphibians are one of several concerns, buffering pools with hydroperiods longer than four months may provide the greatest conservation-investment return. Note that our results describe amphibian response to a single clearcut configuration (i.e., circular, 100-m wide). Different responses might be observed with alternative clearcut designs, but investigating other designs was beyond the scope of our project.

Additional research is needed to understand how individual impacts scale up to influence local and regional population dynamics and ecosystem function, especially across diverse landscapes. Our landscape is largely forested and our cuts regenerated mostly undisturbed. Clearcut structure and micro-climate can change rapidly with regeneration (deMaynadier and Hunter Jr. 1995; Patrick et al. 2006; Popescu and Hunter Jr. 2011). Cuts that are initially unsuitable for amphibians should regain suitability with time (deMaynadier and Hunter Jr. 1995; Aubry 2000; Morris and Maret 2007). Though cutting strongly impacted individual amphibians, especially in the 30m treatment, certain metrics, like recaptured salamander mass, started to rebound by the study's end. In this landscape, there seems to be a vulnerability window of 8 to 14+ years post-clearcut, when adult body size, condition, and biomass are reduced and local

populations may be particularly sensitive to additional disturbance or stressors. If regeneration continues undisrupted and habitat quality improves, individual traits likely recover and the vulnerability window closes. Lacking additional stressors, local population persistence and abundance may remain relatively stable and regional population dynamics may be little affected. Recent genetic studies from our landscape support this hypothesis. While clearcutting strongly impacted individual amphibians and increased population vulnerability at many of our focal pools, spotted salamander and wood frog populations across the broader industrial forest demonstrated high genetic connectivity, suggesting regional population resilience (Coster 2013; Coster et al. *in review*).

Ultimately, forest managers must consider the cumulative impacts of cutting on a landscape and whether additional stressors are likely to compound the local effects of any single cut. Existing practices, including strategic clearcut rotation on a multi-decadal interval (04-058 CMR ch.20; Seymour et al. 2006), may be sufficient to maintain amphibian connectivity with minimal buffering, given current climatic conditions and forest-product demand. If projections for the northeast are accurate, however, and summers become hotter (Anderson et al. 2010) with more frequent droughts (Hayhoe et al. 2007), while forest harvests intensify (Irland 1999), landscape resistance to amphibian movement may increase (Rodenhouse et al. 2009; Veysey et al. 2009) and regional connectivity be disrupted. In this case, buffers will be a critical tool for maintaining local population resilience in forestry-based landscapes.

Table 2.1. Mean and variability of predictor and amphibian size variables, by species, capture status, and sex.

		Mean ± SE	Range								
Mean hydroperiod (days)		126.0 ± 6.0	44.8-197.0								
SD hydroperiod[a] (days)		31.8 ± 1.6	6.3-48.8								
		SVL/SUL[b] (mm)		**Mass (g)**				**BCI[c]**			
		Mean ± SE	Range	Mean ± SE			Range	Mean ± SE			Range
Spotted Salamander											
recapture	F	80.8 ± 0.4	55.0-100.0	16.5	±	0.2	6.5-28.0	0.072	±	0.019	-0.942-1.082
	M	72.2 ± 0.3	51.0-98.0	12.4	±	0.1	5.5-21.0	0.127	±	0.014	-0.715-1.034
new-capture	F	79.5 ± 0.3	53.0-102.0	15.3	±	0.1	6.0 – 31.0	-0.021	±	0.011	-1.153-1.939
	M	70.2 ± 0.2	51.0-96.0	10.8	±	0.1	4.5-24.0	-0.043	±	0.008	-1.589-1.103
Wood Frog											
recapture	F	51.4 ± 0.2	35.0-59.0	12.6	±	0.1	5.3-19.3	0.023	±	0.009	-0.318-0.454
	M	44.1 ± 0.1	31.0-56.0	9.1	±	0.1	4.1-14.3	0.019	±	0.006	-0.462-0.710
new-capture	F	49.4 ± 0.1	33.0-60.0	11.7	±	0.1	3.7-22.0	-0.003	±	0.004	-0.958-0.656
	M	43.3 ± 0.1	27.0-61.0	8.7	±	<0.1	3.3-19.6	-0.004	±	0.003	-0.777-0.821

[a] Standard deviation of pool hydroperiod.
[b] Snout-vent or snout-urodyle length.
[c] Body condition index. Obtained via ordinary least squares regression of mass on SVL/SUL. Mass and SVL/SUL were square-root transformed for salamanders and log-transformed for frogs, prior to regression. BCI measures relative energy reserves. BCI > 0 indicates better body condition than BCI < 0. Mean BCI may not equal zero because BCI was calculated over recaptured and new-captured animals combined, for each sex.

Table 2.2. Mean and variability of total annual breeding amphibian biomass by species, forestry treatment, capture status, and sex.

Adult Biomass (g)										
Species	**Sex**	**Treatment**	**Mean ± SE**			**Range**			**Total**
Spotted Salamander									
recapture	F	Reference	71.2	±	17.2	0	-	227.2	1068.4
		100m	160.0	±	66.5	0	-	1273.4	3199.1
		30m	52.2	±	14.6	0	-	240.5	992.3
	M	Reference	102.6	±	23.1	0	-	286.0	1539.5
		100m	171.8	±	48.8	0	-	750.8	3435.9
		30m	55.7	±	12.0	0	-	191.6	1057.8
new-capture	F	Reference	214.8	±	26.1	29.6	-	436.0	3866.9
		100m	390.5	±	108.9	0	-	2158.6	9373.1
		30m	213.9	±	32.0	27.4	-	551.5	4920.4
	M	Reference	179.6	±	33.1	0	-	570.9	3232.9
		100m	383.1	±	96.7	0	-	1493.5	9195.4
		30m	210.8	±	37.2	45.0	-	819.7	4848.7
Wood Frog									
recapture	F	Reference	99.3	±	25.7	0	-	337.8	1489.2
		100m	74.9	±	27.1	0	-	515.4	1498.8
		30m	33.9	±	11.0	0	-	175.2	645.0
	M	Reference	222.1	±	82.6	26.3	-	1347.7	3331.4
		100m	106.9	±	25.9	0	-	421.6	2137.5
		30m	55.5	±	11.5	0	-	189.8	1054.4
new-capture	F	Reference	498.2	±	87.5	109.8	-	1319.2	8968.2
		100m	341.3	±	55.2	17.8	-	1049.5	8192.3
		30m	329.1	±	48.9	22.7	-	897.5	7570.2
	M	Reference	600.7	±	139.8	88.2	-	2765.9	10812.0
		100m	385.4	±	69.6	27.5	-	1386.3	9249.4
		30m	390.1	±	50.5	51.8	-	855.2	8972.3

Table 2.3. Linear mixed regression results showing the relative impact of forestry treatment, hydroperiod, and study year on size, body condition, and total annual biomass of breeding spotted salamanders and wood frogs.

Size Metric	Predictor[c]	F value$_{(df)}$[j]	t value$_{(df)}$[l]	Coefficient ± SE
Spotted Salamander				
Recaptured Females				
SVL[a] (mm)	treatment(30m)[d]	$3.61_{(2,312)}^{*}$	$-2.10_{(312)}^{*}$	-9.089 ± 4.336
	intercept	$683.04_{(1,312)}^{***}$	$26.13_{(312)}^{***}$	86.708 ± 3.318
mass (g)	treatment(30m)	$7.90_{(2,6)}^{*}$	$-3.89_{(6)}^{*}$	-8.938 ± 2.296
	30m.year[e]	$4.28_{(1,300)}^{*}$	$2.07_{(300)}^{*}$	1.049 ± 0.507
	intercept	$64.15_{(1,300)}^{***}$	$8.01_{(300)}^{***}$	20.062 ± 2.505
BCI[b]	treatment(30m)	$6.38_{(2,301)}^{*}$	$-2.01_{(301)}^{*}$	-0.385 ± 0.192
	cut.year[f]	$5.78_{(1,301)}^{*}$	$-2.40_{(301)}^{*}$	-0.066 ± 0.027
	30m.year	$4.28_{(1,301)}^{*}$	$2.07_{(301)}^{*}$	0.105 ± 0.051
	mean.hydro[g]	$7.91_{(1,301)}^{*}$	$-2.81_{(301)}^{*}$	-0.002 ± 0.001
	sd.hydro[h]	$7.46_{(1,301)}^{*}$	$-2.73_{(301)}^{*}$	-0.005 ± 0.002
	intercept	$15.25_{(1,301)}^{**}$	$3.91_{(301)}^{**}$	0.530 ± 0.136
biomass (g)	30m.year	$16.37_{(1,47)}^{**}$	$-4.05_{(47)}^{**}$	-0.734 ± 0.181
	mean.hydro	$4.00_{(1,47)}^{\bullet}$	$2.00_{(47)}^{\bullet}$	0.024 ± 0.012
New-captured Females				
SVL (mm)	treatment(30m)	$4.78_{(2,1079)}^{*}$	$-2.53_{(1079)}^{*}$	-7.820 ± 3.095
	30m.year	$5.75_{(1,1079)}^{*}$	$2.40_{(1079)}^{*}$	0.660 ± 0.275
	intercept	$397.14_{(1,1079)}^{***}$	$19.93_{(1079)}^{***}$	84.855 ± 4.258
mass (g)	treatment(30m)	$3.25_{(2,1051)}^{*}$	$-2.34_{(1051)}^{*}$	-4.461 ± 1.905
	intercept	$51.52_{(1,1051)}^{***}$	$7.18_{(1051)}^{***}$	19.008 ± 2.648
BCI	treatment(30m)	$2.34_{(2,1054)}^{\bullet}$	$-1.96_{(1054)}^{\bullet}$	-0.229 ± 0.117
biomass (g)	treatment(100m)[i]*mean.hydro	$7.91_{(2,45)}^{*}$	$3.88_{(45)}^{**}$	0.040 ± 0.013
	treatment(100m)	$6.62_{(2,45)}^{*}$	$-3.48_{(45)}^{*}$	-5.212 ± 1.496
	intercept	$21.21_{(1,45)}^{***}$	$4.61_{(45)}^{***}$	5.564 ± 1.208
Recaptured Males				
SVL (mm)	treatment(30m)	$5.38_{(2,478)}^{*}$	$-3.05_{(478)}^{*}$	-9.778 ± 3.201
	intercept	$415.79_{(1,478)}^{***}$	$20.39_{(478)}^{***}$	79.218 ± 3.885

Table 2.3 continued.

mass (g)	treatment(30m)	$7.31_{(2,473)}^{**}$	$-3.53_{(473)}^{**}$	-4.796	± 1.359
	30m.year	$3.05_{(1,473)}^{\bullet}$	$1.75_{(473)}^{\bullet}$	0.373	± 0.214
	intercept	$92.18_{(1,473)}^{***}$	$9.60_{(473)}^{***}$	15.321	± 1.596
BCI	treatment(30m)	$5.15_{(2,468)}^{*}$	$-3.17_{(468)}^{*}$	-0.439	± 0.138
	mean.hydro	$5.54_{(1,468)}^{*}$	$-2.35_{(468)}^{*}$	-0.001	± <0.001
	intercept	$6.73_{(1,468)}^{*}$	$2.59_{(468)}^{*}$	0.297	± 0.114
biomass (g)	treatment(100m)*mean.hydro	$4.24_{(2,45)}^{*}$	$2.90_{(45)}^{*}$	3.038	± 1.047
	treatment(100m)	$3.15_{(2,45)}^{\bullet}$	$-2.50_{(45)}^{*}$	-314.310	± 125.594
	sd.hydro	$3.62_{(1,45)}^{\bullet}$	$-1.90_{(45)}^{\bullet}$	-3.457	± 1.818
	intercept	$4.19_{(1,45)}^{*}$	$2.05_{(45)}^{*}$	251.847	± 123.053
New-captured Males					
SVL (mm)	treatment(30m)	$4.36_{(2,1444)}^{*}$	$-2.73_{(1444)}^{*}$	-7.820	± 2.865
	cut.year	$3.15_{(1,1444)}^{\bullet}$	$1.77_{(1444)}^{\bullet}$	0.500	± 0.282
	30m.year	$5.39_{(1,1444)}^{*}$	$2.32_{(1444)}^{*}$	0.556	± 0.239
	intercept	$398.02_{(1,1444)}^{***}$	$19.95_{(1444)}^{***}$	77.363	± 3.878
mass (g)	treatment(30m)	$6.78_{(2,1410)}^{*}$	$-3.01_{(1410)}^{*}$	-3.620	± 1.204
	30m.year	$22.70_{(1,1410)}^{***}$	$4.76_{(1410)}^{***}$	0.409	± 0.086
	mean.hydro	$3.27_{(1,1410)}^{\bullet}$	$-1.81_{(1410)}^{\bullet}$	-0.015	± 0.008
	intercept	$78.92_{(1,1410)}^{***}$	$8.88_{(1410)}^{***}$	14.336	± 1.614
BCI	treatment(30m)	$11.02_{(2,1410)}^{***}$	$-3.22_{(1410)}^{*}$	-0.274	± 0.085
	30m.year	$12.03_{(1,1410)}^{**}$	$3.47_{(1410)}^{**}$	0.043	± 0.012
	mean.hydro	$3.62_{(1,1410)}^{\bullet}$	$-1.90_{(1410)}^{\bullet}$	-0.001	± <0.001
biomass (g)	treatment(100m)*mean.hydro	$4.28_{(2,45)}^{*}$	$2.91_{(45)}^{*}$	0.030	± 0.013
	treatment(100m)	$4.53_{(2,45)}^{*}$	$-2.90_{(45)}^{*}$	-4.409	± 1.522
	cut.year	$3.79_{(1,45)}^{\bullet}$	$1.95_{(45)}^{\bullet}$	0.172	± 0.088
	30m.year	$9.45_{(1,45)}^{*}$	$-3.07_{(45)}^{*}$	-0.269	± 0.088
	intercept	$16.56_{(1,45)}^{**}$	$4.07_{(45)}^{**}$	5.202	± 1.278
Wood Frogs					
Recaptured Females					
SUL[a] (mm)	30m.year	$4.21_{(1,284)}^{*}$	$-2.05_{(284)}^{*}$	-1.284	± 0.626
	intercept	$473.14_{(1,284)}^{***}$	$21.75_{(284)}^{***}$	53.190	± 2.445
mass (g)	intercept	$89.78_{(1,236)}^{***}$	$9.48_{(236)}^{***}$	14.303	± 1.509

Table 2.3 continued.

BCI	treatment(30m)	$4.44_{(2, 231)}^{*}$	$-2.97_{(231)}^{*}$	-0.221	± 0.074
	sd.hydro	$5.97_{(1,231)}^{*}$	$-2.44_{(231)}^{*}$	-0.002	± 0.001
biomass (g)	treatment(100m)*mean.hydro	$6.10_{(2,45)}^{*}$	$3.49_{(45)}^{*}$	0.038	± 0.011
	treatment(100m)	$5.94_{(2,45)}^{*}$	$-3.33_{(45)}^{*}$	-5.794	± 1.741
	treatment(30m)		$-1.89_{(45)}^{\bullet}$	-5.005	± 2.654
	intercept	$14.18_{(1,45)}^{**}$	$3.77_{(45)}^{**}$	4.958	± 1.317
New-captured Females					
SUL (mm)	cut.year	$5.50_{(1,2041)}^{*}$	$2.34_{(2041)}^{*}$	0.349	± 0.149
	intercept	$1019.22_{(1,2040)}^{***}$	$31.93_{(2041)}^{***}$	50.362	± 1.577
mass (g)	cut.year	$5.55_{(1,1869)}^{*}$	$2.36_{(1869)}^{*}$	0.229	± 0.097
	intercept	$116.32_{(1,1869)}^{***}$	$10.78_{(1869)}^{***}$	12.572	± 1.166
BCI		ns[k]			
biomass (g)	treatment(100m)*mean.hydro	$3.45_{(2,56)}^{*}$	$2.63_{(56)}^{*}$	0.015	± 0.006
	treatment(100m)	$5.98_{(2,56)}^{*}$	$-3.45_{(56)}^{*}$	-2.931	± 0.850
	30m.year	$5.58_{(1,56)}^{*}$	$-2.36_{(56)}^{*}$	-0.268	± 0.113
	intercept	$59.07_{(1,56)}^{***}$	$7.69_{(56)}^{***}$	5.737	± 0.746
Recaptured Males					
SUL (mm)	30m.year	$3.91_{(1,706)}^{*}$	$-1.98_{(706)}^{*}$	-0.914	± 0.462
	sd.hydro	$11.44_{(1,706)}^{**}$	$-3.38_{(706)}^{**}$	-0.045	± 0.013
	intercept	$2064.37_{(1,706)}^{***}$	$45.44_{(706)}^{***}$	44.803	± 0.986
mass (g)	sd.hydro	$6.35_{(1,684)}^{*}$	$-2.52_{(684)}^{*}$	-0.033	± 0.013
	intercept	$202.99_{(1,684)}^{***}$	$14.25_{(684)}^{***}$	9.559	± 0.671
BCI	sd.hydro	$2.90_{(1,685)}^{\bullet}$	$-1.70_{(685)}^{\bullet}$	-0.002	± 0.001
biomass (g)	30m.year	$3.50_{(1,47)}^{\bullet}$	$-1.87_{(47)}^{\bullet}$	-0.518	± 0.277
	mean.hydro	$7.11_{(1,47)}^{*}$	$2.67_{(47)}^{*}$	0.015	± 0.006
	intercept	$5.21_{(1,47)}^{*}$	$2.28_{(47)}^{*}$	2.471	± 1.083
New-captured Males					
SUL (mm)	intercept	$5523.34_{(1,3082)}^{***}$	$4.32_{(3082)}^{***}$	44.060	± 0.593
mass (g)	sd.hydro	$5.86_{(1,2932)}^{*}$	$-2.42_{(2932)}^{*}$	-0.022	± 0.009
	intercept	$432.10_{(1,2932)}^{***}$	$0.79_{(2932)}^{***}$	9.403	± 0.452
BCI	sd.hydro	$5.60_{(1,6)}^{\bullet}$	$-2.37_{(6)}^{\bullet}$	-0.002	± 0.001

Table 2.3 continued.

biomass (g)	mean.hydro	$5.11_{(1,58)}^{*}$	$2.26_{(58)}^{*}$	0.008	± 0.004
	intercept	$43.91_{(1,58)}^{***}$	$6.63_{(58)}^{***}$	4.775	± 0.721

[a] SVL = snout-vent length; SUL = snout-urodyle length.
[b] Body condition index. BCI > 0 indicates better body condition than BCI < 0.
[c] All models included the following predictors: treatment, mean pool hydroperiod, standard deviation of pool hydroperiod, a treatmentXyear interaction, and a treatmentXmean.hydro interaction. Based on an a priori decision, we dropped the treatmentXmean.hydro interaction from the model if the interaction was not significant. Only significant fixed-effect results are shown.
[d] Categorical variable, coded 0 = reference treatment and 1 = 30m treatment.
[e] Dummy variable representing the marginal impact of the 30m treatment over the six study years.
[f] Dummy variable representing the difference between the reference treatment and the two cut treatments, over the six study years.
[g] Mean pool hydroperiod in days.
[h] Standard deviation of pool hydroperiod in days.
[i] Categorical variable, coded 0 = reference treatment and 1 = 100m treatment.
[j] We used F tests to assess overall significance of each variable. We provide results just once for each categorical variable.
[k] None of the independent variables were significant predictors of female new-capture wood frog body condition.
[l] We used t tests to compare between individual levels of categorical predictors.
*** $p < 0.0001$; ** $p < 0.001$; * $p < 0.05$; $^{\cdot}$ $0.05 \leq p < 0.1$

Figure 2.1. Experimental design implemented at 11 natural vernal pools in east-central Maine, USA. Undisturbed buffers of either 100m (left; n = 4) or 30m (right; n = 4) were left adjacent to pools and 100m wide clear cuts were created around the buffers. Forest beyond the clear cut was undisturbed. No cutting occurred at reference vernal pools (not shown; n = 3).

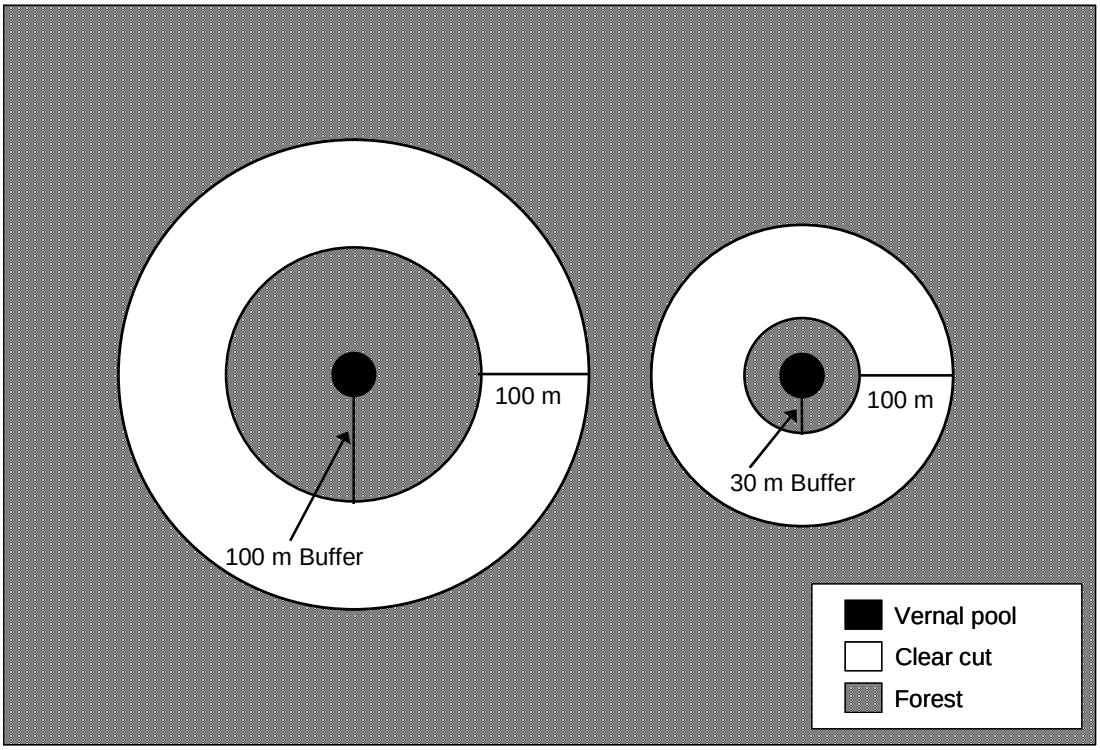


Figure 2.2. Mean (±1SE) A) snout-vent length (SVL; mm) across 3 experimental forestry treatments and B) body condition index (BCI) by forestry treatment and study year of recaptured breeding female spotted salamanders at 11 vernal pools in east-central Maine, USA. Treatments were: reference (uncut), 100m undisturbed buffer, and 30m undisturbed buffer.

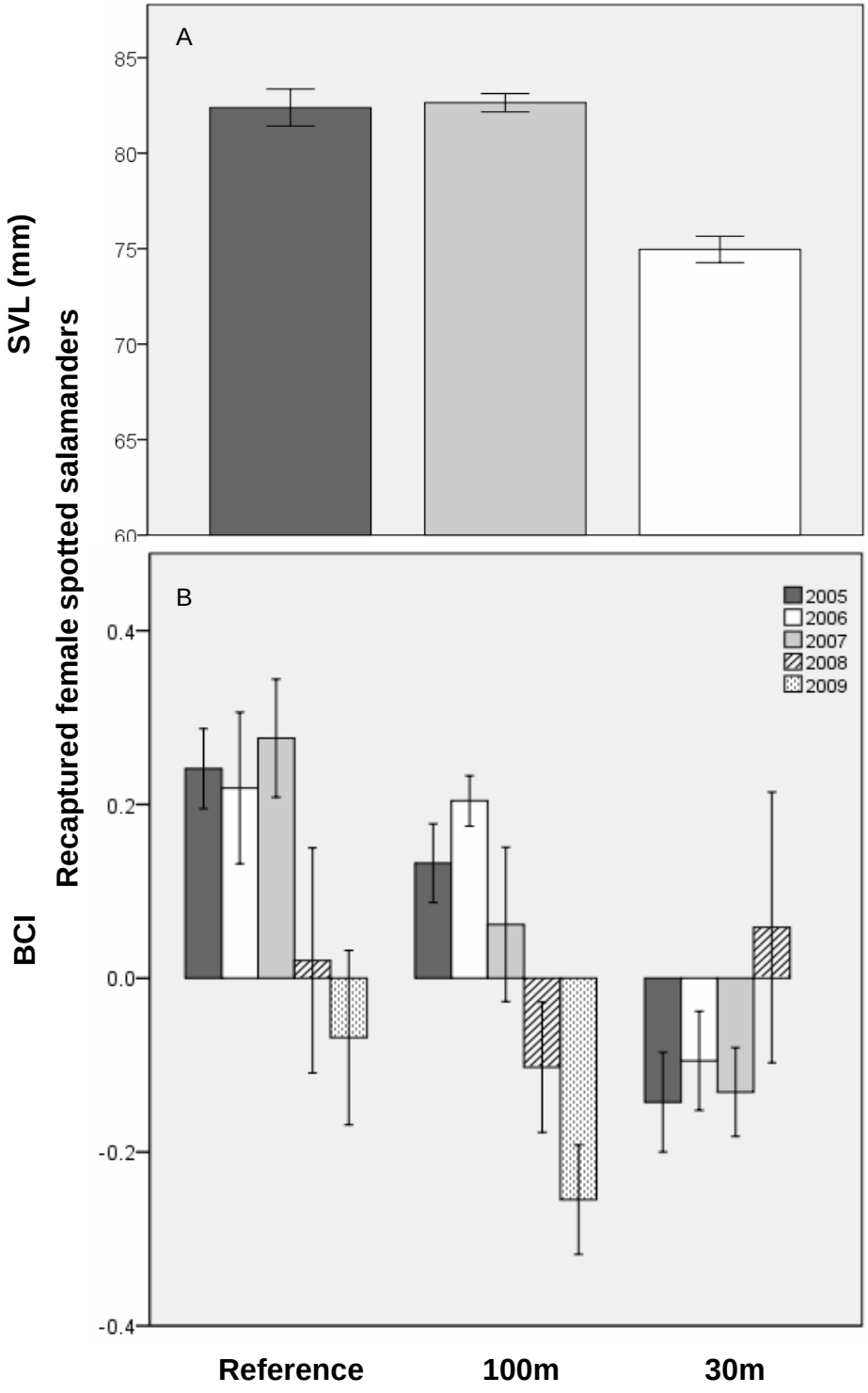


Figure 2.3. A) Mean (±1SE) body mass (g), B) mean (±1SE) snout-vent length by year (SVL; mm), and C) total annual biomass (g) of new-captured breeding female spotted salamanders across 3 experimental forestry treatments at 11 natural vernal pools in east-central Maine, USA. Treatments were: reference (uncut), 100m undisturbed buffer, 30m undisturbed buffer.

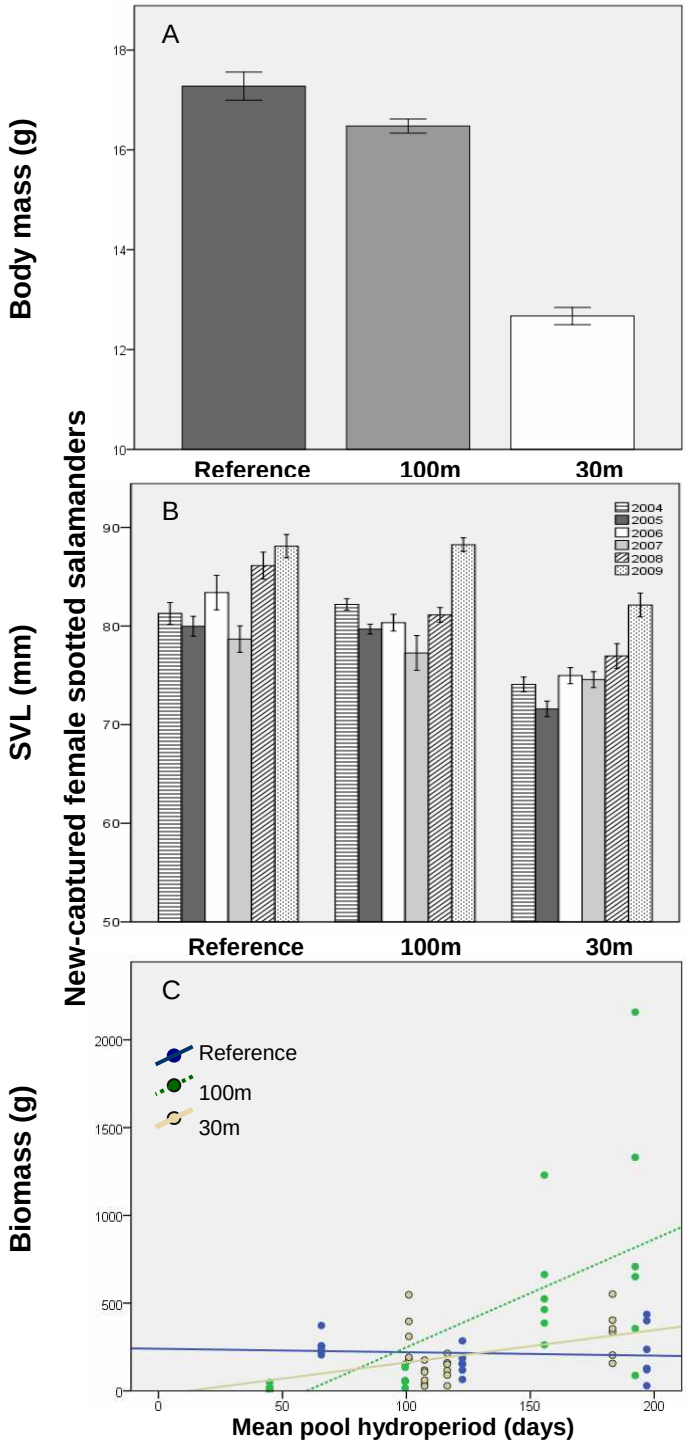


Figure 2.4. Mean (±1SE) A) body condition index (BCI) of recaptured breeding male spotted salamanders across 3 experimental forestry treatments and B) body mass (g) of new-captured breeding male spotted salamanders by forestry treatment and study year at 11 natural vernal pools in east-central Maine, USA. Treatments were: reference (uncut), 100m undisturbed buffer, and 30m undisturbed buffer.

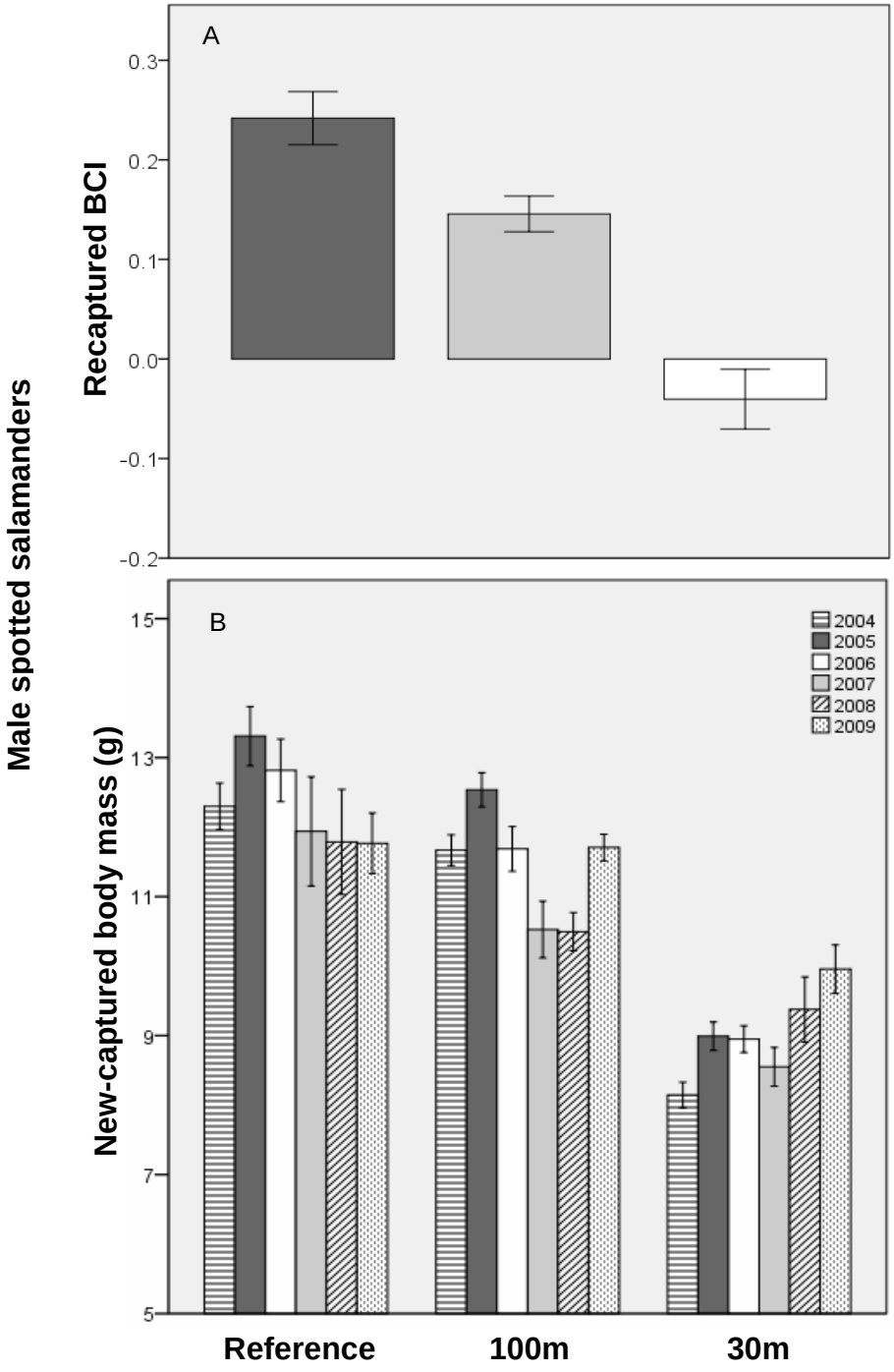


Figure 2.5. Mean (±1SE) A) body condition index (BCI) across 3 experimental forestry treatments and B) snout-urodyle length (SUL; mm) by forestry treatment and study year of recaptured breeding female wood frogs at 11 natural vernal pools in east-central Maine, USA. Treatments were: reference (uncut), 100m undisturbed buffer, and 30m undisturbed buffer.

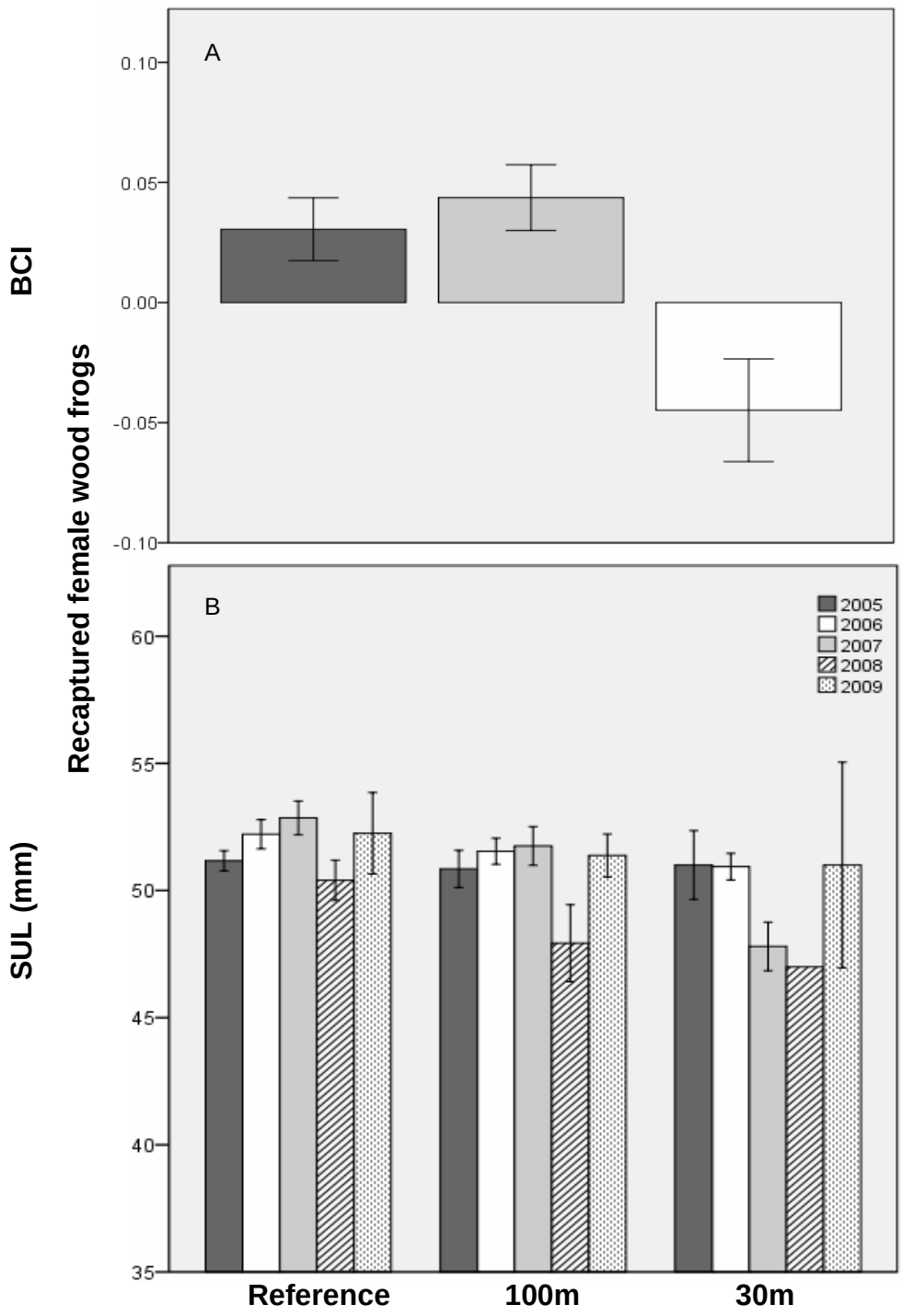


Figure 2.6. Total annual biomass (g) of recaptured breeding wood frogs at 11 natural vernal pools in east-central Maine, USA. A) Mean (±1SE) biomass of male frogs by forestry treatment and study year. B) Biomass of female frogs by forestry treatment and mean pool hydroperiod (days). Treatments were: reference (uncut), 100m undisturbed buffer, 30m undisturbed buffer.

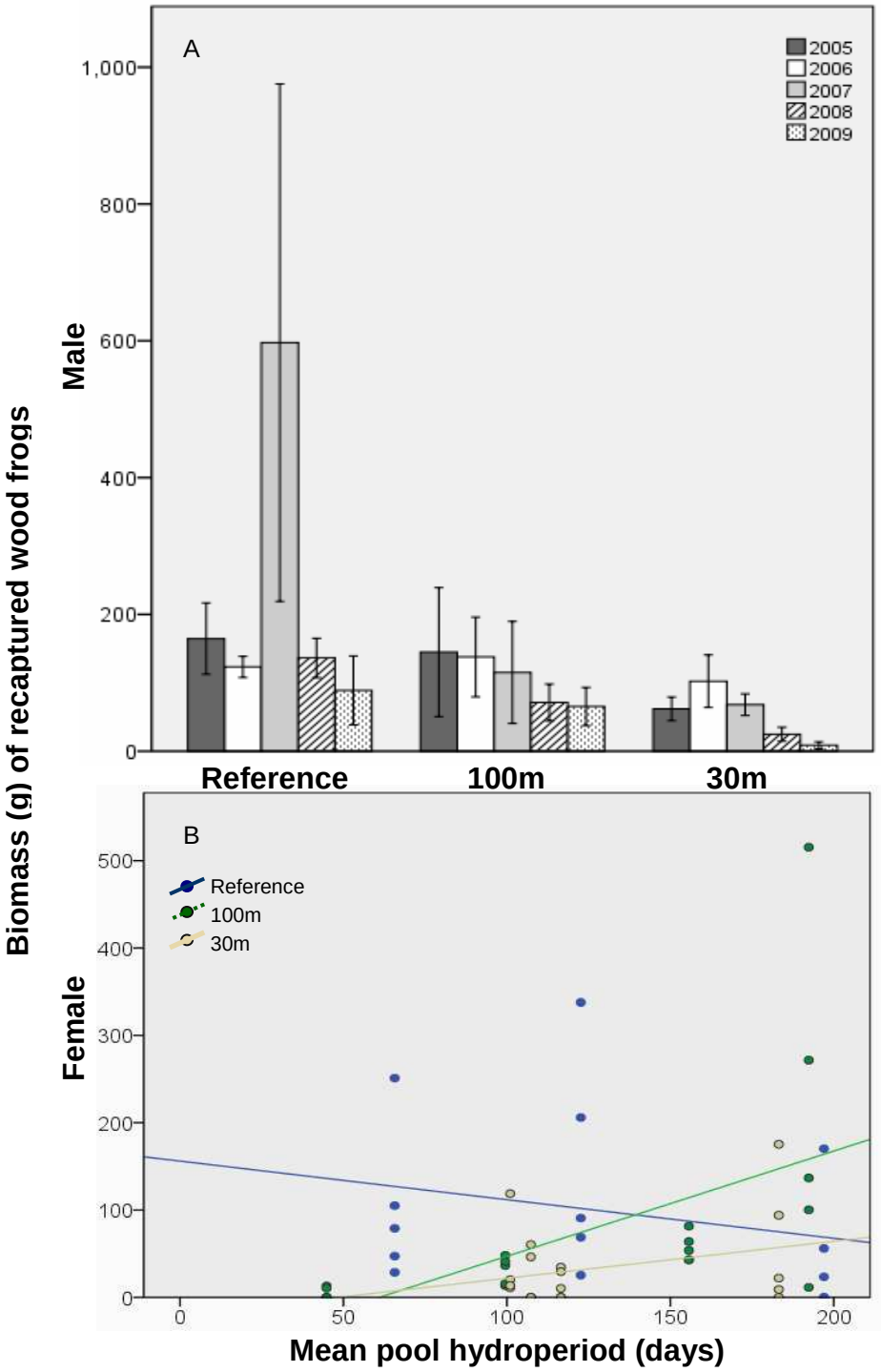
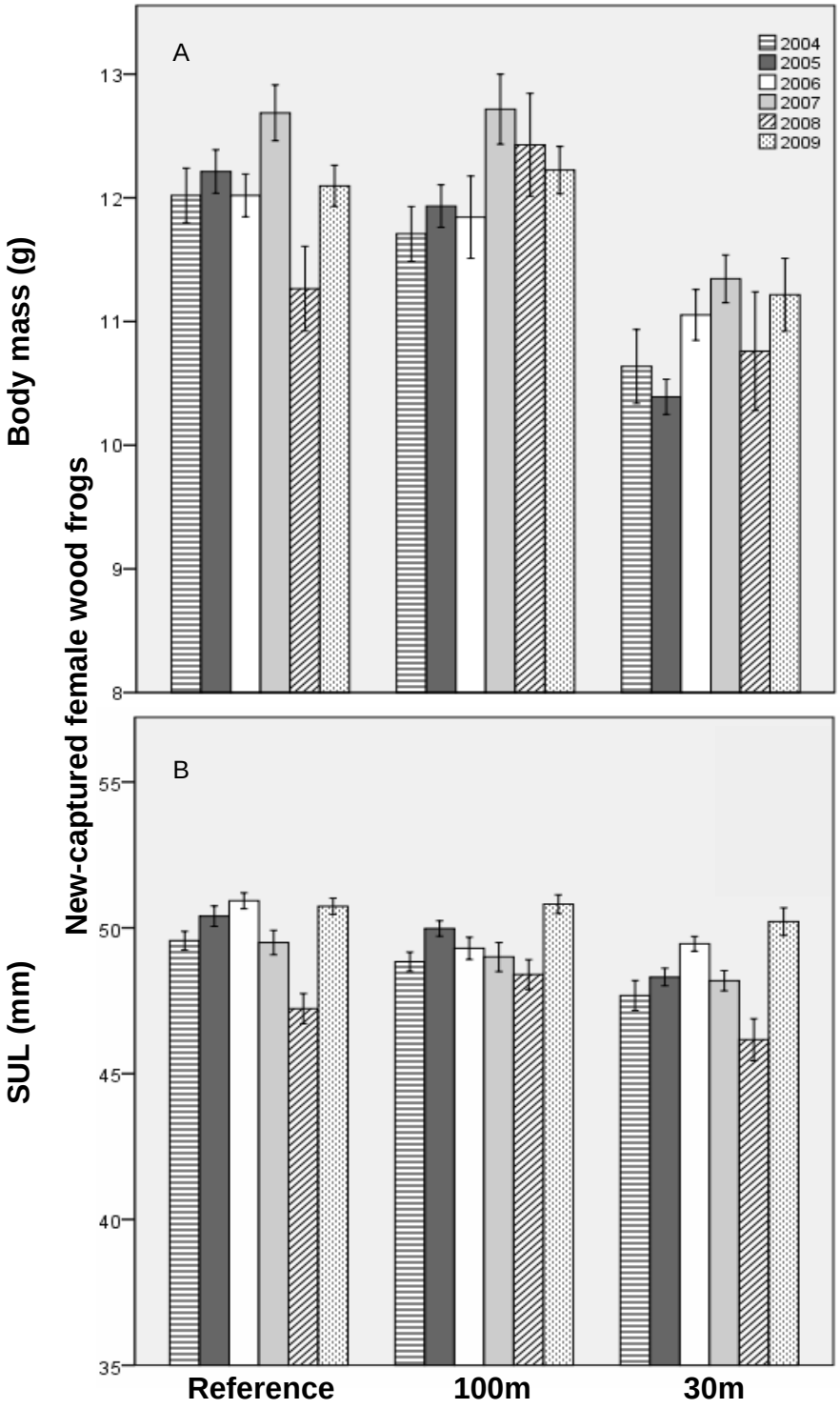


Figure 2.7. Mean (±1SE) A) body mass (g) and B) snout-urodyle length (SUL; mm) by forestry treatment and study year of new-captured breeding female wood frogs at 11 natural vernal pools in east-central Maine, USA. Treatments were: reference (uncut), 100m undisturbed buffer, and 30m undisturbed buffer.



CHAPTER 3

TOWN IDENTITY, COMMUNICATION, AND KNOWLEDGE: SOCIAL FACTORS DRIVE WETLAND CONSERVATION IN EXURBAN NEW ENGLAND TOWNS

Abstract

Freshwater wetlands are a valuable resource, but current policies fail to prevent continuing wetland destruction. Policy-makers have increasingly decentralized decision authority to address such policy failings for wetlands and other natural resources. Though decentralized governance improves social satisfaction with decision processes, scant research has investigated whether it also enhances ecological outcomes or explored how social and ecological effectiveness (SE and EE) interact. To address this gap, I analyzed the SE and EE of municipal wetland-permit programs, using four exurban New England towns as case studies. I assessed EE using regression techniques to quantify spatial impacts to wetland ecosystems on 50 construction site plans per town. To determine SE, I conducted and qualitatively coded 45 key-informant interviews. The site plans showed that EE varied significantly across towns, with one town clearly permitting less, and another more, wetland-ecosystem disturbance than the other towns. The interviews revealed a similar SE pattern: the town with the highest EE had the broadest support for its wetland program and vice versa. Overall, EE was largely a function of SE and policy content. SE was driven by multiple interacting factors, with no single SE prescription fitting all towns. Nevertheless, eight core drivers strongly influenced SE. Having a conservation-based town identity and being able to communicate about wetland permitting were key factors driving positive SE. Property-rights and town organizational structure were critical contextual factors that shaped stakeholder attitudes about wetland-permitting. Education and wealth enabled,

but were not essential to, positive SE. Finally, stakeholders used public participation and local politics as tools to express SE, thus shaping wetland decisions. The case towns show that local control can effectively protect wetlands if the necessary social factors are aligned. When that occurs, decentralized governance harnesses local knowledge and interests and applies them to protecting the public good of wetland ecosystems, increasing EE over that produced by state programs alone. When social factors do not align, however, stakeholder malcontent can weaken EE and destabilize social relations. Safeguards against such negatively spiraling conditions are important. To this end, I offer recommendations for enhancing local wetland programs based on the empirical data derived from my case towns. Some strategies work by inserting collaborative elements into the regulatory process, while others target municipal strategic-planning goals, town structure, and community capacity.

Introduction

Freshwater wetlands provide a number of vital ecosystem services, including flood control, pollution sequestration, and wildlife habitat. These services are critical to human health and globally are estimated to be worth $15 trillion/year (MEA 2005). Wetlands will become even more valuable as climate change unfolds and growing human populations demand additional buildable land (Erwin 2009). Despite their great ecological and anthropological value, over 50% of wetland area in the contiguous United States (US) has already been destroyed (Dahl 1990) and wetlands continue to be lost at a rapid pace. For example, over 569 km^2 of freshwater, forested wetlands were destroyed annually between 2004 and 2009 in the contiguous US (Dahl 2011). Such extensive wetland losses suggest that current wetland policies are deficient and need to be improved.

Experts fundamentally disagree on an optimal strategy for managing freshwater wetlands, however. Current approaches differ widely with respect to control mechanism (e.g., regulatory, voluntary), scale (i.e., spatial, temporal), and landscape integration (i.e., whether protection applies to adjacent uplands). Nevertheless, two wetland-policy trends prevailed in the US over the last two decades. First, decentralized governance structures flourished as concerns about fairness in existing regulatory regimes grew (Beierle and Cayford 2002; Meyer and Konisky 2007b). Second, buffers (i.e., strips of undisturbed land adjacent to wetlands) were championed as a tool for protecting wetland integrity (Castelle et al. 1994; Semlitsch and Bodie 2003; Lovell and Sullivan 2006). Ultimately, a successful wetland conservation strategy must address both the social and ecological needs of a wetland system (Clark 2002), but the optimal approach may vary with each location's specific mix of politics, ecology, and social values.

To date, little research has examined both the ecological and social effectiveness of decentralized governance structures, generally, and wetland buffers in particular. Holistic evaluation of both policy trends is necessary to determine whether their popularity enhances or detracts from wetland management and is a wise use of public resources. In this paper, I assess the validity of decentralized, wetland-buffer policies using case-study analysis to compare the environmental and social implications of municipal wetland-policy decisions across exurban New England towns.

Decentralized Governance

Decentralized governance has grown in popularity and use in western democracies since the late 1960s (Denters and Rose 2005a; Kraft and Mazmanian 2009). Localized governance is seen as a way to offload some of the financial burdens of centralized government (Denters and

Rose 2005b). It is also viewed as an antidote to the problems of administrative regulation, which include: a lack of accountability and fair representation among appointed agency personnel; political susceptibility (Dryzek 1997; Kerwin 2003; Creighton 2005); and difficulty addressing complex, uncertain, dynamic, and contested problems (John 1994; Denters and Rose 2005b). By contrast, decentralized governance brings local stakeholders, knowledge, and interests into decision processes, ideally allowing for increased implementation efficiency, decision-quality, and oversight (Sabel et al. 2000; Beierle and Cayford 2002; Creighton 2005). In the US environmental arena, the most studied form of decentralized governance may be collaborative watershed groups, which usually combine federal or state facilitation with consensus-based stakeholder deliberation (Wondolleck and Yaffee 2000; Meyer and Konisky 2007a).

As predicted, collaborative watershed programs can deliver positive decision-process outcomes and social changes. Among these are: increased civic capacity (Stedman et al. 2009), trust in government, and integration of public values in decision processes (Beierle and Cayford 2002); enhanced social, political, and human capital (Lubell et al. 2005b; Mandarano 2008); decreased stakeholder conflict; and public environmental education (Beierle and Cayford 2002). Collaborative watershed groups can also successfully implement restoration projects (Leach and Sabatier 2005) and protect open-space (Mandarano 2008). Social and implementation success depends on a variety of contextual factors (e.g., funding, strong leadership; Leach and Pelkey 2001), however, indicating that decentralized governance is not universally suitable. Moreover, very little research has evaluated the environmental impacts associated with collaborative watershed deliberations (Meyer and Konisky 2007b). Where environmental effects were considered, the results were unreliable, since the predominant outcome variable, perceived

environmental effectiveness, can be artificially inflated by feelings of inter-participant trust (Leach and Sabatier 2005).

Local environmental regulations are an alternative form of decentralized governance whose social and environmental outcomes have been increasingly scrutinized over the last decade. Theoretically, local regulations combine the benefits of having local stakeholders participate in decision processes with a motivational regulatory 'hammer' (John 2000; Meyer and Konisky 2007b). Typically, citizens participate by becoming a member of the local government board charged with implementing the regulation or contributing comments about specific projects proposed under the regulation. Though collaborative processes often provide more durable and substantive opportunities for public participation, local regulatory processes promise consistency, predictability, and efficiency and may thus be more politically palatable than collaborative processes (Emel and Brooks 1988).

From an environmental perspective, towns with local wetland regulations permit less disturbance to wetlands, adjacent buffers, and generalized open space than towns without such policies (Meyer and Konisky 2007b; Sims and Schuetz 2009). Furthermore, local land-use regulations, including wetland policies, can substantially dampen open-space conversion and residential-development rates (Glaeser and Ward 2009; Sims and Schuetz 2009). However, the positive environmental outcomes associated with local regulations may be possible in part because negative feedbacks are externalized to other places and later time-points (Bowman and Thompson 2009; Beuschel and Rudel 2010). Developers may initially avoid towns with local wetland regulations by building in neighboring municipalities, but eventually return to regulated towns when developable land becomes scarce elsewhere.

Compared to collaborative programs, the social dynamics of local environmental regulatory processes are less well studied. Local planning processes have been criticized as elitist and exclusionary (Jacobs and Paulsen 2009), parochial, and subject to capture by developers (Hawkins 2011). Though developers frequently comply with project conditions, they are also discouraged from pursuing innovative designs by poorly incentivized policies and disinterested local officials (Beuschel and Rudel 2010; Allen et al. 2012; Göçmen 2013). Conflict between developers and other stakeholders is also relatively common (Nolan et al. 2013). Yet this very conflict sometimes motivates adoption of new wetland-protection, conservation-subdivision, and growth-management regulations (Hawkins 2014). Moreover, recent work in communicative planning shows it is possible to integrate participative and collaborative sub-components into local regulatory processes, possibly enhancing social outcomes (Nolan et al. 2013; Pocewicz and Nielsen-Pincus 2013; Zabik and Prytherch 2013). In general, the conditions driving social effectiveness and the potential for complex feedback and interactions between social and environmental effectiveness are poorly understood for local regulatory processes.

Vegetated Buffers

Wetland ecosystems extend far beyond the edge of visible water. Bi-directional flows of energy and material regularly move between wetlands and the adjoining landscape. Such fluxes derive from both anthropogenic and natural sources. For instance, a common cause of water pollution in exurban wetlands is nitrogen derived from septic systems (Withers et al. 2013). As another example, many amphibians breed in wetlands, but spend the rest of the year in nearby forest, annually migrating up to hundreds of meters between these equally vital habitat patches (e.g., Semlitsch and Bodie 2003; Rittenhouse and Semlitsch 2007; Veysey et al. 2009).

Despite strong connections between wetlands and surrounding landscapes, wetland policies traditionally protected only the wetland proper. As knowledge and concern about wetland connectivity increased over the last three decades, however, buffers became increasingly popular as a wetland-ecosystem management tool. Initially, land managers used buffers to protect wetland water quality, since buffers can be very effective at removing sediment and nutrients from surface water (Lee et al. 2004; Lovell and Sullivan 2006) and reducing flood levels in wetlands (Castelle et al. 1994; Cariveau et al. 2011). Subsequently, managers used buffers to protect habitat for wetland-dependent wildlife.

Though buffers are an improvement on traditional policies that only protect the wetland proper and are popular among conservationists, they may not be an ideal policy tool for several reasons. First, research provides mixed reviews of the habitat value of wetland buffers. While buffers seem adequate for protecting some species, especially generalist, edge-tolerant, or in-stream species (Olson and Rugger 2007; Pollett et al. 2010; Kardynal et al. 2011), other species respond negatively to buffered disturbances (Windmiller et al. 2008; Marczak et al. 2010). In some cases, buffers simply may not be wide enough. Typical buffers range from 3 to 30 m wide, but a meta-analysis of the migratory behavior of 65 species suggested that protected strips between 142 and 289 m wide might be necessary to maintain viable populations of wetland-dependent herpetofauna (Semlitsch and Bodie 2003). Such empirical data is supported by population modeling which also indicates that wetland buffers, even those up to 76 m wide, may be insufficient to sustain amphibian population viability (Harper et al. 2008; Bauer et al. 2010a; Bauer and Swallow 2013). Second, buffers do not adequately address issues of landscape connectivity, especially given that species' ranges are expected to shift with climate change (Freeman and Bell 2011; Freeman et al. 2012; Ruddock et al. 2013). Being centered on a single

wetland, buffers typically contribute very little to habitat connectivity. Finally, buffers may exact a high social cost. Because buffers can only be minimally disturbed (if at all), there are considerable opportunity costs associated with foregone development (Bauer et al. 2010a; Bauer et al. 2010b). Significant outreach and strategic planning may be required to mobilize support for local implementation of state buffer policies (Jansujwicz et al. 2013b). Wetland policies may also breed resentment if construed as government interference (Lokocz et al. 2011; Jansujwicz et al. 2013a; Jansujwicz et al. 2013b). Despite their potential limitations, buffers are a favored policy tool in municipal wetland programs. Holistic evaluation of both the social and ecological outcomes associated with wetland buffers will help to determine whether their popularity in this context enhances wetland management and is a wise use of public resources.

New England Policy and Culture

New England has abundant freshwater wetlands, intense development pressure, and multifarious wetland policies, making it ideal for exploring the complex interactions of different wetland management strategies. All six New England states and many towns have adopted wetland policies. Policy stringency and enforcement, however, differ strongly among states and towns. I capitalized on the cultural and structural differences between Massachusetts (MA) and New Hampshire (NH) in order to isolate the fundamental factors driving social and ecological effectiveness of municipal wetland-buffer policies in each state.

Before exploring the nuances of municipal wetland programs, however, it is necessary to understand the institutional and cultural contexts within which these programs are embedded. MA and NH were the first two states to establish state-level wetland-protection policies. Both are regulatory, permit-based instruments that require avoidance, minimization, and mitigation of

wetland impacts. The two policies differ with respect to the type and size of wetlands and disturbances regulated and mitigation required. Additionally, MA regulates activities within a 30-m buffer around jurisdictional wetlands, while NH does not have a state-wide buffer. (NH towns can opt-in to a 30-m buffer under the 'prime wetland' provision of the state policy, but only 33 of 234 municipalities have done so. Major waterbodies are buffered under a separate law). Permit decisions under both states' wetland laws are appealed to the state department of environmental protection (DEP) first and then, if necessary, to state courts.

Officially, MA is a home-rule state, while NH operates under Dillon's rule. Technically, this means that MA towns can exercise all powers not strictly reserved to the state or federal government, while NH towns exercise only those powers expressly granted by the state. Since 1966 and 1983, in MA and NH respectively, these powers included control over local land-use decision-making. Despite devolution of much land-planning power to the municipal level and strong traditions of civic engagement in both states (Gibbs and Krueger 2011; Lee 2011), home rule and Dillon's rule are fundamentally disparate governing philosophies which produce local policies and town power structures that differ in potentially important ways.

In both MA and NH, municipalities use permit-based zoning and subdivision policies[1] to condition where and how development occurs in town. Via the zoning code, many towns use 'overlay' zones to limit development in proximity to wetlands. Some towns have additional innovative provisions (e.g., growth-management or conservation-subdivision rules) that can influence wetland-ecosystem integrity by controlling the pace, configuration, and scale of

[1] In NH, local laws are called ordinances. In MA, local zoning laws are often referred to as codes, while other town laws are called bylaws and other city laws are called ordinances. To minimize confusion throughout this chapter when discussing local policies, I refer to zoning policies as 'zoning codes' and to other town policies (or specific portions of the zoning code) as 'bylaws,' unless otherwise noted. Similarly, I use the term 'wetland permit' to refer to both independent wetland permits and generalized land-use permits that encompass wetland issues.

development. Under home rule, 199 of 351 MA municipalities also have independent wetland bylaws. Though bylaws resemble the state wetland law in basic structure and content, they also reflect town-specific concerns and are often more stringent than state law. For instance, some towns emphasize wider buffers, while others protect extra resources like small isolated wetlands or wildlife habitat. By contrast, no NH towns have stand-alone wetland bylaws. However, wetland-overlay provisions in zoning codes tend to be considerably more detailed in NH than in MA. Thus, the NH overlay zone may serve as a functional equivalent of the MA wetland bylaw. In MA, where wetland-overlay zones exist, they often predate or are used instead of wetland bylaws. In general, wetland, zoning, and subdivision bylaws can vary substantially across towns, even within the same state (Glaeser and Ward 2009).

Most MA and NH towns have three government boards that share responsibility for local wetland permitting. Planning boards (PBs) administer zoning and subdivision policies and issue construction permits. Zoning boards (ZBs) issue permits for special exceptions or variances to the zoning code. All MA towns and 92% of NH towns also have conservation commissions (CCs) which advise the planning board in its land-use decisions, inventory and map natural resources, and implement land-conservation programs. In MA, but not NH, CCs also administer the state and local wetland-permit policies. MA towns can use administrative discretion at this stage to infuse local interests and knowledge into the state-permit process (Meyer and Konisky 2007a).

In MA, wetland bylaw decisions are appealed directly to state superior court, not to the DEP. Thus, wetland bylaws provide towns with increased decision-making independence for wetland resources (Payne 1998; Meyer and Konisky 2007a). In both states, zoning and planning decisions are usually appealed first to the ZB and then, if necessary, to superior court. Public hearings are mandatory for state and local wetland and land-use permit decisions in MA, but

NH's state-wetland law only requires public hearings if a project is of 'substantial public interest' or significantly impacts wetlands. In practice, this means most NH state-wetland permits are issued without a public hearing (though public comments can be submitted). Locally in NH, PBs and ZBs hold public hearings for permits requested under zoning and subdivision policies.

Though policy and structural differences between the states are substantial, politics and cultural norms can also influence land-use patterns. In MA, for instance, home rule has been zealously guarded, allowing local decision-making to significantly shape land-use patterns (Gibbs and Krueger 2011; McCauley and Murphy 2013). Also, the MA development and real-estate industries are powerful political entities, with considerable influence over local and state decision-makers (Gibbs and Krueger 2011; Hawkins 2011; McCauley and Murphy 2013). For its part, NH's reputation as a libertarian stronghold has some basis in reality (Nagy 2001; Harmon 2005), with state environmental laws developing later and containing more voluntary provisions than in MA. All three traditions (i.e., home rule, developer power, libertarianism) express underlying resentment of regulation and outside intervention (Foster 2009; Lee 2011; Lokocz et al. 2011) and sometimes lead to intense conflict at local land-use hearings (Nolan et al. 2013).

Boston's role as a global economic hub also strongly shapes the social and ecological landscape in MA and, more recently, NH (Gibbs and Krueger 2011; McCauley and Murphy 2013). Workers searching for affordable housing spurred tremendous residential growth in the Boston metropolitan area over the last half-century (Collins and Ober 2009; Gibbs and Krueger 2011). In response to this rampant growth, many towns enacted restrictive land-use bylaws that effectively pushed development away from urban and town cores, into the exurban fringe (Gibbs and Krueger 2011; McCauley and Murphy 2013). Initially, this sprawl concentrated in the inner and outer Boston beltways, but later spread into more rural areas of MA and southern NH.

Most of this growth was low-density residential development: a land-use with potentially large environmental impacts. Such exurban development alters the biological communities and physical structure of affected landscapes and is a major cause of habitat loss and alteration in MA and NH (Sundquist 2010; Lautzenheiser et al. 2014). The roads, houses, lawns, and trails associated with exurban development fragment habitats (Hansen et al. 2005), reduce forest understory complexity, and create edge effects in adjacent undisturbed habitat (Suarez-Rubio et al. 2011). Though responses vary with taxonomic group and ecosystem type (Merenlender et al. 2009; Schlossberg et al. 2011), many native species experience declines in abundance, survival, and reproductive success in response to exurban development (Hansen et al. 2005; Schlossberg et al. 2011; Suarez-Rubio et al. 2011). Conversely, some predators and non-native species thrive in exurban landscapes (Hansen et al. 2005; Merenlender et al. 2009; Schlossberg et al. 2011).

The political and cultural nature of MA and NH towns may also be changing as the goals and sensibilities of newcomers mix, and sometimes conflict, with those of long-time residents. Though residents generally share a desire to maintain rurality in exurban towns, they have competing definitions of what constitutes ‘rural’ and divergent visions of how best to preserve it (Ryan 2006; Lokocz et al. 2011; Zabik and Prytherch 2013). In MA, exurban sprawl may also, ironically, be hastening the demise of home rule, by spurring the state to assert authority and promote regional smart-growth development (McCauley and Murphy 2013). Home rule may be further undermined by a disconnect between local land-use policy objectives and implementation (Warren et al. 2011), disinterest in civic engagement among knowledge-sector immigrants (Gibbs and Krueger 2011), and popular concerns that towns lack the planning capacity to strategically combat sprawl (Gibbs and Krueger 2011).

Research Questions

The MA system of wetland regulation has been praised as possibly ideal because the state program combines local democracy with state oversight (Payne 1998), while municipal wetland bylaws bolster local autonomy and offer superior wetland and buffer protection compared to the state program alone (Meyer and Konisky 2007b). Despite such strong support, research on the MA system suffers several problems shared by the local-environmental-regulatory literature generally. In particular, they do not explain why towns with similar wetland policies and financial and demographic profiles can have widely different wetland-protection outcomes. Further, they ignore whether wetland policies are socially effective (i.e., if a community supports a policy and is involved in its implementation). They also do not describe the nature or potential implications of interactions between social and ecological effectiveness. Finally, being focused on MA, the research may not accurately represent wetland-policy processes in other states.

I address these critical gaps with a comparative case-study analysis of the wetland-protection structures and processes of municipalities in MA and NH. Though towns in both states shape the landscape through local decision-making and though human migration may be weakening traditional inter-state cultural differences, MA and NH nonetheless differ in formal policies, reputation, and town structures. My objective was to identify and compare the factors that drive ecological and social effectiveness of wetland-buffer policies at the municipal level in each state. Specifically, my research questions were:

1) How does ecological effectiveness interact with social effectiveness to influence wetland-management efforts?
2) Why, mechanistically, do towns with local wetland policies and similar financial and demographic profiles sometimes have widely-different wetland-protection outcomes?

3) Are these mechanisms similar in both Massachusetts and New Hampshire?

Methods

I used a mixed-method, case-study design to assess how and why New England towns differ in their abilities to manage wetlands in a socially and ecologically effective manner. Individual towns in Massachusetts and New Hampshire constitute the cases. Towns are an appropriate analytic unit because they are gate-keepers in the wetland arena: being facilitators of land-use change locally, but possible impediments to management regionally (Webler et al. 2003). My study period was 1990 to 2011. All towns experienced considerable growth during the first part of this period, but had growth slow during the recession of the late 2000s.

To quantify ecological effectiveness (EE) of wetland-permit programs within and across towns, I conducted a spatial analysis of construction site plans, assessing the extent and configuration of development impacts on freshwater wetlands and adjacent buffers. I used construction site plans because they are readily available in exurban municipalities; document the wetland-ecosystem disturbances that a town intentionally permits; are relatively inexpensive to obtain; and, as longitudinal data, allow exploration of both recent and historical disturbances. Site plans were preferable to alternative spatial data sources, like aerial photographs and satellite imagery, because site plans detail disturbance impacts and wetland features at a finer scale, allowing more accurate quantification of wetland-ecosystem impacts.

I used qualitative interviews to assess social effectiveness (SE) of wetland-permit programs and learn how human attitudes and actions influence policy implementation. The interviews provided a nuanced understanding of stakeholders' perceptions and attitudes towards, and motivations within, wetland-permit programs, which complemented the quantitative results

generated from the site plans. I selected in-depth interviews over other qualitative techniques, like surveys and focus groups, because interviews better accommodate exploration of emergent themes and encourage trust and deep sharing between researcher and research subject. To triangulate my results, I supplemented the site-plan and interview data with informal analysis of documentary evidence from a variety of sources, including: permit applications, public-hearing notes and transcripts, newspaper articles, annual town reports, and state reports.

Effectiveness Definitions

I used the goals outlined in the MA and NH state wetland laws, supplemented by recent research on wetlands and wetland-dependent wildlife, to define EE. While imperfect, for reasons relating to the dynamic nature of ecosystems, shifting baselines, species-bias, and differences between functional and geographical integrity (Pauly 1995; Dale and Gerlak 2007; Mitsch and Gosselink 2007), these sources enabled a working definition that allowed me to assess towns' relative capacities to implement wetland policies in an ecologically effective manner. I defined EE as development projects that:

1) Minimize disturbed areas within wetlands and adjacent uplands;
2) Maximize the distance (i.e., buffer) between disturbances and wetlands;
3) Avoid designs requiring mitigation, but when necessary, prioritize wetland restoration over creation (Brown and Veneman 2001; Spieles 2005; Kettlewell et al. 2008);
4) Do not locate disturbances directly between neighboring wetlands (Joyal et al. 2001; Freeman and Bell 2011);
5) Cluster on-site disturbances (Göçmen 2013; Hawkins 2014);

6) Where appropriate, use corridors to connect wetlands with supporting uplands and other wetlands (Joyal et al. 2001; Rittenhouse and Semlitsch 2006; Freeman and Bell 2011); and
7) Limit land-use intensity within corridors and buffers (Bauer et al. 2010a).

While I defined EE quantitatively, I defined SE more broadly and in qualitative terms. SE is not a standardized concept, but an umbrella category which has multiple constituent parts and can be measured using a variety of approaches (Stedman et al. 2009). I broadly categorized a wetland program or its constituent components as socially effective if stakeholders were familiar with, accepted, supported, and/or promoted program policies and their implementation (Rubin 2000; Clark 2002; Stedman et al. 2009). To assess SE, I examined stakeholders' knowledge, beliefs, and actions and relied on multiple SE indicators (Appendix 1). These indicators gauged whether stakeholders: were knowledgeable about and valued wetland ecosystems and policies; perceived their municipal wetland program to be ecologically effective; could access and influence the wetland-permit process; were frustrated, accepting, or content with the program; could empathize with other stakeholders; took actions that impacted wetlands, policy content, permit-decisions, or program implementation; or experienced opinion or value-changes about wetlands.

Case Selection

To choose my case-towns, I first analyzed the land-use policies of all towns in north-central MA and south-central NH and created a database of town-specific demographic and environmental data. I focused on these sections of MA and NH because they contain only

freshwater (not coastal) wetlands and are generally exurban. I was interested in exurban towns because they experience strong development pressure, yet contain sizeable open-space parcels. Exurban towns have the power to dictate the spatial configuration and ecological composition, of much of the remaining landscape in MA and NH.

From this database, I used purposive sampling to select two case-towns per state. Since I expected town organizational structure to influence effectiveness and since town structure differs markedly between states, I used state affiliation as my first case-selection criteria. I based additional criteria on an experimental logic: I attempted to control some variation by selecting cases with similar demographic, environmental, and policy profiles. The four towns I ultimately selected are within commuting distance of Boston (i.e., < 120 km) and outside the MA Route 495 loop. To ensure the towns were more typical than exceptional, none was adjacent to a major city (i.e., population > 90,000); had more than 25% of the town permanently conserved by a single landowner; or contained a major highway (i.e., greater than two lanes), industrial or retail center, or university. All four towns had municipal wetland-buffer policies and similar demographics, land cover, and land-use policies (Appendix 2). For confidentiality, I use fictitious town names and approximate demographic data throughout this chapter.

Quantitative Site Plan Analysis

Site Plan Selection

To quantify wetland impacts, I conducted a spatial analysis of construction site plans, completing each of the following steps for each town. First, I selected 100 site plans from among projects that occurred within 30 m of a wetland and between 1990 and 2011. Because MA has a state-wide 30m wetland buffer that is regulated by local CCs, all projects within 30m of wetlands

were available in the CC files for the two MA towns. I randomly selected site plans for Robin and Lark from their respective CC files. By contrast, NH lacks a state-wide wetland buffer, complicating site-plan selection. In both Teal and Gannet, wetland-buffer width depended on the proposed project type. Generally, all projects within 15m of wetlands were recorded in the CC files, while project between 15 and 30 m of wetlands were spread across the CC, ZB, PB, and/or building department files, if recorded at all. Teal and Gannet each had over 1000 building files. As a first step in the NH project-selection process, I took a random sample, constituting about 25%, of the building files in Teal and of the mixed building/ZB files in Gannet. Of these, 48% of 316 files and 27% of 502 files in Teal and Gannet, respectively, included work within 30 m of a wetland. I pooled this wetland-project subset from the building/ZB files with the wetland files from the CC, PB, and ZB. I randomly selected the final 100 site plans for each NH town from this pooled file-set. When project plans were not available in the town offices, I obtained plans from the NH DES archives, as available. I took a digital photograph of each selected site plan, using a Nikon D700 camera with a 50-mm Nikon lens. I imported each digital photograph into ArcGIS 10/10.1 (Environmental Systems Research Institute, Inc., Redlands, CA, USA) and created a separate GIS map for each project.

Many projects extended across political boundaries, multiple years, and iterative revisions. Other projects were not associated with clear lot lines. Often key portions of subdivision plans were missing. For quality control, I set the following additional rules for site-plan selection. I only used those portions of projects located in one of my four case towns. Where multiple plans were available for a single project, I used the most recent, permitted site plan. I treated multiple revisions of the same project or multiple projects on the same site as the same project if the permit date of the earlier project was less than a year prior to the application

date of the later project. Subdivisions were an exception to this rule, due to incomplete files which prevented me from constructing full work timelines for some subdivisions. Thus, I treated single-family homes within subdivisions as independent projects unless the home was permitted as part of the original subdivision permit (i.e., along with the subdivision road). I did not use linear projects without clear lot lines; this included activities like utility and rail-trail projects, which sometimes extended for kilometers along existing roads and rights-of-way. Because I wanted to analyze the impacts of exurbanization on wetland systems, I also excluded projects that did not propose development (e.g., forestry, agriculture, invasive-plant management).

Spatial Analysis

For the first 50 site plans per town, I used ArcGIS 10/10.1 to quantify the geographic impacts of project disturbance on proximate wetlands and wetland buffers. I created polygons for the lot, wetlands, uplands, project disturbance, and impervious area on site. I then created a 30m, 400m, and 1000m buffer around each wetland. I used these GIS layers to calculate the area disturbed and the new and total impervious areas in each wetland and buffer. New impervious area refers to impervious surfaces that covered previously pervious areas; whereas total impervious area refers to all impervious area generated as part of the proposed project, whether new or replacing previously-existing impervious surfaces. To standardize impacts across differently-sized lots, I also calculated the percent of each wetland and buffer that was disturbed and the percent covered in impervious area. Often, the project site and/or the wetlands were not entirely delineated on the plans. Consequently, I had 40-60% fewer projects, depending on the outcome variable, in my standardized versus unstandardized analyses. For the unstandardized analyses, I generally used 160 and 194 projects, for wetland and buffer metrics, respectively. For

the standardized analyses, I used 80 and 109 projects for the wetland and buffer metrics, respectively.

For each project, I also measured the distance from the wetland to the nearest new disturbance, impervious area, and road, where applicable. I defined “road” as any public way designed for automotive use, plus any private way of a commercial operation that serviced the public or a common drive servicing more than two houses. Where projects required wetland replication, I calculated the total area of created wetland, created wetland area as a percent of original onsite wetland area, and the ratio of created to permanently disturbed wetland areas.

To determine if each project created a permanent barrier between the on-site wetland and the next nearest wetland, I created town-wide maps in ArcGIS 10/10.1. I used 30-cm color aerial photographs (from 2008-09 for MA and 2010 for NH) for the base layers and the US Fish and Wildlife Service’s National Wetlands Inventory maps for wetland data. I obtained these layers from the MA Office of Geographic Information and the University of New Hampshire Complex Systems Research Center GRANIT database, respectively. I located each project and the on-site wetland on the aerial photograph and visually assessed whether the project created an inter-wetland barrier.

I used FragStats v4 (McGarigal et al. 2012) to quantify the spatial configuration of project impacts. To prepare site plans for FragStats, I created raster files of each project’s disturbance and total impervious areas, and then converted each raster to an ASCII file. With the ASCII files as input, I used FragStats to calculate the class edge density (ED; m/ha) and class correlation length (CRL; m) of each project’s disturbance and impervious patches. Edge density describes how convoluted the patch perimeter is. Correlation length describes whether the patch is elongate or compact, with correlation length increasing as the patch becomes larger and/or

more elongate (McGarigal et al. 2012). Together, ED and CRL describe the degree to which project disturbance was clustered or dispersed across the site.

In general, my analysis of wetland and buffer impacts is slightly conservative, for three reasons. First, most site plans provided scant information on land-uses of adjacent lots and in some cases, on large portions of the project lot itself. Buffers for wetlands located in these unmapped areas could have extended onto the project site. I could not account for project impacts to such buffers as I had no record of these buffers existing. This problem was worse in NH than MA, since the MA state-wide 30m buffer prompted more project applicants in MA to survey for wetlands beyond lot borders. Second, to ensure consistency across sites, I used contour and hay bale lines to mark the maximum extent of disturbance where other disturbance boundaries were absent. Small amounts of disturbance likely occurred just beyond the contour and hay bale lines, however. Finally, in all four towns, there were no reliable records for projects that had no work within 30m of a wetland, but had work between 30m and 400m of a wetland. Since having work within 30m of a wetland was a selection criteria for my analyses, this bias is spread equally across all four towns. Nevertheless, overall impacts in the 30m-400m zone may actually be different than the impacts I present in this analysis.

Statistics

I used generalized linear regression and generalized least squares (gls) regression to test for differences between towns in 27 different measures of wetland and buffer impacts (Table 3.1). I did not analyze the distance-to-the-nearest-road metric because my per-town sample sizes were too small. I used multinomial regression to test for differences between towns in the frequency of proposed project types. Because project impacts rarely extended beyond 400m from the on-site

wetland, 400m and 1000m buffer impacts were essentially equal and I did not conduct separate analyses for the 1000m buffer. Potential model predictors were: town, decade (i.e., 1990s or 2000s), project type, and a town X decade interaction.

To accommodate data structure, I made several adjustments to the regression models. First, heterogeneous variance across predictor groups was typical for continuous outcome variables. To adjust for heterogeneous variance, I explicitly modeled the variance structure within each regression. In many cases, I also needed to transform the outcome variable to achieve variance homogeneity or to adjust for residuals that were particularly non-normal. Second, the data for 12 metrics were zero-inflated. I employed a two-part process to model zero-inflation. I used logistic regression to determine which factors predicted whether the metric was zero or not. I then used gls regression to model the nonzero values. Finally, quasi-separation was a problem for project type and town in several of the logistic regressions. I corrected for quasi-separation by condensing predictor categories, according to the specific needs of the given model. In some cases this correction did not resolve the quasi-separation. In such cases, however, model p values are still valid, though coefficient estimates are unreliable (Menard 2010).

I used the model selection protocol of Zuur et al. (2009) to finalize the error structure and predictor variables in each model. All models ultimately satisfied the assumptions of their respective regression types. I fit the logistic regressions using the “glm” function with a logit link in S-plus 8.0 (Insightful Corporation, Seattle, WA, USA) and R 2.15 (R Core Team 2012). I fit the generalized least squares regressions using the “gls” function in S-plus 8.0 and the multinomial regression using the “multinom” and “mlogit.display” functions in the “nnet” and “epicalc” libraries, respectively, in R 2.15. I used deviation contrasts for town and project type,

except in the multinomial regression, where I used simple contrasts for project type. I also used simple contrasts for decade.

Qualitative Key-informant Interviews

I conducted 44 semi-structured, key-informant interviews (of 46 interviewees) to assess social satisfaction with wetland policies and develop hypotheses about the specific human and ecological factors that drive wetland-policy effectiveness. I used stratified, purposive sampling to select at least ten interviewees per town, one state-government interviewee per state, and three federal-government interviewees (one from each state and one who worked in both states). I stratified town-level subjects across four groups: town boards (i.e., at least one interviewee from each of the conservation commission, planning board, and zoning board of appeals), developers/permit-applicants, environmental consultants (e.g., wetland scientists, civil engineers, surveyors), and project abutters.

I developed a list of potential interviewees from the wetland-permit applications associated with the site plans that I analyzed for EE. From this list, I purposively selected interviewees across stratification groups so that I would have a diverse representation of existing opinions about wetland-permitting in each town. Since I had little background information on abutters, however, I randomly selected abutter interviewees from my candidate list. Across all four towns, some interviewees belonged to more than one of these categories and/or were also members of independent interest groups (e.g., land trusts, non-profit environmental groups). State and federal interviewees were wetland-permit regulators working in MA and/or NH whose names were obtained from the permit applications and/or recommended by other interviewees.

I sent each selected candidate an introductory letter or email, describing my project and my desire to interview them (Appendix 3). I subsequently contacted each selected candidate by phone to schedule an interview. I conducted interviews at the time and location of the interviewee's choosing, with all interviews completed between 3 May and 3 September 2013. In two instances, I interviewed two subjects during the same session. My interview questions ranged across five thematic areas: wetland science; perceived effectiveness of and attitudes about wetland-permitting; home-rule; property-rights; and organizational structure (Appendix 4). Mean (± 2SE) interview length was 69 ± 7 minutes, with a range of 24-118 minutes. To protect interviewee confidentiality, I do not use interviewee proper names throughout this manuscript.

I audio-recorded each interview and transcribed the interviews verbatim using NVivo 9.0 (QSR International, Burlington, MA, USA). Drawing on case-study and grounded theory methods, I used a blend of open-coding, memo-writing (Hesse-Biber 2004; Rubin and Rubin 2005; Charmaz 2006), and explanation-building (Yin 2003) to analyze the transcribed interviews. I began memo-writing and developing codes while conducting interviews, but formally coded data only after all interviews were complete. During analysis, I considered each case separately and examined cross-case patterns (Yin 2003). I present the cross-case analysis in this manuscript. My over-arching analytic objective was to identify factors (e.g., number of participants; degree of conflict) that influenced decision-making and decision outcomes (e.g., required buffer widths), thereby determining causal pathways linking town characteristics with ecological and social outcomes.

Results and Discussion

Interviewee Demographic Data

Of the 46 interviewees, 14 were females and 32 were males, split relatively evenly across towns, though all developers, consultants, and state/federal interviewees were male. The average interviewee was 58.5 years old (range: 34-74 years), had spent 28 years in her current hometown (range: 7-70 years), and had 2 adults and 2.7 children (range: 0-9 children) in her household. Most interviewees grew up in New England; though three were originally from New Jersey and origin information was unavailable for two federal permitters. Nine interviewees had a master's degree, 16 a bachelor's, 7 an associate's, 12 a high-school, and 1 a middle-school degree. Five interviewees were retired and the rest held diverse jobs (e.g., housewife, petroleum geologist, nurse, welder). All but one owned land, with the majority owning > 4 ha. Of the landowners, 36 had wetlands on their land and 6 did not. (This information was unavailable for the remaining three). Interviewee characteristics are further detailed in Table 3.2.

Among the first words that came to mind when interviewees thought of wetlands, water or some reference to vegetation were most popular (N=12 and N=13, respectively), then soils (N=5), then various other words that referenced wetlands' ecological characteristics (e.g., bogs, frogs, wildlife), and/or dissatisfaction with the permitting process (e.g., 'can't build [in] it', 'not consistent', controversial). Negative words were more common among developers, consultants, and Gannet and Teal interviewees. Technical words were more common among board chairs in Robin and Teal.

Subject-defined Ecological Effectiveness

Broadly, interviewees' EE definitions were similar both to my operational definition and across towns. Subjects identified both spatial and non-spatial EE elements. Board members and consultants defined EE in more detail and technical verbiage than abutters and developers. Following is a summary definition generally shared by subjects across towns and types.

> Wetland ecosystems are healthy and functioning. Wetlands are not drained or filled. Unavoidable impacts are minimized and mitigated. A 17-30m+ buffer is adjacent to the wetland. Impervious surfaces in the buffer are limited. The buffer, plus other conserved parcels, facilitates wildlife connectivity and persistence. Habitat fragmentation and sprawl are limited. Rare species and communities persist. Invasive species are controlled. Large, open-space parcels are permanently conserved. Stormwater management limits development-induced flooding and water quality issues. Specifically, pollutants, erosion, velocity, volume and infiltration of runoff are similar pre and post-development. Culverts accommodate flood volumes and migratory wildlife. Septic waste is treated before reaching wetlands and drinking water. Groundwater volume and quality is maintained.

Interviewees also identified less universal EE attributes, including town-specific concerns. Teal subjects were most concerned about flooding; Gannet subjects highlighted the importance of permanent land conservation; and Robin subjects focused on (different definitions of) wetland buffers. EE definitions diverged more strongly in three problem areas. First, many developers, consultants, and NH interviewees believed that only high-priority wetlands should be protected and/or buffered. They defined 'high-priority' differently, but generally agreed that priority should be based on wetland function and social value, not just size. Second, interviewees had different visions of an ecologically effective buffer, diverging on the subjects of buffer width and

allowed disturbances. Finally, subjects disagreed on whether wetland mitigation could be ecologically effective. Among those who supported mitigation, some denounced wetland replication, preferring mitigation by permanent conservation of ecologically-valuable, off-site parcels. Others favored on-site wetland replication.

Site Plan Analysis

The 194 analyzed site plans were relatively evenly distributed across towns and years (Table 3.3). Single-family houses (SFHs) were the most common project type, followed by septic projects, SFH accessory projects, and conventional subdivisions. SFHs were also the most common type of inter-wetland barrier, followed by conventional subdivisions. Mean lot size was greater in the NH towns than the MA towns (Table 3.4). Wetlands occupied about 14% of the typical lot. Only two site plans, both in Teal, were denied permits because wetland impacts were too severe. CCs tried to deny three additional projects (two in Robin, one in Lark), but the MA DEP ultimately issued superceding permits, allowing the projects. Only permitted projects were included in the regression analysis, the results of which are described below.

<u>Town</u>

Town was important for predicting project impacts for 23 of 27 metrics (Table 3.5). Town did not predict: new impervious area in the 400m buffer, standardized new impervious area in the 30m buffer, or disturbance correlation length. Wetland-impact patterns were generally consistent, while buffer-impact patterns were more discordant, between raw-area (unstandardized) and percent-area (standardized) measures. Given wetland impacts, the MA towns were more likely to require wetland replication than the NH towns.

Wetland Impacts

Robin was least likely, and Gannet most likely, to allow wetland disturbance, with disturbance odds 76% lower in Robin, and 227% higher in Gannet, than in the average town (Fig. 3.1). Wetland disturbances were also bigger than average in Gannet (Fig. 3.2). A typical Gannet project had approximately 155% more disturbed wetland area than a similar project in the average town. Lark and Teal were as likely to allow wetland disturbance as the average town, but typical disturbed wetland areas in Lark were predicted to be 62% smaller than in the average town. Conversely, percent of wetland disturbed was larger than average in Teal.

In Robin, projects had less impervious area in wetlands than in the average town (Fig. 3.3). In Gannet and Teal, by contrast, typical (total) impervious areas in wetlands were bigger than average. In the 1990s, a typical project in Robin was predicted to have 27 m^2 less, while a similar project in Teal or Gannet to have about 35 m^2 more, total impervious area in wetlands than the average town. Raw new impervious wetland areas were also bigger than average in Gannet. Lark had similar amounts of raw impervious area in wetlands, as the average town. Due to a lack of cases, I excluded Lark from standardized impervious-area wetland analyses.

30m Buffer Impacts

In the 1990s, Robin had, on average, larger disturbances in the 30m buffer than any other town, but in the 2000s, mean raw disturbed area in the 30m buffer in Robin was smaller than the cross-town average (Fig. 3.4). In Gannet, by contrast, mean raw disturbed area in the 30m buffer was smallest in the 1990s, compared to all other towns, but increased in the 2000s. Percent of the 30m buffer disturbed was less in Gannet and Teal, and greater in Robin and Lark, than the cross-

town average for both decades (Fig. 3.5). Neither Lark nor Teal differed from the average town in raw disturbed area in the 30m buffer.

Robin was more likely to have impervious surfaces in the 30m buffer in the 1990s than the 2000s, such that during the 2000s, the odds of new impervious area occurring in the 30m buffer were 60% lower in Robin than in the average town (Fig. 3.6). Conversely, Lark was less likely to have new impervious area in the 30m buffer in the 1990s, but more likely to have impervious area in the 30m buffer in the 2000s, than any other town. Specifically, in the 1990s, the odds of new impervious area occurring in the 30m buffer were 81% lower in Lark than in the average town; but in the 2000s, the odds were 61% higher in Lark than in the average town. Both Gannet and Teal were as likely as the average town to allow impervious area in the 30m buffer.

Robin had smaller, and Gannet larger, areas of (raw) new impervious surface in the 30m buffer, than the average town (Fig. 3.7). The four towns did not differ in percent of the 30m buffer covered in new impervious area, however. Nor did the towns differ in the raw size of total impervious areas in the 30m buffer. In Teal, however, the percent of the 30m buffer covered in total impervious area decreased from the 1990s to the 2000s.

400m Buffer Impacts

Robin had larger, and Gannet smaller, disturbances in the 400m buffer than the average town (Fig. 3.8). For example, a typical SFH was predicted to disturb 1694m^2, 778m^2, and 1115m^2 of the 400m buffer in Robin, Gannet, and the average town, respectively. Neither Lark nor Teal differed from the average town in raw disturbed area in the 400m buffer. However, Lark had larger, and Teal smaller, standardized disturbances in the 400m buffer.

Teal was less likely than the average town to have (total) impervious area in the 400m buffer. Robin, Lark, and Gannet did not differ from the average town in how likely they were to have impervious surfaces in the 400m buffer. The towns also did not differ in the area of new impervious surfaces in the 400m buffer. However, both measures of total impervious area in the 400m buffer increased in Robin, while raw total impervious area in the 400m buffer increased in Lark, from the 1990s to the 2000s (Fig. 3.9). During the 2000s, a typical project in Robin or Lark was predicted to have about 50% more raw total impervious area in the 400m buffer than a similar project in the average town. In Teal, both measures of total impervious area in the 400m buffer decreased from the 1990s to the 2000s. For example, mean raw total impervious areas in the 400m buffer was predicted to be, on average, similar in Teal and the average town in the 1990s, but about 46% less in Teal than the average town in the 2000s. Impervious areas in the 400m buffer did not differ in size between Gannet and the average town.

Landscape Position

Robin was most likely, and Teal least likely, to have disturbances set-back from wetlands (Fig. 3.10). The odds of having undisturbed land between a project and wetlands were 253% higher in Robin, and 44% lower in Teal, than in the average town. Lark and Gannet were as likely as the average town to buffer wetlands against disturbance. Among set-back projects, Gannet's disturbances were farther from wetlands in the 1990s, but as close to wetlands in the 2000s, as in the average town (Fig. 3.11). For example, a typical Gannet project was predicted to be 13 m and 6 m from wetlands in the 1990s and 2000s, respectively, while a similar project in the average town was predicted to be about 6m from wetlands in both decades. Lark's

disturbances tended to be closer than average to wetlands. For example, in the 2000s, a typical project was predicted to be set-back 4 m and 6 m in Lark versus the average town.

Impervious areas were closer to wetlands in Teal than in any other town, with a typical impervious area predicted to be 6m closer to wetlands in Teal than in the average town (Fig. 3.12). By contrast, Robin tended to have greater distances between wetlands and impervious areas than the other towns, with a typical impervious area predicted to be 2.9 m further from wetlands in Robin than in the average town. Gannet and Lark were similar to the average town in the distance between impervious areas and wetlands.

Projects in Robin were less likely, while projects in Teal were more likely, to create permanent inter-wetland barriers, compared to the average town. Projects in Lark and Gannet were as likely as the average town to create permanent inter-wetland barriers.

Project Shape

Though the towns did not differ in how compact disturbed areas were, as measured by correlation length, impervious areas in Robin were more compact in the 1990s and less compact in the 2000s, compared to the average town. By contrast, impervious areas in Teal were less compact in the 1990s, but about as compact in the 2000s, as in the average town. Lark and Gannet were similar to the average town in impervious-area compactness.

Disturbances in Gannet had lower edge densities in the 1990s, but similar edge densities in the 2000s, compared to the average town. By contrast, disturbance edge density decreased in Teal from the 1990s to the 2000s. Impervious edge densities tended to be lower in Teal and Robin, for both decades, compared to the average town. In Lark, edge densities of disturbed and

impervious areas were higher than in the average town in the 1990s, but decreased in the 2000s.

Decade

Overall, the raw area of new and total impervious surfaces in wetlands decreased from the 1990s to the 2000s across all towns and project types (Fig. 3.13). For example, a typical project in the average town was predicted to cause 32 m^2 versus 8 m^2 of total impervious area in wetlands in the 1990s and 2000s, respectively. Projects tended to be more likely to create inter-wetland barriers in the 2000s than the 1990s. Several impact metrics were not influenced by decade, most notably: the standardized wetland-impervious impact measures, raw disturbed wetland area, raw disturbed area in the 400m buffer, and all of the standardized disturbed and new impervious measures for both buffers. Likewise, the relative frequency of each project type tended to be similar across decades.

Project Type

Project type influenced all wetland and buffer impact metrics (except percent of 30m buffer disturbed), though its relative importance varied across metrics. In general, project type was more important in predicting raw impacts than standardized impacts. For the raw metrics, traditional subdivisions consistently caused more impact than the average project. Similarly, in both buffers, commercial projects were consistently associated with larger disturbances and total impervious areas than the average project; while septic projects, SFHs, SFHs within subdivisions, and SFH accessory projects were consistently associated with smaller-than-average impacts.

After accounting for lot area (i.e., standardized metrics), project type was important for predicting buffer, but not wetland, impacts. Septic projects had smaller percent impervious areas

in both the 30m and 400m buffers, but otherwise, project type was a poor predictor of the percent of 30m buffer impacted. In the 400m buffer, driveway projects had less, while commercial projects had more, percent disturbance and impervious area; conventional subdivisions had greater percent disturbance and new impervious area; and ANR subdivisions had lower percent impervious area, than the average project. SFHs and SFH accessory projects had lower edge densities and more compact work than the average project. Conversely, conventional subdivisions had less compact work and greater edge densities overall, while commercial projects had less compact disturbed areas and impervious areas with greater edge density. Project type was a weak predictor of distance between impacts and wetlands.

Compared to the average town, Robin was more likely to have conventional subdivisions and SFHs within subdivisions than septic projects (Table 3.6). Teal was more likely to have conventional subdivisions and commercial projects than septic projects. Conversely, Lark was more likely to have septic projects than conventional subdivisions. Gannet was more likely to have septic projects than SFHs within subdivisions, but less likely to have septic, than commercial, projects.

Perceived Ecological Effectiveness and Ecosystem Changes

Some context is necessary before describing perceived EE. Interviewees differed in the longevity and depth of their ecological and place-based experiences. While most subjects could comment on spatial and project-based aspects of EE, their ability to describe non-spatial EE varied with duration in town, scientific knowledge, and proclivity for outdoor activities. Inter-town comparisons of non-spatial EE should thus be interpreted cautiously. Nevertheless, perceived EE complements and helps triangulate the site-plan data.

Some interviewees provided an historical perspective that further contextualized the perceived-EE discussion. They believed wetland water quality had improved and wetland-fill rates slowed considerably in both states since the 1970s and 80s, when wetland-protection laws were new and the housing industry booming. Subjects with narrower temporal frames were more likely to describe worsening conditions or no changes in wetland ecosystems than subjects with this long-term perspective. Interviewees from all four towns also described resurging beaver populations in recent decades (especially in MA since the 1997 state-issued trapping restrictions) and associated increases in wetland area, which contrast with development-induced wetland loss. Finally, subjects from the two MA towns indicated that forest succession over the last several decades had altered landscape structure, appearance, and wildlife communities.

Interviewees also described some town-specific, long-term ecosystem changes, many of which centered on large waterbodies. Lark has at least 10 lakes and self-identified as a lake town, but contained no significant lentic waterbodies in 1900. The lakes were created in the early 1900s as tourist attractions by damming streams and flooding wet meadows. Over time, chemical and hydrological lake management, as well as lake-side development, altered water quality and hydroperiod. Robin has just one lake, naturally formed and shared by two other towns, but it also experienced significant water-quality degradation in the last 60 years due to recreational lake-use and lake-side development. In particular, water clarity decreased and nutrient loads increased. Regular water drawdowns, which helped manage invasive milfoil vegetation, also disrupted the ecosystem. In Teal, major changes associated with succession and housing developments drastically altered the ecosystem around one large pond (Pond A). By one account, the pond shrunk from 24 to 2.5 hectares as succession transformed it into a marshy wetland. Further, land clearing, wetland filling, and stormwater runoff associated with two abutting subdivisions

diminished wildlife habitat value and increased flooding in the system. Though Gannet has several lakes and experienced significant growth in the last 60 years, there was no consensus among Gannet interviewees about long-term ecosystem changes.

Perceived Spatial Effectiveness

The quantity and configuration of wetland and buffer disturbance constitute the spatial attributes of EE. Broadly, interviewees' perceptions of spatial effectiveness paralleled the site-plan results: wetland and buffer impacts were perceived as generally minor in Robin, reasonable in Lark, somewhat concerning in Teal, and significant in Gannet. Notably, interviewees rarely talked about project impacts beyond the first 30 m of buffer. The 400m-buffer site-plan data thus highlight a little-considered, but ecologically important, zone of development impact. Finally, interviewees from all four towns deemed permanent land conservation an effective wetland protection tool and felt their towns successfully engaged in land conservation.

In more detail: Robin subjects recognized that some work occurred in wetlands and buffers, but that most disturbances were outside their 19-m no-build and 7-m natural-vegetation zones. Everyone agreed that Robin permitted less wetland and buffer impacts than neighboring towns and most thought Robin's wetland program was basically ecologically effective. Still, some board members felt that wetland ecosystems would be healthier if development were kept farther from wetlands. Lark subjects observed that some work was allowed in wetlands and even more in buffers, but did not think these alterations significantly changed wetland ecosystems. Teal subjects referenced many projects that degraded wetland ecosystems. In particular, residential development severely altered Pond A and its buffers. Subjects expected future developments and industrial activities to further degrade wetlands and buffers. Gannet subjects

disagreed about spatial effectiveness. Subjects acknowledged that much work had occurred in wetlands and buffers, but diverged on the extent of, and harm caused by, impacts. For instance, an abutter described massive amounts of wetland fill that accompanied new housing throughout town and two CC members lamented the negative impacts resulting from Gannet's general practice of limiting project reviews to within 15 m of wetlands. Conversely, a project applicant and ZB member both thought the town misguided in protecting low value wetlands and non-essential buffers. Subjects also disagreed about whether Gannet's policy of restricting impervious surfaces within 15 m of wetlands enhanced wetland ecosystems or was superfluous.

Perceived Non-spatial Effectiveness

Non-spatial EE encompasses factors that cannot be measured from construction site plans, including: flooding, surface and groundwater quality and quantity, wildlife, and invasive species. Perceived non-spatial effectiveness was based mostly on personal observation since towns rarely had access to or engaged in quantitative monitoring of environmental conditions.

Lark subjects offered few comments on non-spatial effectiveness. Besides concerns about lake water quality and ecosystem integrity, they generally remarked on individual-project impacts. One abutter noticed increased flooding after house construction at a couple different sites. She also noted that the CC unexpectedly required a sewer extension, rather than septic, to guard wetland water quality at one new subdivision. Robin subjects perceived surface water quality as somewhat degraded by roads, malfunctioning septic systems, lawns, pets, and other aspects of development; though they thought road-side water quality was improving due to reduced winter salt use and drinking water remained unpolluted. Water quality was worst in the lake. Invasive species abundance was increasing throughout town, though management was only

pursued on the lake. In general, wildlife populations were seen as stable or, in the case of beavers, rebounding. One 70-year resident remarked that he now sees mockingbirds and cardinals, two species associated with human development, which he never saw as a child in Robin. In Teal, board members agreed that poorly-engineered past development causes major flooding problems. Of particular concern were under-sized culverts and altered drainage patterns. Some flooding "pinch-points" were only obvious after sufficient development amassed in town. Flooding damaged town infrastructure and inspired concern for flood-intolerant species. Observed and potential water-quality degradation also troubled board members. They cited multiple examples where untreated road or industrial runoff, erosion, and/or septic leachate contaminated wetlands. By contrast, open-space subdivisions were popular in Teal and perceived as an ecologically-smart planning tool because they leave large buffers, conserve wildlife habitat, and promote connectivity across the landscape. Nevertheless, multiple interviewees worried about groundwater impacts in open-space subdivisions, which concentrate wells and septic systems in a relatively small area and are poorly regulated. Several Gannet interviewees described water-quality degradation associated with development near wetlands. A massive erosion event during construction of a commercial building was mitigated with new detention basins, but left a strong impression on one CC member. Likewise, multiple subjects described run-off from an unpaved restaurant driveway as dumping silt and pollution into an adjacent wetland over many years.

Integration of Ecological Effectiveness Measures

Site-plan and perceived-EE results provide complementary perspectives on the EE of municipal wetland programs. Where site plans show quantitative nuances of land-use configuration, perceptions provide insights into EE qualities that go beyond distances and shapes.

Both data types show that development generally impacted wetlands and buffers least in Robin. This was achieved, as the site plans reveal, by shifting disturbances farther from wetlands, beyond the 30m buffer. Despite positive spatial outcomes, the perceived EE results indicate somewhat negative non-spatial impacts, such as reduced water quality and changes in wildlife communities. Combined, the results suggest two potential lessons. First, some inevitable wetland impacts accompany development, despite relatively competent local land-use choices. This is likely true in all four towns, even if interviewees didn't recognize or acknowledge negative effects. Second, 30m buffers and low-density zoning are insufficient to completely prevent wetland impacts.

Both data types indicate that Lark and Teal experienced intermediate levels of wetland and buffer impacts, but the site-plans differentiate the towns. Buffer disturbances, of average size in both towns, were proportionally larger in Lark, suggesting Lark allowed the same alteration area but on smaller lots. If this trend continued, cumulative buffer disturbances could potentially be much larger in Lark. (Robin showed a similar trend, whereby it permitted the greatest percent change to the 30m buffer, per project, out of the four towns, but unlike Lark, raw disturbance size in Robin was smaller than in the other towns). The distance-to-work metrics reveal additional inter-town differences. Teal commonly left no buffer between disturbances and wetlands and only narrow buffers between impervious areas and wetlands. Lark, by contrast, was more likely to require buffers between wetlands and disturbances, but the buffers were relatively narrow. These results suggest that both towns might improve wetland-program EE by siting work farther from wetlands. This may be especially feasible in Teal, where large lots and open-space subdivisions were normal.

The results also confirm that perceived EE may be unreliable as a sole source of information about the environmental effects of wetland-permit programs. The conflicting EE perceptions in Gannet exemplify this problem. Some subjects thought Gannet's program was ecologically effective, while others did not. Meanwhile, the site plans show that Gannet had the largest wetland impacts and, over time, allowed larger disturbances in the 30m buffer and situated them closer to wetlands, than any other town. The conflicting results suggest that human valuation of wetland ecosystems influences perceived EE and/or that some interviewees were not knowledgeable enough to provide accurate EE descriptions. Perceived EE in Lark supports these conclusions. Lark subjects thought their wetland program was relatively effective from an ecological perspective. But the site-plans showed that Lark allowed proportionally larger disturbances in close proximity to wetlands. Either Lark's projects were so well-designed that wetland integrity was preserved despite development or subjects were ill-equipped or used different values to assess EE.

Social Effectiveness

SE varied widely between towns and evolved over time within towns. Nevertheless, two observations about SE were nearly universal. First, most interviewees supported and were proud of their town's permanent land conservation achievements. Moreover, they viewed conservation as a progressive management tool because it protected wetlands from development, but also met landowner interests. Second, interviewees from all towns were dissatisfied with the amount and efficacy of municipal wetland-permit enforcement. Board members, however, were internally conflicted about weak enforcement because they understood it as a trade-off that allowed boards to be strict in other ways (e.g., permit conditions) without losing public support. As with EE,

Robin had the highest SE and Gannet the lowest, while Lark and Teal were in the low-middle range. High SE was characterized by stakeholders who were knowledgeable about wetlands and wetland policies and were generally satisfied with, and engaged in actions that supported, the local wetland-permit program. Conversely, low SE was distinguished by stakeholders who possessed little knowledge about wetlands and wetland policies, were frustrated with local wetland-permit programs, and/or tried to change such programs. Below, I explore in more detail how SE varied across towns.

Ample evidence indicated high SE in Robin. All interviewees expressed respect for the CC and most lauded its members' knowledge, experience, and passion. The abutters, who best represented an average citizen, all thought Robin successfully balanced wetland protection and development. Most significantly, stakeholders widely accepted Robin's strict land-use bylaws and policy implementation, including the CC's informal 7-m natural-vegetation buffer. Abutters and applicants usually accepted project conditions and litigation was rare. Different political interests in Robin generally cooperated and successfully negotiated compromises that benefited wetlands. For instance, the public voted in and maintained a 19-m impervious-free buffer and decided to participate in the MA Community Preservation Act which supports conservation but raises local taxes. Robin's wetland program was not universally accepted, however. At one annual town meeting, for instance, citizens voted to oppose a bylaw revision which would have expanded vernal-pool protections. Occasionally, wetland issues soured inter-board relations, as when the PB and ZB re-zoned a lot, against the CC's recommendation, allowing commercial trucks to be stored in riverfront area. Mostly though, Robin seemed divided between insiders and outsiders, especially in the engineering and developer communities. Insiders accepted the strict wetland policies and even promoted conservation as prominent members of the local land trust.

Outsiders complained about the duration, expense, and strictness of Robin's permit process. To avoid such aggravation, they sometimes abandoned projects or choose to work in less difficult towns.

In Lark, SE was relatively low, but improved marginally at the end of the study period. The CC was the focus of considerable grief and consternation in both the development community and among CC members. On the development side, interviewees found the CC uncooperative, aggressive, overly strict, and inaccessible. They found the permitting process onerous and expensive. They accused the CC of intentionally delaying projects and driving economic development from town. In the most striking manifestation of this frustration, angry citizens commandeered CC public hearings, overfilling meeting rooms, yelling at the CC and other citizens, refusing to back down, and dragging the meetings out into the early morning hours. This 'hostage'-taking went on for several years, until one CC member finally called in the police (a move which also met with strong and lingering public resentment). One applicant thought the CC should be abolished and their duties transferred to the PB. Wetland permitting also discouraged CC members, some of whom were intimidated by the angry crowds, alienated by the status-quo lack of funding and inter-board cooperation, or frustrated at members who pursued personal agendas rather than policy compliance. Most notably, one beleaguered, decade-long member quit when Lark cut funding for a full-time conservation agent. Despite the many negative SE indicators, interviewees tempered their frustration with some positive comments about Lark's wetland program. For example, one large, repeat developer praised a bylaw provision that allowed expedited local review for minor projects. A ZB member recalled several highly educated, well-intentioned former CC members. In the last five years, overall Lark SE was improving under the guidance of a new CC chair who was a professional wetland consultant,

adamantly focused on compliance. Recently, for example, few people attended CC hearings and hearings were civil and well-managed.

SE in Teal was mostly negative. Discontent with wetland and land-use programs occurred as occasional strong eruptions, with lingering aftershocks. Three eruptions protested attempts to strengthen land-use policies. First, Teal tried to pass a mandatory open-space subdivision bylaw. In response, a citizen(s) sent a mailing to the entire town portraying the bylaw as an attempt to encourage uncontrolled sprawl. The bylaw never passed. Second, Teal approved a 100-m buffer along the river in town. Several large landowners on the river protested at a series of PB hearings and the town rescinded the buffer. Third, the CC tried to get the town to designate prime wetlands under NH state law. (Projects proposed near prime wetlands receive extra scrutiny during permitting). With the 100-m river buffer fresh in their memories, citizens protested in force at the PB's prime-wetland hearing and defeated the proposed designation. These eruptions demonstrate strong discontent with the wetland and land-use programs and a citizenry that boldly expressed its dissatisfaction. The eruptions are part of a longer history of dissent in Teal, where land-use litigation is relatively common. This legacy has shaped SE among board members, some of whom confessed to enduring timidity and conflict avoidance in their public work. Specifically, they would not sponsor new wetland or buffer policies, despite a recognized need, and leniently implemented existing buffer policies. The PB also showed timidity during the prime-wetland hearing when it tried to distance itself from the pro-prime CC. Poor SE was also evident in more typical ways, including complaints about an over-involved PB secretary and the duration and expense of the permit process. Positive SE was rarer and more subtle. Though the mandatory open-space subdivision bylaw was rejected, an optional version was later passed. Such subdivisions are now popular with some Teal developers. A native

surveyor described Teal as one of the better towns to work with because its PB and CC members were knowledgeable and/or cared about the town and were generally competent and respectful.

In Gannet, SE was low, yet polarized. Interviewees made positive statements about land-use boards, but their negative descriptions were more vehement. For instance, some thought the CC was diligent, fair, or effective, but one agitatedly described it as manipulative and ignorant. Similarly, some found the PB fair and open, while others complained that it lacked transparency and objectivity, or that its process was too long and costly. Polarity also extended to developers and the land-conservation process. One abutter claimed Gannet was controlled by developers and described how a prominent local contractor threatened him when he resisted a proposed land swap. By contrast, a CC member described local developers as reasonable and level-headed. Similarly, while most Gannet interviewees were enthusiastic about land conservation, especially the recent purchase of a pond near a river's headwaters, one bitterly complained that conservation removed land from the tax rolls. Based on town demographics, I suspect this interviewee represented a significant portion of Gannet landowners. Citizen actions are further proof of low SE. Gannet passed its wetland bylaw in 1986 with little resistance, but the policy has been attacked multiple times since, with one campaign to repeal it entirely in 2008. The distribution of the land-use change tax (levied on landowners who received tax reductions for keeping land in forestry or agriculture, but now want to develop the land) has a similar history. In 1999, the town voted to apply 100% of the tax to land conservation. In 2007, citizens tried, but failed, to rescind this decision. Active discontent with Gannet's wetland and land-use programs was also evident in the PB's weak implementation of existing wetland buffers; the CC's tendency to rely on DES, not Gannet's code enforcement officer, to enforce wetland violations; and repeated political battles for control of the PB, ZB, and board of selectmen. These power

struggles were citizens' main method of protesting land-use policies and caused regular reversals of political power.

Combined, EE and SE results suggest that Robin and Lark, the two MA towns, had somewhat higher EE and SE than the NH towns. Interviewees with experience in both states and other municipalities, however, described considerable inter-town SE variation in MA and NH. Developers and consultants, in particular, expressed similar frustrations with some towns in both states. Wherever board members were ignorant about wetlands or the permit process, biased against applicants based on reputation, pursuing personal agendas, or generally obstructionist, consultants found wetland-permitting unpredictable and interactions with the board excruciating. Developers and consultants also complained passionately about some local wetland bylaws, which they described as excessive without environmental benefit, not rational or science-based, and created principally for obstructing development. This broad SE view highlights inter-town variation and reinforces the need to understand what drives SE and EE in individual towns and how the two effectiveness measures interact to shape wetland systems.

Critical Social Effectiveness Drivers

Each town followed a different recipe for social effectiveness, though some patterns were shared and certain towns had greater SE than others. I draw the strongest lessons about SE achievement from Robin, which had the highest SE. But other towns had successful moments that merit examination and failure can also be an important teacher. In the following sections, I describe the principal factors that drove SE patterns in each town (Fig. 14). These factors stand-out among the many complex, interacting attributes that comprise the municipal wetland governance system. I classify the factors into four types: key, contextual, enabling, and tools.

Key factors were essential ingredients whose presence and proper use were vital for high SE. Contextual factors were important components of the matrix in which SE develops: they set the stage, but did not prescribe SE. Enabling factors facilitated SE when present, but SE could be achieved in their absence. Finally, stakeholders used tool factors to express SE and influence decision-processes.

Key Factors

Town identity and communication are the two key factors. Town identity is a productive strategy which, if carefully curated with a pro-wetland objective, can lead to high SE and EE. Communication refers to a critical skill set that can make or break an otherwise seamless wetland management program. Both key factors were instrumental in creating high SE.

Town Identity

Town identity is the theme(s), objective(s), and feature(s) that define a town's essence. In the land-use realm, it influences what projects a town pursues and approves and how strict the town is in conditioning them. It can be intentionally cultivated or arise organically. Town identity is embedded in citizens' descriptions of town priorities. Among the four cases, having a strong town identity influenced the SE of local wetland programs in both positive and negative ways. The theoretical disciplines of place branding and place attachment help contextualize and explain the towns' relative success at using the town-identity concept to improve, rather than lower, SE.

Place branding is the practice by which a geographic territory identifies and markets its unique features, with the goal of attracting new people, business, or funding and achieving a

competitive advantage over other territories (Hanna and Rowley 2008; van Ham 2008). Retaining existing citizens is a vital, but less prominent aspect of place branding, which relies on maintaining a high quality of life from a cultural and/or environmental perspective (van Ham 2008; Ashworth 2011; Gulsrud et al. 2013). Successful place branding requires a long-term strategy, implemented through frequent symbolic communication, institutional change, and active management and cultivation (Anholt 2008; Johansson 2012).

Place attachment refers to the emotional and psychological bonds that people develop for a particular place (Walker and Ryan 2008). People can attach to different place features (e.g., lakes, buildings) and for different reasons (e.g., privacy, security; Lewicka 2011; Lokocz et al. 2011; Kondo et al. 2012). Residence time, mobility, and age also shape attachment (Stedman 2003; Walker and Ryan 2008; Lewicka 2011). Over time, individuals and communities may integrate place into self-constructed identities, such that place changes, like land development, can disrupt identity and cause feelings of loss (Stedman 2003; Walker and Ryan 2008; Devine-Wright 2009). Attached individuals express positive feelings for a place and are more involved in their communities (Walker and Ryan 2008; Taylor 2009). In rural and exurban places, attached persons are more likely to support land conservation (Bunce 1998; Walker and Ryan 2008; Lokocz et al. 2011). This last point is critical because many exurban landscapes are experiencing sprawl and residents are searching for ways to maintain 'rural character' (Walker and Ryan 2008; Kondo et al. 2012; Zabik and Prytherch 2013). If towns can motivate citizen attachment to rural landscape features, then landscape preservation, rather than alteration, may result.

Place branding is one tool that could be used to nurture place attachment, by strategically linking town identity to the rural landscape and communicating about the benefits that rural life

provides existing residents. The conflicting definitions and values that stakeholders associate with rurality and landed property could hamper branding, however. For instance, some residents define rural as farms and forestry, while others see low-density housing as rural (Ryan et al. 2006; Abrams and Gosnell 2012; Zabik and Prytherch 2013). Similarly, some prize land's use and investment values, while others prioritize preservation for aesthetic or ecologic reasons (Abrams and Gosnell 2012; Abrams et al. 2012; Kondo et al. 2012). A successful place-branding strategy, therefore, must capitalize on the broadly shared desire to preserve 'rural' landscapes and portray rural preservation as an identity that encompasses diverse rural perspectives and promotes shared place stewardship (Anholt 2008; Taylor 2009; Abrams and Gosnell 2012). Branding requires careful balance, however, since it can accelerate sprawl by making a place more appealing to immigrants who then require constructed space to live and work (Lokocz et al. 2011; Kondo et al. 2012; Zabik and Prytherch 2013). Conversely, policies designed to protect rurality (e.g., minimum lot sizes) risk being exclusionary (Glaeser 2007; Kondo et al. 2012). The cases reflect this tension between conservation and development and show that while a carefully cultivated town identity can bolster rural preservation and SE of wetland programs, a poorly managed identity, or one that does not prioritize natural place features, can degrade rurality and SE.

Though interviewees from all four towns expressed a desire to keep their town rural, only Robin cultivated a rural identity in a strategic, unified manner. Robin viewed itself as a small, agricultural town with abundant conserved land. Despite intense development in surrounding towns, Robin preserved its rurality through the efforts of a dedicated, passionate group of leaders who actively prioritized, cultivated, and managed a strategy of rural preservation over several decades. Their strategy was relatively simple. They promoted rurality because it was broadly appealing. They built relationships with diverse stakeholders through inter-personal engagement.

They developed credibility and continuity via action and personal commitment. They used institutions to support and promote the rural-identity concept. In particular, the group established a non-profit land trust in the early 1970s and worked within town government to enact strict wetland and zoning bylaws. The land trust was instrumental in promoting and recruiting diverse citizens to the conservation cause, via public celebrations and education. The bylaws formalized the rural vision. As part of the promotional strategy, the land trust led numerous nature walks, with the goal of exposing citizens, and inspiring attachment, to the rural landscape. Similarly, the CC worked to deepen farmers' existing attachment to the landscape by explaining how protecting open space would benefit their livelihood.

By single-mindedly promoting this identity, Robin achieved several positive SE outcomes. First, it succeeded in getting politically disparate groups to cooperate for the common goal of conservation. The land trust, for instance, was founded and led by a mixture of local developers, conservationists, and professionals. Similarly, the CC convinced farmers and Tea Partiers to tolerate wetland-policy revisions that the groups initially opposed. One government leader described Robin politics as a 'benevolent dictatorship,' because all parties knew that if they didn't work in unison, 'the builder wins.' Second, the rural identity made strict wetland bylaws palatable to citizens and local developers because it portrayed strictness as a tool that served the larger purpose of rural preservation. Third, the rural identity provided a socially acceptable cover for environmental action and facilitated back-door wetland conservation. Hundreds of hectares were permanently conserved and withdrawn from potential development in the name of the rural idyll. As one CC and land trust member declared in reference to the land trust's promotional methods: "It's not *conservation* land. It's not *town* land. It's [Robin] *Rural Trust* land." In the end, Robin citizens and leaders had stronger allegiance to their town identity

than to many individual and political goals. People who didn't value the quiet, yet strict lifestyle tended to move out. The remaining citizens were quite attached to Robin and supported a town identity applied like, and bearing many hallmarks of, a successful branding campaign.

No other town strategically pursued a town-identity campaign. Rather, all had divided identities that weakened SE. Teal thought of itself as a small, rural, agricultural town, but also recognized its status as a bedroom community with growth pains, no good water supply, and development-induced flooding problems. Teal citizens generally wanted to preserve rurality, but disagreed on tactics. Town boards and some local developers pursued rural preservation with planning tools like open-space subdivisions and wide wetland buffers. Many landowners valued rural land for its productivity or aesthetics and thought private stewardship best guaranteed protection. These conflicting visions motivated landowners to repeatedly block the boards' attempts to strengthen wetland and land-use bylaws and damaged Teal's prospects for building a unified identity around rural preservation.

Lark saw itself as a small, rural, lake town, hampered by limited revenue. Lark had minimal industry and commerce and contained a tax-exempt, non-profit educational institution that occupied much land. Thus, though a conservation and rural identity were important for some citizens, others were driven to develop the town's economic base. These latter were a bit resistant to conservation and hostile towards wetland permits they perceived as excessively strict. The lakes also created tension: inspiring conservation, but also attracting development. Lark's dual identities seemed to frequently conflict, though the town enjoyed a brief collaborative Golden Age in the mid-2000s. During this period, the town administrator (TA), PB, CC, Board of Health, and business-development board cooperated on a comprehensive plan to counteract development spilling into Lark from nearby cities. The plan reserved part of town for economic

development and part for open-space conservation. The TA coordinated the project and encouraged inter-board communication. The CC and PB agents, working from the same physical office, sustained the effort. The Golden Age was an attempt at strategic planning in support of Lark's dual identities. Unlike Robin, however, Lark's strategy and moment of high SE were short-lived and powered by professional, non-resident employees. After several months**,** it disintegrated into political squabbling. The comprehensive plan was forgotten; the PB and CC ceased communicating; and conservation was once again pitted against economic development.

Gannet had the most strongly divided town identity. Like Lark, Gannet was a rural, bedroom community with a large, tax-exempt educational institution and lakes that attracted development. Though Gannet had a larger commercial and industrial base than any other town, perceived financial strain motivated a significant portion of the population to prioritize economic development, often to the detriment of other interests, including wetland protection. A less vocal contingency identified principally with the high quality of life that Gannet's rural environment offered. This included conservationists and strategic planners (who wanted to re-brand Gannet as high-tech business center with natural amenities). The deep political polarization between these groups was part of Gannet's identity and their power struggles revealed mutual malcontent with each other's decisions and policies. Recently, conservationists initiated an explicit campaign to re-construct Gannet's identity. As in Robin, their strategy was simple: build a new sense of community, rooted in Gannet's natural amenities, by recruiting politically-unattached newcomers. Specifically, get people outside and expose them to nature, thereby cultivating place attachment and support for land conservation. It is unclear whether this strategy will prevail. Success may depend on whether conservationists and other quality-of-life supporters unite and articulate a broadly-appealing alternative vision of economic redevelopment.

When intentionally applied like a branding campaign, town identity can promote place attachment and enhance the SE of local wetland and land conservation programs. This is precisely the strategy that Robin pursued. It focused on rural preservation as a simple, broadly appealing identity. Using rural attachment as a foundation, the town instituted systemic changes to support its identity, including strict land-use bylaws; worked to maintain the power of its identity over multiple decades; and built relationships across political lines to get citizen buy-in. The results were public acceptance of a strict wetland program, political cooperation, and support for land conservation. But town identity is not a panacea and, among other risks, can be used to promote priorities that actually hurt conservation, as when Gannet exclusively pursued economic development. Other obstacles may include political in-fighting, legacy conflict, undesired amenity-based development, and the evolving priorities of changing demographics. Ultimately, what may have differentiated Robin from the other towns was its ability and commitment to communicate town identity across traditional political and demographic divides.

Communication

Communication, the second key SE driver, is the flow of information and ideas between individuals. Communication is critical for wetland conservation because it is the means by which information about wetland function and permitting is transmitted from knowledgeable to uninformed parties and it allows diverse stakeholders to express opinions about development near wetlands. Through communication, values and interests can be revealed and strategies developed for building common ground and policy support (Jacobson 2009). Organizational structure and politics shape information flow, but successful communication requires human skill, benefits from human intention, and relies on a receptive, even responsive audience (Hall and

Tolbert 2005; Jacobson 2009). In the case towns, effective communication was essential for building positive SE and deficient communication handicapped otherwise promising wetland programs. As with town identity, Robin was a leader in successful communication.

Robin's success derived from multiple inter-related factors. First, Robin had several skilled communicators, concentrated on the CC, capable of teaching citizens about wetland ecosystems, negotiating political deals, and maintaining a low-stakes atmosphere at public hearings. Second, the CC communicated in a regular, strategic manner. At wetland hearings, it intentionally cultivated informal, open dialogue to encourage public comment and cooperation. Extra-hearing interpersonal interactions were equally important. The CC was politically savvy and regularly reached out to Robin's key power players to informally converse or, in advance of critical wetland or conservation votes, to negotiate acceptable compromises. Thus did the CC build a support web that bridged political divides and tolerated strict bylaw implementation. The CC was a central node in this network, but non-governmental actors were also essential. The land trust was particularly instrumental since its leadership strongly overlapped with professional, local development, and conservation sub-networks. The CC also networked beyond town borders: actively building relationships with other conservation organizations and the MA wildlife agency. This communicative investment paid off. For example, a watershed association reduced wetland impacts of a major proposed subdivision by brokering talks between the CC and applicant, and the MA wildlife agency awarded Robin several conservation grants. Both the CC and land trust also recognized the importance of using non-verbal techniques to complement verbal communication. For instance, the CC used site walks to physically demonstrate their diligence and commitment to site-specific data. The land trust used photographs in their annual calendar and website to visually engage the public and immersed citizens in full-sensory experiences

during nature walks and annual festivals. Robin's final strategic ingredient was its consistent message. Whether CC members negotiated wetland buffers or the land trust pursued donations, they framed communication in terms of maintaining the town's rural identity. Because of the skill, accessibility, consistency, and extent of its communications, Robin's conservation community had credibility and generally enjoyed public trust and support.

Each other case town was deficient in communication skills, intention, and/or a receptive audience. Gannet lacked a wholly receptive audience, but had one skilled, intentional communicator. As CC chair, he developed a conservation campaign based on experiential communication. His goal was to expose as many people as possible to nature so they could appreciate its ecological and cultural worth. He led hundreds of tours on potential conservation properties and worked with journalists to publicize fundraising activities. His efforts were rewarded with land donations and a town conservation bond. He applied a similar non-aggressive approach to wetland permitting. The CC typically suggested wetland-permit conditions to the PB and ZB, but rarely confronted either board if they ignored its opinion. The CC chair regarded aggressive communication as counter-productive to building CC credibility and SE, even if the trade-off was occasional wetland degradation. He felt this strategy increased public acceptance of wetland conservation and the CC over the last 40 years. While partly true, significant hostility towards wetland-bylaw restrictions persisted in Gannet. The town's contractor network was one source of this hostility. Gannet had many families with deep roots, a common heritage, strong religious ties, and conservative values. Most worked in construction and communicated frequently. Their network was dense and, by some accounts, exclusionary. Even the non-confrontational, patient CC chair had difficulty penetrating it. Network members viewed wetland bylaws as an unnecessary development obstacle, mounted major challenges to Gannet's bylaw,

and successfully increased permitted disturbances for some local permits. Given the strength of the contractor network, the CC's ability to generate any credibility and SE was remarkable.

Lark and Teal both lacked skilled communicators and a receptive audience. This was most obvious in Teal, where an outraged public repeatedly defeated the CC and PB's attempts to strengthen wetland and land-use policies. Both boards were led by environmental engineers who had a strong desire to protect wetlands, but couldn't translate their technical knowledge and environmental ethic into convincing lay terms. Recently, they realized that intentional and extended outreach might be necessary to overcome past hostilities, engender support for wetland conservation, and build public trust. Reflecting on the demise of the river buffer and prime-wetland initiative, the CC chair remarked: "I think what we learned is that…We probably didn't spend enough time talking to the individuals and talking to the folks that…it impacted… Communication is kind of the key in all of that." Nevertheless, they have not launched a strategic communications campaign or cultivated relationships with opposition leaders. Political squabbles and fear of negative public perception were two reasons communication stalled. Petty vendettas stifled inter-board communication, leaving the isolated boards vulnerable to manipulation by developers. PB and CC efforts to improve inter-board communication in the late 2000s restored civility, but the legacy of friction and public discontent persisted. While the PB respected the CC chair for his wetland knowledge, they made it clear that the CC's opinion was advisory and only consulted the CC at the end of permit negotiations. Board disunity was also communicated during the prime-wetland process, when the PB, faced with public aggression, distanced itself from the CC, stating unequivocally that the CC, not the PB sponsored the prime-wetland proposal. The PB secretary similarly distanced herself from the PB's land-use initiatives so as to

remain apolitical. The PB repeatedly asked her to promote PB initiatives, but she refused. Inter and intra-board disunity likely undermined recent attempts to enhance public communication.

Like Teal, Lark's dearth of skilled communicators contributed to a lingering rift between the CC and the public and limited SE. The public perceived the CC to be biased and unhelpful and the CC made no concerted effort to dispel this image. Though the current CC chair runs respectful, orderly, accessible public hearings, the CC's reputation remains tarnished and SE low. The CC achieved a short communication break-through in the mid-2000s, with a series of public presentations that explained and justified its wetlands work. The town responded positively and provided funding for a full-time conservation agent. Without sustained public outreach, however, CC support dwindled and within a couple years, the agent was reduced to part-time.

The case towns provide several lessons about communication in the local wetland-permitting arena. First, communication can strongly influence stakeholder support for wetland programs and produce either high or low SE. In Robin, for instance, communication bridged political divides and fostered acceptance of strict wetland policies. In the other towns, malcontent festered in the absence of effective or enduring communication about the need for, and mechanics of, wetland permitting. High SE was best achieved when communication was skillful, intentional, active, and expressed a pro-conservation ethic couched in a willingness to listen and negotiate. Such strategic communication may be uncommon in exurban towns, because local officials rarely receive communications training and politics infiltrate planning, making land-use hearings potentially volatile and rife with miscommunication (Gober et al. 2013; Nolan et al. 2013). Skilled communicators were but one of three elements essential to successful communication in the case towns, however. A strategic message and receptive audience were also vitally important, as demonstrated by Teal, Lark, and Gannet. Managers looking to enhance

SE, therefore, should first develop an explicit communications strategy. Sending local officials for communications training could be a key strategic feature, as it has the potential to vastly improve wetland-program SE. Cultivating a receptive audience is also important, however. This may be best approached indirectly, by working first to build generalized trust with opposition leaders through informal, repetitive interactions, as explored further below.

A second lesson from the case towns is that communication is not monolithic. At least three different types of communication skills were relevant to SE: intra-board, inter-board, and board-public. The first two types were useful for coordinating knowledge and purpose within and between boards and creating a unified public message. Board-public communication was critical for educating citizens about wetland permitting and generating support for wetland conservation.

Thirdly, the case towns show that diverse communication methods facilitate SE. Robin and Gannet's effective use of non-verbal and interpersonal communication enhanced and even surpassed their verbal strategies. Nonverbal communication is effective because it has visceral appeal and taps into emotions that language cannot access (Ivakhiv 2010). Interpersonal communication is vital where knowledge or opinion changes are sought (Jacobson 2009; Hambleton and Howard 2013). Other reliable methods were: site walks, informal stakeholder meetings, and joint-board meetings. Site walks and informal meetings allowed for negotiation in a lower-stress environment than typically found at public hearings. Joint-board meetings reduced stakeholder frustration by facilitating efficient information sharing.

Finally, the towns indicate that communication and trust are mutually reinforcing in the wetland realm and foster SE by building credibility, social capital, and strong networks. Recognizing these connections is particularly important for wetland-permitting because trust can be a prerequisite for behavioral change (Jacobson 2009). Communication transmitted to a

distrustful audience risks being miscomprehended or ignored (Jacobson 2009; Reynolds 2011). This happened in Teal, when the CC explained that designating prime wetlands would limit future flooding and the public, distrustful because of the river-buffer experience, accused the CC of orchestrating a state-backed land-grab. By comparison, communication that reinforces trust builds social capital (Wondolleck and Yaffee 2000; Rojas et al. 2011; Taylor 2011), which can facilitate effective and efficient communication, even when stakes are high (Wondolleck and Yaffee 2000; Focht and Trachtenberg 2005; Hanna et al. 2009). Such was the case in Robin, where CC leaders consulted trusted developers and farmers before proposing wetland-policy revisions, confident these contacts would rally their respective networks to support the negotiated revisions. Though communication networks can drive pro-wetland policy decisions by mobilizing resources and building conservation support (Toikka 2010; Chang et al. 2012), networks can equally serve other objectives (Hanna et al. 2009), as happened in Gannet. Despite the CC chair's communication skills, the contractor network was resilient, powerful, and frequently dominated the land-use arena.

Contextual Factors

Property rights and organizational structure provide context for SE. Each shapes citizens' predispositions to support or oppose municipal wetland programs. Neither dictates SE, however.

Property Rights

Property rights describe who controls landed property and how it may be used (Carruthers and Ariovich 2004). In the US, property rights evoke strong emotions and shape personal identities (Freyfogle 1998; Hurley et al. 2002; Jacobs 2004). Many landowners expect

exclusive, private property rights, but their land may contain resources, like wetlands, that serve the public good (Freyfogle 1998; Jacobs and Paulsen 2009; Fraley 2011). Conflict can arise when public-good protection hampers landowner ability to fulfill autonomy expectations (Jacobs 2004; Jackson-Smith 2005; Trapenberg Frick 2013). Wetland permitting, for example, can cause considerable conflict if permit conditions overly restrict land-use (Freyfogle 1995; Dale and Gerlak 2007; Calhoun et al. 2014). Under US property law, the 'taking' of land rights for public use may trigger economic compensation for the landowner. In New England, high-profile, wetland-taking court cases signify such conflict and imply that private property rights are deeply valued and may strongly structure how stakeholders approach wetland-permitting in the region (Freyfogle 1995; Shelby 2008). The case towns provide some support for this view, but also demonstrate a diversity of property-rights ethics that sometimes inspired consensus for wetland protection, rather than conflict.

Table 3.7 shows the diversity and relative strength of property-rights ethics in the towns. The property-rights literature has explored some of these ethics, like "autonomous stewardship" and "economic balance" (Freyfogle 1998; Dutcher et al. 2004; Jackson-Smith 2005), but not others, like "autonomous conservation" and "necessary ill." In each town, some autonomy variant was common, but ethics that favored wetland conservation were also present. Overall, Robin had the strongest consensus on property rights. Despite seemingly high diversity, most people believed both that some land-use restrictions were reasonable to protect the public interest and that people should otherwise be allowed to use their land as they pleased. This balanced ethic extended even to the CC, whose chair stated: "So it's a little bit different mindset in this town…There's a lot of: 'This is my land. You can't tell me what to do!' And…some of us kind of

agree with that. But at the same time, there are laws and rules that…you have to play by. So, we try to be as gentle and...coaxing and… reasonable as possible. But…we really haven't had any… issues." Robin demonstrates that even where autonomy is valued, high SE can occur if land-use boards combine empathy for autonomy seekers with a conciliatory implementation style.

In the other towns, property ethics diverged more strongly and often contributed to low SE. Conflict typically arose when landowner property expectations, often limited by ignorance of land-use policies, were confronted by officials implementing such policies. But clashing intra-board property ethics also caused conflict. Low SE manifested as protest, board capture, and anger and sometimes caused boards to issue weaker permits, avoid policy revisions, or reduce bylaw strictness. Political turnover and intimidation were the two paths to board capture. In Gannet, for example, the pro-development bloc were fervent autonomists (and some libertarians) who clashed with minority groups that held either economic-balance or neighbor-control property ethics. When such groups issued restrictive permits or policy revisions, the autonomists vehemently responded. Rather than threaten takings litigation, the autonomists rallied political support and wrested board power from the opposing group. As one interviewee explained:

> There's a lot of people who feel zoning is land taking…any kind of regulation *at all* is land taking. [This] will cause people to run for boards and get on the boards and then start tearing things down. And…we've had that happen. And…that's…scary…You start getting people that…get on the board and…their agenda is to tear it all down and get rid of it. And there was a lot of anti-wetland...There was like a big…: 'We don't want any wetlands ordinance. Wetlands ordinances ruin everything.'

Board capture through intimidation characterized property-right dynamics in Teal, where land-use boards tended to be populated by economic-balance adherents, but many large-landholders were autonomists or autonomous stewards. Fundamentally, landowners protested the river and prime-wetland buffers because the buffers transferred land-use control from the owners to government permitters. As one landowner stated: "I'm the one who [knows] and protects [my

land]; don't take that out of my hands." They also resented the boards' insensitive implementation style, particularly the boards' failure to personally notify individual owners about public meetings and seeming disrespect towards landowners. Landowner protests over the buffers and other land-use issues were so aggressive as to be fearful. The intimidated boards abandoned the buffers and expressed timidity about policy implementation and revisions even years later. In general, political conflict over property rights can be common in the land-use arena because land-use decisions fundamentally confer power to some individuals and withhold it from others (Carruthers and Ariovich 2004; Jackson-Smith 2005; Jacobs and Paulsen 2009).

Strongly diverging property ethics did not always lead to low SE, however. Individual decisions about behavior and policy implementation mediated the impact of property rights on SE. Some local officials found ways to achieve wetland conservation despite conflicting property ethics. In Teal, for instance, some developers and officials eventually embraced open-space subdivisions because such subdivisions diffused potential property-rights conflict. Specifically, the subdivisions protect wetlands and other sensitive environmental features, but reserve considerable control over project design, and provide economic returns, to landowners. Open-space subdivisions also consolidate a project's undeveloped land into a single parcel held by a home-owners association, town, or land trust. This shifts ownership of conservation land away from individuals to organizations, ultimately reducing the intensity of autonomous feelings.

Gannet provides another example of property rights that provide context for, but do not wholly dictate SE. Though autonomists fought angrily to dismantle the wetland bylaw, the CC chair convinced some to endorse easement-based wetland conservation. While raising funds to conserve a significant wetland, the chair realized that some autonomists would willingly support conservation if they were not forced into it. He then revamped recruiting efforts to capitalize on

the autonomists' desire for self-determination, developing methods that helped autonomists think of conservation as a preferred land use: "…that's where… the educational part and the information comes in. Because when they see the value of it themselves…they're not goin' against the better good, as long as they're the ones that are deciding. There *definitely* is a streak of Yankee, and: 'You're not gonna tell me anything.'" This strategy worked, in part, because the chair projected an affable, apolitical style and invested in personal interactions with autonomists. The CC chair thus succeeded in conserving wetlands and achieving a measure of SE, in a town where political wrangling dominated and regulatory decisions were often highly contested.

As some of these examples suggest, property rights were not static, but evolved with changing social values, shifting demographics, board turnover, zoning and litigation decisions, and the occasional intrusion of outside interest groups. This finding supports previous assertions that property rights evolve over time and in response to shifting social and cultural norms (Emel and Brooks 1988; Freyfogle 1998; Carruthers and Ariovich 2004). Teal and Lark provide strong additional examples of property-rights dynamism. In Teal, most citizens over the last half century believed autonomy was essential and resented government restrictions. Recently, however, some long-time autonomists have died and been replaced by young professionals who acknowledge the common benefit of protecting wetlands, as diagrammed by a PB member: "…the people who are...more educated, younger, more technical professionals, they're gonna be more accepting...[They] understand that all zoning is a form of taking for the common good, and they understand the common good...I think it's shifted a little bit, to the good side…" In Lark, property-rights conflict subsided when a new CC chair was appointed in the early 2010s and the CC's overall ethic shifted from one of deviant regulatory control to economic balance. Whereas the former chair angered citizens with his unyielding attempts to maximize CC control of

development projects, the new chair quelled property-rights complaints by focusing on wetland-policy compliance and what he perceived as reasonable policy interpretation.

Overall, private property rights did strongly shape how stakeholders approached wetland permitting in the case towns, but autonomy was not monolithic. I discovered diverse and nuanced property-rights ethics in each town. Certainly, autonomy was a dominant theme, but diverse interviewees also expressed concern for how land use impacts public welfare. Despite broader media and judicial rhetoric to the contrary, private property rights in these New England towns were personalized and community-specific. This finding extends previous research, which found similar variability in other natural-resource arenas, to wetland permitting (Hurley et al. 2002; Jackson-Smith 2005; Yung 2007). Combined, these results confirm that American understanding of private property is more nuanced than the myth of absolute autonomy suggests and that individual citizens mix components of competing narratives to create a property ethic that suits their particular community and landscape (e.g., Freyfogle 1998; Jackson-Smith 2005; Fraley 2011). From a policy perspective, this means that multiple outreach techniques might be needed to bridge remaining gaps between permitters and the public in each town.

Despite their prominent role, property rights did not prescribe SE, however. They set the stage and established a predisposition, but were not determinative. Rather, SE resulted from the interaction of property-rights expectations with wetland-program implementation and other dynamic factors, like board composition and changing demographics. Where stakeholders and local officials held contrasting, yet comparably strong, property-rights ethics, SE tended to be low as developers resisted permit and policy decisions. In these circumstances, the threat of takings-based litigation was present, even if generally subdued or undeclared. Conversely, where ethics were more homogenous or temperate, SE tended to be higher as permitters and developers

sought common ground. These patterns were not ubiquitous, however, as demonstrated in Gannet, where the CC chair discovered that strong autonomists might support wetland conservation if they believed it was their own preferred land use. Indeed, this and similar tactics provide ways to circumvent property-rights conflict in the wetland-permit arena. Other such tactics included using open-space subdivisions, in-lieu mitigation, or pre-application meetings to share decision authority between landowners, local officials, and sometimes, abutters.

Local Government Structure

Local government structure encompasses the organization of town boards and the distribution of authority across local policies. Institutional structure is the stage upon which stakeholders interact while shaping wetland decisions and influencing SE and EE. Structure largely dictates who holds decision-making power and how information is used in making decisions (Hall and Tolbert 2005). Though many structural features are prescribed by state policy, towns retain authority over certain elements which can be used to facilitate SE.

State laws prescribe how decision-making power is divided among the CC, PB, and ZB and whether wetland policies are split between a stand-alone wetland bylaw and the zoning/ planning bylaws or entirely contained within the zoning/planning bylaws. In MA, the three boards share decision power. The CC implements state and local wetland policies, while the PB and ZB make wetland decisions under the zoning/planning bylaws. In NH, all local wetland decisions arise from the zoning and planning bylaws, which the PB and ZB implement with advice from the CC. While MA CCs hold dedicated wetland-permit hearings as dictated by state and local policies, no such wetland hearings occur at the local level in NH. Instead, wetlands are one of many issues discussed in the broader context of site development at PB or ZB public

hearings. In both states, zoning/planning-bylaw appeals are made to the ZB, but in MA, wetland-bylaw appeals go directly to superior court. In practice, these structural differences meant that MA CCs held more decision power over development projects near wetlands than NH CCs. In NH, power was concentrated with the PB and, to a lesser extent, the ZB. Interestingly, both state structures inspired fierce supporters and strident detractors.

Many MA interviewees praised the concentrated strength of their CCs partly because they thought it enhanced environmental outcomes. Indeed, the power difference between MA and NH CCs likely contributed to higher EE in the MA towns for several reasons. First, CC members (from both states) had more wetland and environment-specific training, on average, than PB and ZB members, which presumably translated into higher-quality wetland decisions in MA (see section 3.6.3.1 below). Second, dedicated wetland bylaws and hearings meant that wetland projects were subject to more intense scrutiny in MA. Finally, as indicated by consultant interviewees, greater CC authority meant more frequent and consistent enforcement across MA towns. The tri-board decision structure in MA was similarly described as beneficial because it meant more people with diverse expertise assessed each wetland-development case.

Despite these benefits, the MA structure was not universally lauded and contributed to negative SE. Many project proponents felt that the content and implementation of wetland bylaws were often unreasonable, excessively strict, and intentionally obstructionist. They thus harbored great and lingering animosity towards certain MA CCs. Such resentment was more prevalent in Lark than Robin. One applicant was so disgusted with the Lark CC's perceived power abuse that he thought CCs should be abolished: "They should do away with [the CC]. *Period*…this is just…*another hurdle*...Which I think is wrong…I just think that the conservation commission is waaay, waaay overbounds. They've given 'em…waaay too much…power." More

commonly, detractors of the MA structure felt that towns should not be allowed to have separate wetland bylaws. Besides the potential for power abuse, they criticized the appeals pathway as subjective and biased. One of Lark's biggest developers summarized the problem:

> Because [Lark has] a wetland-protection ordinance, if they denied my project…I go to superior court. And now you're dealing with judges that have absolutely *no* clue as to what's going on.…Oftentimes projects are stalled or... revoked or not permitted because you were in front of a superior court judge, not in front of the scientists and specialists at the DEP. A…judge…can't support the developer. He has to support the community because they're working within their bylaws.

This finding reinforces the importance of simultaneously evaluating EE and SE. Owens and Zimmerman (2013) examined the power structure of wetland-permit decisions in Connecticut, where local CCs are similarly vested with substantial authority. They only assessed EE and concluded that powerful CCs were a near-optimal structure for protecting wetland acreage. My study shows that high EE does not guarantee high SE and raises the potential for negative feedback between the two.

Though MA CCs were quite powerful, some interviewees lamented the complexity and redundancy inherent in a system that nevertheless shared decision-making across multiple boards. They complained that each board had its own standards and that boards rarely communicated and coordinated land-use decisions. Project proponents had difficulty designing projects that satisfied the many boards' demands and resented the extra work and costs arising from boards' redundant application requirements. Though joint-board meetings minimized coordination problems, such meetings were rare. One engineer articulated how structural redundancy led to low-quality site plans: "…one thing that frustrates me…is that the planning boards have their own set of regulations, as do the conservation commission and the board of health….They don't recognize all the overlap that involves….Our work becomes...working around the regulations. And your

end result is not a properly planned project…individual boards mean well, but I think they ought to work together more often."

NH interviewees similarly found NH's multi-board structure inefficient and frustrating. Though NH CCs had little authority and no separate wetland bylaws, project proponents still needed to consult CCs and coordinate between PBs, ZBs, and BOHs. After expressing how onerous this can be, a Teal CC member suggested solving the problem by using a single land-use board. Other interviewees roundly rejected this idea, being unwilling to trade-off the check-and-balance security of a multi-board system for greater efficiency. In general, sharing wetland-decision power across boards adds horizontal complexity to a town's organizational structure, which can cause coordination and communication problems, both between boards and with the public (Hall and Tolbert 2005). Such problems can be alleviated without changing the number of involved boards, by dedicating specific organizational members to the tasks of coordination and communication, as discussed further below (Hall and Tolbert 2005).

NH CCs' lack of authority also troubled some interviewees. In NH, project proponents typically presented proposed work first to the PB. Only later, when major design decisions were firm and developers resistant to additional changes, did they approach the CC. Because PB members typically knew and cared less about wetlands, conservation interests were often overlooked until raised by the CC, late in the application process. Similarly, and because PBs limited their scope to a project's parcel boundaries, broad-scale impacts were only considered late, if at all, when the CC conducted its review. Though a similar CC-PB dynamic occurred in MA, CC frustration was stronger in NH because the PB permit process was their main outlet for influencing wetland decisions. MA CC members might be disappointed at being consulted late in the development process, but they could independently block a project if it did not meet state and

local wetland-policy standards. NH CC members had no such fall-back. As one Teal CC member expressed: “I would also like to see the conservation commission more involved in…wetland… procedures….I'd like to see them…[interact] with planning…as projects are contemplated....To have people come in and talk about the projects to begin with…Because often…as the conservation commission, we don't see the project until it's already got approval by the state. So, there's very little we can do to put good input into it…”

Conversely, other interviewees strongly supported the NH structure, specifically because CCs lacked power. Without real authority, they maintained, CCs could focus on permanent land conservation, rather than just dealing with permits. They felt this was a wise trade-off because land could be conserved in perpetuity, while permits expired and allowed some wetland-ecosystem disturbance. Without authority, CCs could also remain apolitical, which kept them from being overrun by ill-intentioned power-seekers and helped project proponents accept that CCs issued authentic permit recommendations. The Gannet CC chair stressed this point: “When New Hampshire set up conservation commissions, we were deliberately stripped of any real authority. We're an advisory panel…the idea was to make it less adversarial….That's actually been quite effective… You get people that cooperate as long as you can explain to them what's going on. …If you're not the one that's telling them no or we're going to fine you, they're going to listen better.” While his experiences indicate the NH structure can work smoothly, his account is somewhat idealized. Gannet endured intense protest over wetland permits and policies. Conversely, the Robin CC successfully pursued land conservation, despite permit obligations, and was not a hotbed of political grappling.

Consultants also appreciated NH’s local appeals pathway, where ZBs (not the DEP or courts) hear appeals and applicants can obtain individualized variances or special exceptions for

projects that disturb wetlands. Because ZBs examine projects on a case-by-case basis, they can permit individual projects without endangering the security of an entire bylaw. In practice, ZB appeals often exacted less grief and expense than appeals to state entities. One engineer celebrated the NH system, saying: “You can variance anything, anywhere.” And was echoed by her contractor husband: “On an individual basis…and then you can all sit at a table and decide.”

The NH structure may also promote high SE, ironically, because it cloaks wetland issues within the folds of its zoning code and multi-purpose PB objectives. As one factor among many in the zoning and planning regulations and lacking a dedicated public hearing and implementing commission, wetlands may be a less obvious and therefore less divisive issue in NH. In the permitting arena, it may be normal for citizens to focus on wetlands less intensely in NH than in MA. I base this proposition primarily on comments made by consultants’ who worked in multiple towns and, often, both states. They acknowledged the pros and cons of each state’s structure, but suggested that overall, project proponents were more satisfied with the NH system because it drew less fire from CCs and abutters. This hypothesis generally rang true for permitting in Teal, where the public rarely attended hearings and then, usually only to protest non-wetland issues. One Teal PB member argued against designating prime wetlands in part because he thought designating would force the town to hold local wetland hearings, which he considered undesirable: “…if it's designated a prime wetland, then you've gotta hold a public hearing. And…a hearing held at the local level, it-- all the local interpersonal conflicts can creep into that.” However, in both Teal and Gannet, the public did strongly protest when boards tried to increase wetland-policy strength. It may be that SE is high as long as wetlands are a subsidiary concern of the zoning code, but once a policy decision focuses a spotlight on wetlands, as

happens every day in MA, SE in NH may decline. These hypotheses merit further inquiry since they are generalized propositions about many towns and are not specific to the case towns.

Though state policy prescribed basic board and bylaw structures, towns controlled several structural features that influenced SE. Specifically, towns could choose whether to: hire a town planner and/or conservation agent; establish inter-board liaisons with full voting rights; charge the town administrator with coordinating comprehensive planning among boards; mandate CC review of relevant planning, zoning, and building applications; share administrative personnel across boards and/or locate personnel in shared office space; dedicate a compliance officer to environmental issues; or use subcommittees to focus on multiple environmental concerns.

Most of these actions supported positive SE because they enhanced inter-board or board-public communication. A town planner, for example, often meets with applicants to discuss project details and answer questions before an application is submitted. She then presents potential issues in a distilled format to the PB during the formal hearing process. A planner thus enhances communication and SE by guiding proponents through the application and translating concerns between the PB and applicant. In reference to this facilitative role, one of Gannet's largest developers said he starts a project by speaking to the planner: "…I do go to the planner, because they…move it along…They have…direct contact…with the people [the PB]…They basically can be the salesman…for or against a project…they actually are the link that has the most amount of power..." As with many town-controlled structural features, however, not all towns employed, and benefited from the expertise and communicative skills of, a professional planner. For instance, Teal had a planning secretary who, despite years of experience, had little formal planning training and was resented by diverse interviewees because she seemed to follow a personal, not a professional, agenda.

Some town-controlled structural features, like inter-board liaisons, served the dual purpose of enhancing communication and maintaining the topical saliency of wetlands. Liaisons reported on the activities and concerns of each board and could argue in favor of wetland protection to PBs and ZBs, where conservation interests might otherwise be poorly represented. Teal had one PB member who informally liaised with the CC: “Now we've always had a member …who attended all the conservation commission meetings. An ambassador. Who would bring back the concerns…She was on the planning board [but] she couldn't care less about being obstructionist…She wanted to save the environment, that was her number one priority.” Teal and Robin similarly maintained wetland saliency by dedicating subcommittees to wetland permit-review and/or conservation. Like liaisons, subcommittees regularly reported to the larger board, keeping wetlands a conspicuous discussion topic. Similar effects could be achieved without formally creating liaisons or subcommittees. For instance, individuals could independently sit as full members of multiple boards. Such informal cross-pollination could dissolve when the individuals quit, however. By formalizing the liaison or subcommittee structure, a town can both safeguard against dissolution and enhance authority of the given structure. Teal learned this the hard way when their PB-CC liaison left town: “Planning board and conservation, there's…a *lack* of communication....but it's mostly because we lost key players…they were on conservation and it would come back to the planning board...It's just the *lack* of having someone on conservation.”

Overall, organizational and policy structure strongly shaped how wetland decisions were made in all four towns and both states’ structures presented benefits and problems. A complaint arising from the multi-board structure in both states was that wetland interests were introduced to the design process too late to be effectual. Upstream engagement of conservation interests might improve SE in both states (Weitkamp and Longhurst 2012). States could mandate earlier

conservation input by increasing CC authority. Alternatively, towns might accomplish this through less dramatic means, such as adding structural elements, like joint-board meetings and liaisons, to improve communication and wetland saliency; or reserving PB seats for members with wetland-specific expertise. While structure set the context for wetland decisions and shaped SE, it did not dictate SE. Ultimately, SE depended on the interactions between structure, other SE drivers, and individuals' priorities and implementation styles.

Enabling Factors

Education and wealth were prominent enabling factors. Both facilitated SE when present, though towns with low education and wealth could still achieve SE via alternative pathways.

Education

Education was an important SE driver in all four towns, but educational attainment and the type of education valued varied across towns. Interviewees distinguished between formal generalized education and subject-specific training and outreach, and between the educational levels of town boards and the public.

Robin and Teal valued formal, generalized education more than the other towns and had more advanced degrees on their boards and in their publics (Table 3.8). Extensive research shows that formal education is positively associated with generalized (Gelissen 2007; Franzen and Vogl 2013; Pampel 2014) and many specific environmental concerns, including support for wetland conservation (Kaplowitz and Kerr 2003) and environmental regulation (Kahn 2002). Formal education prepares citizens to assess risks associated with environmental decisions (Kahn 2002) and to understand the importance of maintaining ecosystem integrity (Parisi et al. 2004).

Interviewees from Teal and Robin drew similar connections between formal education and the SE of municipal wetland programs. Teal officials observed that towns were less likely to appoint developers and politicos to their boards when the citizenry was highly educated. Instead, such towns tended to appoint professionals with high ethical standards and meeting management skills, who conducted fair, orderly hearings; made sound permit decisions based on science and logic; and wrote strong wetland and land-use bylaws. The educated citizenry, in turn, was more likely to value wetland conservation and accept strict bylaws. This description seems tailored to Robin, where high formal education contributed to strong wetland and land conservation ethics. Teal officials, however, described their town as located in the middle of this spectrum. As education levels in Teal rose over the last two decades, board professionalism and public support for environmental regulation also increased, but an entrenched, less-educated sub-population still effectively resisted wetland bylaws: "…the older people who've been here most of their lives, who are not as educated...are gonna be *heavier* into...being opposed to legislation…They can't make that bridge...to understanding the need for environmental regulation."

While some interviewees valued generalized education, most viewed subject-specific training and outreach as indispensable to wetland-program SE. This aligns with previous research showing that environmental training of local decision-makers enhances their capacity to protect biodiversity and water quality (Timmer et al. 2007; Miller et al. 2008) and that targeted outreach is a particularly effective way to catalyze environmentally friendly behavior (Brody 2003; Raymond and Olive 2008; Johansson et al. 2013). Across all four towns, subjects believed that board-public relations were enhanced when boards were knowledgeable about wetlands and permitting and engaged in outreach to communicate that knowledge to the public. This was especially important for CCs, PBs, ZBs, and code enforcement officers. Interviewees also linked

training and outreach with numerous specific positive outcomes (Table 3.9). In general, frustration, resentment, and conflict were common when boards and/or the public lacked authentic knowledge about wetlands and permitting, whereas acceptance, confidence, and productive negotiations tended to arise when both boards and public possessed such knowledge.

Robin's boards seemed to have more collective subject-specific training and its public greater knowledge of wetland permitting than in any of the other towns. The CC was loaded with relevant expertise. Members had formal degrees in environmental studies, botany, hydrology/ civil engineering, and forestry. Several members, as well as the land-use agent, had also attended workshops and conferences to learn specifically about wetlands, permitting, land conservation, and land-use planning. Some had professional or experiential training: as a wetland consultant, conservation agent, in agriculture, or from hunting and fishing. This expertise allowed them to interact with stakeholders in a competent, convincing manner that evoked a willingness to accept and negotiate. The CC also had considerable experience explaining environmental subjects to lay audiences. One member was a former civil-engineering professor, one a biology teacher, and the consultant regularly informed other CCs about wetland permitting. Their collective training and outreach skills paid off: the public seemed to know not to disturb wetlands without first obtaining a permit or contacting the CC. As an abutter observed: "You know what you can do; you know what you can't do; and you just abide…by the rules...for the most part."

By contrast, boards in the other towns had less training in environmental subjects and perceived citizens as generally ignorant about wetland permitting. This lack of functional education negatively impacted SE (though public knowledge and acceptance of wetland bylaws was slowly increasing via outreach and demographic changes in Gannet and Teal, respectively). Board members from all three towns lamented this ignorance and opined that training should be

mandatory for board members. Further, insufficient training sparked inter-board, intra-board, and board-public conflict. In Gannet, a PB secretary provoked the CC when she refused to consult it on wetland issues in part because CC members weren't formally trained in wildlife and other environmental sciences. In Lark and Teal, inter-board trust and coordination suffered because the boards were unfamiliar with each others' policies, membership, and duties. The CC in Lark was also accused of driving out knowledgeable members and replacing them with obstructionists and agenda-chasers. But one CC member pointed out that the complexity and evolving nature of wetland regulations contributed to the resulting conflict because the public did not stay informed about, and the CC did not properly explain, changing policies. Lack of permitting knowledge combined with poor communication skills left a deep scar on the community:

> [The regulations] keep changing. There's a lot to it and then you end up in conflict with the community, who *doesn't* understand. So you'll have people there... rooms…with forty people in them. Screaming, yelling. Shaking their fists. Making *threats*. Because you were allowing something. Forty people in the room, screaming, making threats and yelling because you *weren't* allowing something. So it was a lose-lose situation… Having *volunteers* do this is not a good idea. They should be *paid* positions. You should be *trained*... It shouldn't be just anyone who gets on.

The intense CC-public conflict waned during the years the CC had a conservation agent largely because the agent was trained in wetland issues and alleviated stakeholder frustrations by fielding questions about the permitting process, filling gaps in their functional education. As the CC member stated: "The thing that helped the most…was having an agent…They put off a lot of the anxiety, the *justifiable* anxiety that homeowners encounter when they're trying to do...the right thing, but…the paperwork is too...they have too many questions…people get frustrated. They can go [to the agent] and ask…a question and have help…"

All four towns stressed that outreach, a form of educational communication, was essential for cultivating public wetland concern and conservation action. Robin and Gannet were most efficacious in their outreach. One shared, successful strategy centered on exposure to the natural

world. In Robin, this was one of the land trust's main objectives. In Gannet, the CC chair was the mastermind. Experience convinced him that exposure helped people see wetlands as part of a larger ecosystem and realize that wetland protection is desirable, not threatening. Sensitivity to the threatening aspect of wetland conservation catalyzed a unique desire in Gannet to target developers for outreach. As a PB secretary stated: "There needs to be more education and they need to demystify [wetlands]. And make 'em less threatening. Because I think people see wetlands as a threat… conservation and the planning board need to…work together…to [show]…how you develop with wetlands and how they are an amenity….How you can work… development strategies around...wetlands." Still relatively new, it remains to be seen whether targeting developers garners additional support for wetland conservation in Gannet. Initial assessments were contradictory, with the CC chair stating that local developers were slowly warming to wetlands, but the PB secretary indicating that developers hate wetlands now more than ever, as developable land becomes scarcer.

Though town boards, board agents, and land trusts were important sources of information about wetlands and permitting, interviewees identified several other critical education sources. Top among these were non-profit institutions dedicated to conservation outreach or teaching local officials about land planning and ethical governance. For instance, MA interviewees raved about the MA Association of Conservation Commissions (MACC), which provided opportunities for training, networking, and moral support. Noticing a vacuum in PB training prospects, the MACC recently expanded its mission to include PB outreach. By contrast, no interviewees mentioned the NH Association of Conservation Commissions. Instead, multiple board members praised the Local Government Center's governance training programs. Notably, state environmental and wildlife agencies were informative when approached by individuals, but

were generally seen as unavailable due in part to staffing shortages. Real-estate agents were identified as a key, untapped educational source. Real estate agents are in a unique position because they interact with potential landowners after the town permit-process is complete. Often, however, they contribute to landowner ignorance by failing to either inform prospective buyers about a property's wetlands or to describe wetlands as an amenity.

Wetland consultants, surveyors, and engineers considered themselves crucial education sources and board-public mediators. These professionals were most vocal in criticizing board and public ignorance across many towns in both states. One consultant's complaint typified the exasperation this ignorance inspired: "…that's a really frustrating thing…having appointed members who…*really* don't understand the science of it…I actually had one person tell me...'I have no idea what you're talking about. I've *no* idea.' And this is the chairman!...How do you work with that?...I'm like, 'Well then, what the hell are you doing there?'" Despite frustrations, consultants recognized that informed stakeholders were key to an efficient permit process. Thus, as a matter of economic survival, professionals provided technical information, experiential wisdom, and perspective to boards, developers, and landowners.

Education was an important direct SE driver, helping boards and citizens understand and support wetland programs. Education also influenced SE indirectly. For instance, wetland knowledge enhanced the credibility of pro-wetland stakeholders by giving them information, rather than just feelings or beliefs, to communicate. Similarly, outreach provided a way to short-circuit local politics. Through experiential education via exposure to nature, pro-wetland stakeholders were able to gain a foothold in some opponents' hearts and weaken political opposition to wetland programs. Despite education's pivotal role, I classify it as an enabling factor for two reasons. First, stakeholders can be highly educated and yet have a socially-

ineffective wetland program, if they are either unable to communicate their knowledge and concern to necessary audiences (as happened in Teal) or do not have a strategic plan to rally the broader public to environmental action (as happened in Lark). Second, wetland programs can be associated with positive SE, even if local officials are not highly educated. This can occur, as several interviewed consultants indicated, if officials acquiesce to the advice and instruction of consultants or another dominant stakeholder group, avoiding conflict with said group. High SE can also arise if the local officials decide to pursue training in land-use planning, demonstrating a commitment to rational local planning and concern for their town's future. A surveyor articulated how concern could compensate for, and even stimulate, learning, and facilitate high SE: "The operative word is care… If you get people on these boards that genuinely care - and by the way, if they care, they're probably gonna get some education in the areas and…*really* wanna dive in…I have no problem dealing with people that care. *No problem*."

Wealth

Wealth was a conditional factor that, depending on circumstances, facilitated or hindered wetland conservation. Wealth influenced SE and EE principally by mediating the effects of education, town identity, and public participation. Three different types of wealth were relevant in the wetland-permitting arena: individuals' liquid assets, land values, and municipal revenue.

I observed wealth's positive effects in Lark and Robin. Though Lark was a middle class town experiencing some fiscal stress due to a low tax base, it had sufficient funds to hire a full-time conservation agent between 2005 and 2009. During this discrete period, the wetland-permit program in Lark experienced a rise in SE. The agent performed a multitude of administrative tasks and interfaced with the public: helping applicants fill in forms, answering questions about

the permit process, and teaching citizens about wetlands. Having an agent reduced stakeholder anxiety and frustration and also CC-public conflict. In a very concrete way, municipal wealth during this period improved stakeholder tolerance for wetland permitting.

Robin was affluent both in land values and individual liquid assets. Interviewees were conscious of Robin's wealth and deliberately leveraged it for conservation in ways the other towns generally did not. Specifically, they hired an expensive lawyer to educate large landowners about land donation, purchased land outright and raised local taxes for permanent conservation, and were skilled at using various local resources (including harvested trees from the town forest) to win state and federal matching funds. Through these actions, wealth increased awareness and understanding of wetland ecosystems and provided tangible evidence (i.e., conserved property) that the land trust and CC were committed to keeping the town rural. In turn, this knowledge and evidence buoyed SE. Robin saw itself as belonging to a small cadre of wealthy towns who understood that land conservation is more economical than residential development. As one interviewee explained, greater income allows higher education, which helps citizens understand that residential-property taxes do not offset the service and infrastructure costs of residential development:

> Sad to say, level of education, which usually…translates into...income level…I've always been mad as hell…I've said, 'Why is it that a...poor town with *lots* of open space can't see as readily as *Lincoln*?' Which is a *rich* town, and has half the town tied up, and…it's got nothing to do with jobs. They *say* it does. And it's got nothing to do with saving the town money. Actually, you wanna save the town money? Stay small …The only land that doesn't cost you is the land that's open…because then you don't have to have a full-time fire department and 98 cops and…the schools…Why is it that the *average* person can't as readily understand that?

Though interviewees from other towns acknowledged this relationship between wealth, education, and conservation, none described their town as actually fitting this description.

Conversely, all case towns displayed some of wealth's negative effects. Lark and Gannet, for instance, had the lowest household incomes and highest unemployment and poverty rates (Table 3.8), measures typically associated with fiscal stress (Lobao and Kraybill 2009; Jimenez 2014) and low environmental concern (Gelissen 2007; Bredahl Jacobsen and Hanley 2009). Indeed, financial stress plagued both towns, forcing them to cut services. In Lark, the conservation agent position was reduced from full to half-time. In Gannet, the situation was so dismal by the study's end that municipal investment in wetland conservation was implausible. As the CC chair explained: "…there is right now just a sense of: you can't spend money on *anything*." Whereas wealth allowed Robin to reaffirm and pursue its rural identity, austerity strengthened the economic-development side of Lark and Gannet's identities and led some people to perceive wetland permitting as an obstacle to fiscal stability. Prioritizing economic development in times of fiscal stress is not uncommon and often drives trade-offs in local government, though they are best documented in the social-service provision sector (Lobao and Kraybill 2009). In Lark and Gannet, the choice to pursue development over wetland conservation also parallels research showing that environmental concern and support for wetland conservation increase with income in industrialized nations (Kaplowitz and Kerr 2003; Gelissen 2007; Franzen and Vogl 2013). Their choice also suggests that wetland conservation is a quality of life issue for many citizens, which, from a post-materialist perspective, is only pursued after material needs are satisfied (Gelissen 2007; Franzen and Vogl 2013).

Wealth also instigated conflict over land-use and property rights as landowners fought to protect land-investment values. In Gannet, wealthy newcomers tried to use wetland policies to restrict development, believing that having undeveloped land in town enhanced

property values. This is actually a common tactic (Clingermayer 2004; Jacobs and Paulsen 2009), and for good reason: property values and multiple measures of wealth tend to be higher in towns with more green space (Bowman et al. 2009; Ogneva-Himmelberger et al. 2009; Waltert and Schlapfer 2010). Other landowners thought autonomy was the best way to preserve land investments. They opposed policies that restricted development and autonomous land-control. Among these stakeholders were: less affluent newcomers and the pro-development network in Gannet; land-rich, cash-poor farmers in Robin; and large landowners in Teal. This last group actually spent money to campaign against policy revisions. They sent town-wide mailings decrying how the proposed open-space subdivision policy would bring sprawl to Teal and how prime wetlands would weaken land-use rights. In each town, but especially Teal and Gannet, wetland permitting, which can be used to restrict development, was indicted in the conflict between land use and land preservation. Not all citizens could afford to express wetland-permit frustrations via visible tactics like mass mailings, however. One disillusioned Gannet interviewee, for example, had to abandon a proposed project because she ran out of money while trying to obtain a permit. This stands in stark contrast to wealthy developers in some Boston suburbs who, as described by two MA interviewees, invested extreme amounts of money to obtain wetland permits and lobby the legislature about wetland policies, because land values and potential sales were so high.

The case towns and interviews show that, given the right conditions, wealth can facilitate SE and EE. If a town is committed to a rural identity, then wealth provides freedom to better secure rurality, by investing in training, outreach, and conservation. When these conditioning factors are weak, wealth can still promote SE, but the effects may be temporary, as in the case of Lark's conservation agent. Alternatively, wealth can inspire intra-class

resentment and conflict over land-use policies. In this scenario, wealth may be used to express low SE and combat wetland conservation. Finally, scarcity may drive a town into survival mode and cause it to prioritize economic development over wetland conservation.

Tools

Public participation and local politics were important tools used to express SE in some towns. In wielding these tools to express SE, stakeholders often shaped future SE and influenced wetland decisions.

Public Participation

Public participation (PP) was strongly, but complexly, related to wetland-program SE. PP is a process whereby government provides opportunities for the public to learn about, and/or comment or decide upon, public policy (Beierle and Cayford 2002; Creighton 2005). It is considered a critical component of successful decentralized environmental governance (Mermet 1991; Wondolleck and Yaffee 2000; Kraft and Mazmanian 2009). PP typically enhances SE of environmental programs by generating buy-in for public policy (Beierle and Konisky 2000; Wondolleck and Yaffee 2000; Meyer and Konisky 2007b). Specifically, it: allows stakeholders to express values and priorities, promotes understanding among stakeholders, and provides a mechanism for stakeholders to influence program outcomes (Beierle and Konisky 2000; Webler and Tuler 2002; Lubell et al. 2005). In general, public support for program policies tends to be (but is not always) strongest when stakeholders are deeply engaged in program decision-making over prolonged periods, as often happens with collaborative governance (Wondolleck and Yaffee 2000; Beierle and Cayford 2002; Lubell et al. 2009). The wetland-permit programs in the case

towns were regulatory at-heart, but provided various opportunities for stakeholders to influence wetland decisions. Compared to collaborative ventures, such PP hybrids are less well studied. Analyzing the social and process ramifications of PP in wetland-permit decisions is useful because it helps fill this literature gap. It also provides insight into whether and how PP produces similarly beneficial process and environmental outcomes, when embedded in the rapid and more common world of regulatory permitting.

I observed multiple forms of PP across wetland programs in the case towns. Public comment at wetland hearings was the most common and influential PP method used by the general public, especially in Lark and Teal. Stakeholders capitalized on a variety of other substantive and superficial PP opportunities, however, including: volunteering on land-use boards and policy-revision subcommittees; voting on conservation issues; protesting specific projects and decisions through petitions, mass mailings, complaints to town boards outside of hearings, and unpermitted work in and near wetlands; partaking in informal negotiations with local officials; and reporting observed violations. Informal negotiations were a mainstay in Robin, while voting and competing for positions on local boards were popular in Gannet.

Attendance at wetland-permit hearings was typically low. This standard lack of interest made sense to some interviewees, especially in Teal, who explained that modern schedules leave little time for civic engagement. Others, such as Teal's CC chair, worried about the general disinterest in wetland permits: "We have *very little* public...opposition…to developments and… projects. There are...usually…one or two landowners…that will have some concern. But...not a *lot*…One would expect…more people to be more vocal about…development…goin' in." Large projects attracted the most participants, leading to occasional eruptions in Lark, Teal, and Gannet when stakeholders were particularly vexed about a project or policy change. In all four towns,

stakeholders usually attended hearings only if directly affected by a project, though there were exceptions to this trend. For instance in Robin (and only Robin), a few citizens, knowledgeable about wetland science and policy, attended hearings to which they had no direct connection to ask questions and promote wetland conservation. In Gannet, hearings were occasionally so volatile they attracted retirees strictly interested in the theatrical entertainment value.

When abutters did attend hearings, they mostly complained about non-wetland issues (though some Gannet abutters spoke in favor of neighbors' projects). Sometimes they did this with innocent intentions, lacking knowledge of wetland science and policy. Other times, stakeholders intentionally abused the wetland-hearing process, using public comment opportunities to stall or de-rail development projects. This process misappropriation was a major source of frustration for project proponents and local officials. Moreover, such misuse damaged PP processes in the long-term because it caused some developers, consultants, and board members to distrust and peremptorily dismiss public comments. Sometimes, however, PP positively influenced SE. This occurred mostly when protest actions caused wetland decisions to be resolved in favor of the protester. By transition, however, this usually also meant decreased SE among the losing parties.

Though PP produced negative and positive SE, it was more important as a tool for expressing SE, especially in Lark, Teal, and Gannet. Typically, a stakeholder would be unhappy with a board's comments or permit decision and would capitalize on PP channels to voice her dissatisfaction. This usually took the form of public comments at a hearing, but other PP modes (e.g., mass mailings, threatening litigation) were also employed. On numerous occasions, protest caused a board to change the direction of its discourse, the outcome of a permit decision, or a wetland policy, often to the detriment of wetlands. Sometimes PP achieved immediate outcomes.

In the early 2000s, for example, when the Lark CC regularly experienced aggressive, popular PP at its hearings, the CC tried to regain control of one meeting by limiting the time allotted for comments. The crowd was displeased and forced an abrupt concession: "They threaten…it's not like they came in with their guns drawn. They simply came to the door, stood there, and just their presence in the room…[I] really, pissed off a lot of people…because…home-rule… free speech …we gave them another meeting!...The very next week, to make amends. To say, 'OK, I know you…wanna talk. We'll give you… *just you, another* meeting next week.'" Other times, outcomes were delayed or endured for multiple years. For instance, public protests over wetland-buffer and open-space policies seemed to permanently scar Teal's PB and CC, producing a timidity that kept both boards from pursuing stronger wetland policies and permits. When asked why the CC doesn't maximize wetland buffers on construction sites, the chair justified their inaction: "Maybe…it is a conflict avoidance because you know that that's going to be problematic to begin with…I don't know…but…we very seldom look to maximize..."

Whether and how PP, as an expression of negative SE, influenced decision outcomes depended on context, particularly the interaction between protesters' communication styles and boards' conflict-management skills. This finding echoes recent PP research which stresses that context, especially decision-process format, program capacity, and politics, is an important mediator of program implementation success (Lubell et al. 2005; Kraft 2009). In the case towns, PP ranged from polite to outraged. Conflict-management skills varied from proactive to abysmal and changed with board turnover. In general, boards tried to identify legitimate concerns and integrate these into decisions, but this was complicated by uncertainty and emotions. Robin was most effective at managing conflict and parsing through participants' comments and least likely to have PP impair decision outcomes. Multiple factors contributed to Robin's success. First, the

CC and ZB were intimately familiar with their regulations and could knowledgably dismiss irrelevant complaints. Second, the CC invested considerable time developing relationships with opposing groups and negotiating policies that incorporated opponents' deepest interests. Third, they tried to run fair and open meetings and give citizens ample opportunity to express opinions. The ZB, in particular, maintained civility at contentious hearings by outlining hearing structure at the start of each meeting and assuring participants that they would each have a turn to speak. Fourth, they were unafraid of belligerent participative outbursts and treated them in a firm, but unyielding manner. Finally, they were loyal to the town identity, making decisions that revealed a commitment to both conservation and private property rights. Consequently, some abutters grumbled that their comments did not influence decision outcomes, but they tended to accept impotency because they had faith in the boards' overall intentions. Powerful stakeholders, like local developers and farmers, also accepted board strictness because they had previously tempered that strictness through substantive participation during informal negotiations.

The other towns demonstrated some conflict management skills, but were inconsistent in their application and/or lacked communicative finesse. For instance, in the early 2000s, the Lark CC expected participative conflict as status quo and tried to control PP via multiple means, but lacked the communicative skill and social capital to win public support for their decisions. One CC member recalled with discomfort: "Sometimes you would just sit there and grin and bear it, and let people yell and scream, and sometimes you would try to shut them down…[One time,] I called the police in, just to restore order because people were yelling. It hit the *newspaper*...I was chastised, there were people on the commission who were pissed…it didn't go over very well." Lark, Teal, and Gannet also did not use town identity as a tool to diffuse or intercept hostile PP. On several occasions, PP spiraled out of control in each of these towns, as the public voiced

rising frustration at board decisions. In these high-conflict situations, PP often influenced decision outcomes by intimidating board members.

PP in the case towns diverged from the patterns typically ascribed to decentralized governance, which credit stakeholder engagement with improved SE and, often by extension, EE (Leach and Sabatier 2005; Mandarano 2008). PP did shape SE in the case towns, but often in a negative manner. More importantly, stakeholders intentionally used PP as a tool to express negative SE, which often led to decreased EE. Such negative outcomes might be attributed to the prominent use of public hearings, considered a weak PP form with limited opportunity for stakeholder influence (Daniels and Walker 1996; Beierle and Konisky 2001; Trachtenberg and Focht 2005). I argue, however, that municipal wetland-permit programs are hybrid regulatory-participative systems which offer diverse PP opportunities (Meyer and Konisky 2007b) and that stakeholders learned that by expressing grievances via established PP channels, they can strongly influence decision outcomes. Whether individual PP acts proved substantive opportunities that influenced decisions or superficial and symbolic depended on context and the state of other SE drivers. For instance, some board members were deeply engaged and shaped town land use over several decades, while others never sought appropriate training and were members for just a short period. Likewise, some abutters did not attend permit hearings because they thought their input would not matter, while others rallied neighbors to attend and altered board decisions. Despite the many negative links between PP and SE in the towns, some stakeholders discovered ways to foster positive PP outcomes, mostly by enhancing opportunities for early PP focused on meeting stakeholders' mutual interests. Lark's PB, for instance, now encourages developers and abutters to meet before hearings to seek project designs that satisfy both parties. Meanwhile Teal's PB and CC learned through iterative clashes with the public, what Robin has long

practiced: compromise and negotiation with stakeholders via committed and sustained dialogue is a vital path towards policy acceptance. Other methods of nurturing productive PP included: recruiting stakeholders to craft new policies, explaining meeting structure at the start of hearings, using consultants to mediate extra-hearing discussions between small groups of essential stakeholders, and wielding town identity as a balm to soothe disgruntled citizens.

Local Politics

In this study, local politics refers to the struggle between different individuals and interest groups over the power to control wetland and other land-use decisions. Local politics was critical to shaping SE in some towns, like Gannet, but played a more supportive role in other towns, like Robin. Stakeholders from all towns used politics as a multi-purpose tool. One purpose was to express and promote personal ideologies, as shaped by contextual factors, like property-rights and economic-development beliefs. Similarly, some stakeholders used politics to pursue personal vendettas. These ideologies and vendettas, in turn, shaped whether citizens perceived wetland decisions in a favorable or hostile light. A second objective was to express this relative satisfaction with wetland decisions. Finally, stakeholders used politics to increase their power in the wetland-decision arena. In pursuing these objectives, stakeholders utilized two primary strategies. Some rallied support for their views in the public arena, gaining exposure through PP channels and encouraging others to express similar views at public hearings and through voting. Others operated outside the public arena, developing personal connections to recruit supporters.

The former strategy was pervasive in Gannet, where local politics were a dominant force in town government. Gannet's stakeholders were divided into two principal coalitions: pro and anti-development. Developers, less-wealthy newcomers, libertarians, Tea Partiers, and most

multi-generational families constituted the pro-development or ‘Raze and Pave’ coalition. Conservationists, wealthy newcomers, and strategic planners composed the anti-development group. Constituents of both coalitions had varying motivations. Job security, anti-regulation sentiment, or anxiety about the town’s tax base inspired some to fight for unfettered development. Environmental awareness, concern for Gannet’s overall quality of life, or an exclusionist attitude motivated others to support development restrictions. Throughout the study period, these two groups battled for control of town boards. In a typical cycle, the non-dominant group took umbrage with the policies or decisions of the opposing group and attended public hearings to complain and rally support. Leaders of the non-dominant group then ran for and secured local offices, taking control of town boards. Some time later, the second group repeated the cycle. Power thus flip-flopped repeatedly between coalitions.

The pro-development group seemed to embrace this publicly political approach and the anti-development group to find it distasteful, but both camps were satisfied when the tool regained them land-use decision power. Overall though, politics in Gannet exerted a largely negative impact on SE and ultimately, EE. The infighting perpetuated inter-group animosities, disrupted the civility of public hearings, and undermined wetland-policy stability. The mid-2000s were particularly precarious for wetland conservation. During this period, the pro-development group controlled the PB and ZB and tried, several times, to rally their political base to overturn conservation policies, including the wetland-protection portion of the zoning code, the impervious-surface wetland buffer, and the decision to dedicate 100% of the land-use-change tax to conservation. Though they failed to completely overturn any of these, their effort revealed strong discontent with the policies, a deep divide among stakeholders, and weakened wetland-buffer implementation. As the CC chair explained, Gannet had a buffer policy: “But that is the

sore point...The buffer zone is…our crumbling line of defense. Over the years, the planning board has given it less and less respect. It *is* in the ordinance, there's a substantial buffer, but they don't seem to get that…When it comes to actual enforcement, that's…problematic."

Local politics were most dramatic in Gannet, but were also a cumulatively negative force in Lark and Teal. Stakeholders in both towns used politics to express and pursue ideologies. This was especially important in Teal, where anti-regulation stakeholders rallied town-wide support to revoke wide wetland buffers and defeat the proposed mandatory open-space policy. Personal vendettas were also powerful political motivators in both towns that damaged SE by disrupting inter-board communication and trust. In Lark, for instance, the Golden Age of joint-board comprehensive planning was a cooperative anomaly amidst the status quo personality conflicts that beleaguered town government. The common threat of an influx of urban newcomers motivated the brief political détente. During this period, professional staff was hired to support the land-use boards in their joint mission. However, old inter-personal conflicts were not resolved. When they eventually resurfaced, former power figures flexed their political muscle and funding for board staff dried up, inter-board communication halted, and comprehensive planning was abandoned. A CC member succinctly described the detrimental impact of local politics and collapse of the politically harmonious Golden Age: "…someone pissed someone off, and then people were thrown out of office, and the whole thing kinda went...We fell apart as a town. There was *deep* divisions: the conservation commission and the planning board people not talking to each other, and…We just became warring factions."

In Robin, local politics sometimes produced negative effects, but were more often used to enhance SE of conservation efforts. Much political work occurred outside the public arena. CC and land-trust members invested in personal relationships that crossed interest-group boundaries.

The CC worked these relationships to negotiate compromises with key farmers, developers, and other opponents before wetland-policy revisions were daylighted for public deliberation and voting. Robin's 19-m, no-build wetland buffer was a product of such negotiation, as one CC member explained: "We just went with what we knew we could get through town meeting. We... did a little work beforehand and were able to get certain parties to agree to the [19 m] and not give us...flak at town meeting…Basically, we went with what we thought was politically possible, but not environmentally ideal." The land trust also cultivated support for conservation via outreach programs. Through such methods, the CC and land trust fortified their authority and strengthened public support for wetland policies and decisions. Robin also used the concepts of town identity and benevolent dictatorship to limit negative political effects. Town leaders consistently reminded opposing groups about their common rural-preservation goal and used town identity to prod citizens beyond political squabbling. When in power, each group generally tried to be civil and acknowledge opponents' concerns. These political tactics were largely successful and bolstered the SE of Robin's wetland programs by fostering a norm of pro-conservation centrism. One ZB member outlined town politics thus:

> …if that group that is in power is benevolent to the group that's not in power… if they…embrace them and work with them…even…if it sticks in their throat…that's the way they should go, because when the power changes…we hope that the power goes to the other side [and] becomes benevolent again. And if you do that, you *do* have accomplishments. [Otherwise] what happens is: the builder wins. Because the builder now bypasses the local boards and goes right to the state, saying…: 'I can't really deal with these guys.'…it's to the town's best advantage to have all sides work in unison.

Political struggle over land-use decision-making has an intense history throughout the U.S., including in New England (Jacobs and Paulsen 2009; Nolan et al. 2013). This conflict is rooted in the distributive nature of such decisions, which ultimately control who benefits from and who must forgo land's economic and inherent value (Jacobs and Paulsen 2009; Hawkins 2011). Such conflict is commonly portrayed as a battle in which marginalized environmentalists

are pitted against a powerful growth machine, impelled by a coalition of business leaders, developers, and local officials (Molotch 1976; Hawkins 2011; Douglas 2012). Though oft described at the metropolitan or state level (Gibbs and Krueger 2011; McCauley and Murphy 2013), growth-machine dynamics can propel municipalities, as exemplified by Gannet, where contractors and other business leaders controlled the planning board for long stretches and convinced much of the town that economic development was direly needed. Besides providing a battle-ground for fighting over distributive power, local politics can also promote petty, interpersonal strife and ideological bickering and thus distract town officials from adequately considering both municipal and supra-local interests (DeSantis and Hill 2004; Jacobs and Paulsen 2009; McCauley and Murphy 2013). Such was the case in Lark, Teal, and Gannet, where the wetland programs all suffered fall-out from personal, political vendettas. Whether presenting as tension between economic development and environmental protection or as a personal grudge, local politics were used in these three towns to voice discontent about, and garner power to dismantle, wetland programs. But as Robin showed, local politics can be used to enhance SE of wetland programs and limit the negative effects of intra-town fighting. Robin's success rested in its ability to use political techniques as an outlet for its leaders' communication skills and to focus stakeholders' attention on the town's identity: a goal larger than any one political party.

Critical Ecological Effectiveness Drivers

Two principal, interrelated factors shaped EE in the case towns: policy content and social effectiveness. The local wetland policies provided baseline standards and established norms for decision-makers to follow when conditioning the quantity and configuration of work allowed in

and near wetlands. Though each town had a mechanism for allowing exceptions to these standards, the EE results generally reflected policy content. For instance, Robin and Gannet's wetland policies both contained a clause which proscribed impervious surfaces in proximity to jurisdictional wetlands. Where Robin's impervious buffer was 19-m wide, Gannet's was 15-m. The site-plans mirrored these policy differences, showing that in Robin, impervious surfaces were located farther from wetlands and, within 30m of wetlands, covered smaller areas than in Gannet. Robin's site plans also reflected the timing of its impervious-buffer, instituted in 1997, with impervious surfaces concentrated farther from wetlands in the 2000s versus the 1990s.

Policy content alone did not determine EE, however. The complex social interactions accompanying policy creation and implementation muddied the waters, sometimes sloshing wetland decisions well beyond the policies' proverbial banks. In fact, SE had a strong impact on EE. Interviewees provided over 40 examples where stakeholders' emotional or intellectual reactions to a municipal wetland program motivated them to support or oppose, and thereby alter the EE of, a decision or policy. Importantly, these 40 examples were generally consistent with the quantitative EE evidence derived from the site plans. Finding linked SE and EE is not without precedent. Research on collaborative watershed groups shows that meaningful public participation in environmental decision-making improves group SE, which enhances decision implementation and perceived EE (Leach and Sabatier 2005; Lubell et al. 2005; Mandarano 2008). Similarly, Meyer and Konisky (2007b) found that wetland bylaws in MA delivered increased EE for wetland ecosystems, compared to the state policy alone, and suggested this might be because the local nature of wetland bylaws generated greater SE.

My study contrasts with previous research, however, by simultaneously assessing both the SE and EE of a local environmental program and finding that, for municipal wetland-permit

programs, SE is not always or even usually positive and may act as a time bomb that feeds back to negatively impact EE. In fact, in 60% of the interviewee examples, dissatisfaction with a wetland program negatively impacted wetland ecosystems (-SE→-EE). This was especially common in Lark, Teal, and Gannet. Impaired EE manifested in various forms. Frequently, local officials placed weak conditions on wetland permits (i.e., allowed wetland and buffer impacts), often because stakeholders intimidated them or because officials had different priorities than, and disregarded, portions of the wetland policies. Policy changes were another common way that EE was degraded. Across the towns and years, stakeholders revoked, reduced the strictness of, refused to increase the strength of, and/or expressed desires to weaken local wetland policies. SE also negatively impacted EE by driving stakeholders to: conduct unpermitted work, refuse conservation easements on their land (and in some cases sell land to developers to spite conservationists), and limit CC input into permit and policy decisions. Teal was a poster-child for such negative outcomes. Malcontent stakeholders forced the town to revoke the river-buffer policy, blocked the designation of prime wetlands and the proposed mandatory open-space subdivision policy, and were so intimidating to local officials that the officials would not pursue scientifically-sound wetland-policy revisions or substantial wetland buffers for individual permits. The site-plan data confirmed these statements, showing that Teal was least likely to have buffers on project sites, allowed impervious surfaces closer to wetlands, and was more likely to create inter-wetland barriers, than the other towns. Similarly, controversy over Gannet's impervious-buffer policy and conflict between pro and anti-development groups precipitated an attempt to overturn its wetland policy in 2008 and led the PB to have diminishing respect for, and willingness to implement, buffer policies throughout the 2000s. The site-plan data likewise showed that buffers in Gannet were narrower, and disturbances within 30m of wetlands larger, in

the 2000s versus the 1990s. Further, Gannet was more likely to allow wetland disturbances and permitted the largest wetland disturbances of all the towns, reflecting generalized hostility towards the wetland bylaw.

Much less commonly (10% of the examples), wetland-program satisfaction resulted in positive impacts to wetland systems (+SE→+EE). In all four examples, stakeholders voluntarily took actions that benefited wetlands after education or communication events helped them understand the importance of wetland conservation. In Teal and Gannet, landowners supported municipal conservation acquisitions through voting and/or land donations. One Teal developer became a staunch supporter of open-space subdivisions. Lark's conservation agent increased permit compliance by talking with applicants, quelling their frustrations with the permit-application process. Individual examples aside, Robin embodied this positive relationship as a holistic entity, showing that strict bylaws do not inevitably lead to low SE and EE. All Robin interviewees described the town as having a rigorous wetland program with wide wetland buffers that caused some grumbles, but was nevertheless accepted by most stakeholders. The site-plan data support these conclusions, showing that Robin was the least likely town to allow wetland disturbances or create permanent inter-wetland barriers, had the smallest impervious areas in wetlands, and located projects farthest from wetlands.

SE and EE were negatively linked, with program discontent producing positive impacts to wetland systems (-SE→+EE), about 15% of the time. In five of these six examples, applicants were so frustrated with the permit-application process that they abandoned plans mid-project or were deterred from future work in the town. In Lark, town politics, wetland-policy restrictions on land-use rights, and the complexity of the application process exasperated applicants. In Robin, several developers ceased working in town because the policies were so strict they made

development economically unfeasible. In the sixth example, CC discontent over a permit violation motivated a landowner to bring his project into compliance.

SE and EE were linked in the remaining 15% of examples, but in complicated patterns, in part because SE itself is a complex phenomenon. A single wetland-permit, for instance, can please one party while angering another. In a couple examples, feedback extended the SE-EE relationship beyond a simple one-step model. For instance, a Lark CC chair was dismayed to find that lake associations were not complying with permit-renewal rules. He began enforcing the rules, initiating closer oversight of lake-management activities. This improved his satisfaction with Lark's wetland program, but angered other CC and lake-association members who viewed enforcement as meddling (-SE→+EE→±SE). Teal's site-plan data reflected a similarly complex SE-EE relationship. Wary of potential government intrusion onto private property, citizens rejected Teal's proposed mandatory open-space subdivision policy in 2005. Learning from the experience, the PB proposed a voluntary policy, which the town accepted in 2006 and several developers embraced in subsequent years. The site-plan data reflect this uptick in open-space-subdivision construction, with disturbances having less convoluted borders and impervious areas being more compact in the 2000s versus 1990s. These results suggest that decision-makers consciously applied the new open-space subdivision policy and tried to cluster on-site project impacts. (Despite successful clustering, Teal still allowed projects to be close to wetlands, so policy implementation was imperfect. If I ignore this separate buffer issue, the example's SE-EE path would be: -SE→-EE→policy change→+SE→+EE). In the remaining examples, EE was a matter of subjective interpretation. In Lark and Robin, wetland violations upset CC members and quickened their desire to strengthen compliance. However, the resulting enforcement was weak and did not optimally restore wetland function. Nevertheless, CC

members argued that EE was higher than it would be with no enforcement or strict enforcement because violators were receptive to the friendly nature of weak enforcement (-SE→±EE).

Though the normal pattern in Lark, Teal, and Gannet was for low SE to diminish EE, this was not the only SE-EE relationship observed. As a holistic entity, for instance, Robin's wetland program showed that strict bylaws do not inevitably lead to low SE and EE. The SE-EE relationship, rather, depends on a town's configuration of SE drivers and other contextual factors. Different property-rights ethics or town identities, for example, can drive divergent SE-EE norms across towns. Likewise, individual actions or institutional changes can redirect SE and thus EE either in the long-term or temporarily. For instance, both SE and EE improved in Lark during the few years the town employed a full-time conservation agent. The lags between institutional or cultural shifts and SE/EE changes can vary within and across towns. Some changes are almost immediate, while other times SE festers and influences EE much later or at multiple time points. For example, Teal passed its river buffer in 2004 and by 2007, citizens had a petition on the town warrant to repeal all wetland buffers in town. The 2007 vote failed, but in 2008, a new petition succeeded in substantially reducing the river-buffer width. Gannet, by comparison, established its wetland bylaw in 1986. Despite persistent grumblings, however, no major public protest surfaced until 2008, when a petition to repeal the bylaw appeared on the town warrant (and failed). Such delays suggest the potential for lagged impacts to SE and EE, even in municipal wetland programs that superficially appear stable. Ultimately, SE was at least as important as policy content in determining EE, in part because SE was a catalyst for policy revisions.

Summary, Conclusions, and Recommendations

The decentralized governance movement has been a major thrust of public policy in western democracies over the last 25 years (Denters and Rose 2005b; Kraft and Mazmanian 2009). One manifestation of this trend in the US is the devolution of land-use decision-making to local governments. In MA and NH, municipalities are regularly charged with deciding whether and how development should proceed in proximity to wetlands. To structure and formalize this decision-making, many towns have instituted local wetland-permit policies that limit work in wetlands and within a specified buffer zone. In the environmental field, research shows that decentralized governance produces positive decision-process outcomes and can enhance implementation success of associated plans (Leach and Pelkey 2001; Lubell et al. 2005; Mandarano 2008). Such SE may translate into positive ecological impacts, but very little empirical evidence actually links SE with EE (Leach and Pelkey 2001; Meyer and Konisky 2007b). This dearth of empirical research is particularly problematic in the wetland-conservation arena where an on-going theoretical debate questions whether the locus of decision power should be at the local, state, or federal level (Payne 1998; Adger and Luttrell 2000; Owens and Zimmerman 2013). Localists argue that wetlands provide vital services to local populations and that local knowledge improves the quality of wetland decision-making (Adger and Luttrell 2000; Sabatier et al. 2005; Owens and Zimmerman 2013). Moreover, federal and state wetland regulators, limited by staff, funding, and legal authority, admit that they depend on local jurisdictions to scrutinize fine-scale impacts of proposed developments, implement stricter policies, and assist with enforcement. But regional and global publics also depend on the healthy functioning of local wetlands for services such as climate regulation and wildlife-habitat provision (Adger and Luttrell 2000; Owens and Zimmerman 2013). Local-control critics contend

that locals have neither the capacity nor the desire to safe-guard these broad-scale interests (Levi et al. 1976; Payne 1998; DeSantis and Hill 2004). Understanding whether local wetland programs achieve SE and EE in practice is therefore critical to optimizing wetland management from both a policy and ecological perspective.

Here, I provide empirical data on the SE and EE of municipal wetland-permit programs in four towns in MA and NH. I discovered distinct differences and considerable variation in SE and EE between and within case towns and observed both positive and negative SE and EE outcomes. This variation indicates that neither shifting wetland decision power to the local level nor relying on regulatory wetland buffers guarantees good social or ecological results. Rather, effectiveness depends on the interactions between wetlands and the social and institutional contexts: all components of a dynamic, complex system.

EE and SE were not completely random, however. EE was primarily a product of SE and local-wetland policy content. SE, in turn, was determined by a suite of interacting factors, which like most social phenomena was dynamic and not easily predicted. Factors played different roles in promoting SE. Town identity and communication were key factors that could help rally a town around the common cause of wetland conservation. Property-rights and organizational structure were contextual factors that shaped stakeholders' initial perspectives on and control over wetland decisions. Education and wealth were enabling factors that could facilitate wetland conservation when present. Finally, public participation and local politics were tools that stakeholders' used to express ideologies and SE. Alone, no single driver was enough to produce positive SE. Indeed, several factors had the potential to either positively or negatively impact SE, depending on context. Wealth, for example, can fund wetland conservation or wetland development. What determined SE was the interaction among drivers, with different factor combinations important

in each town. Though inter-state distinctions in structure, policy, and culture did provide different contextual baselines for wetland decision-making in the towns, SE driver combinations were not clearly split along state lines. This suggests that mechanisms propelling SE and EE were similar in MA and NH and that inter-town differences in wetland-policy implementation may be as important as inter-state disparities in policy content and other contextual factors.

In support of the decentralized governance literature, I found that SE and EE were often positively correlated, but predominantly in a negative direction, whereby discontent with wetland decisions was linked with negative ecological consequences. I saw this pattern repeatedly across Lark, Teal, and Gannet. But this was not always the case. Less commonly, wetland programs generated discontent, but also deterred stakeholders from developing near wetlands, a positive environmental outcome. Sometimes, satisfaction with a local wetland program led to positive wetland outcomes. Of the four towns, Robin was most successful at achieving both high SE and EE and served as a model for local regulatory governance.

Robin's success was built on the strategic harnessing of personal attributes and community attachment in service of a rural conservation ideal. Robin benefited from relatively high levels of generalized education and wealth; an organizational structure that granted the knowledgeable, skilled communicators on its CC significant power; and leaders that knew how to balance autonomy with regulatory restrictions and generate political support for conservation. As a result, stakeholders in Robin generally accepted even strict wetland decisions, which allowed the town to maintain relatively wide buffers and a high EE standard. No other town had such depths of personal capacity and strategic planning, combined with such a compatible context. Teal, and to some extent Lark, had technically knowledgeable leaders on the PB and CC, but lacked the communication skills to generate support for their efforts. A skilled communicator

led Gannet's CC, but he was overpowered by the regressive impact of local politics and a town identity focused on economic development. Nevertheless, each town demonstrated some strategies for achieving SE and EE despite the capacity, structure, policy, and culture obstacles that otherwise limited wetland-program effectiveness. I provide a sampling of these strategies in Table 3.10. Some strategies worked by inserting collaborative elements into the regulatory process (e.g., extra-hearing stakeholder meetings), while other strategies targeted organizational structure or community capacity (e.g., joint-board meetings; using site walks as a trust-building and teaching tool; requiring ecology and communications training).

Despite these strategies, my results also show that SE and EE sometimes interact through complex or lagged feedback loops, suggesting that current wetland-program status may not always predict future effectiveness. Moreover, a town's internal and external environment changes over time, including its demographic composition, ecosystem integrity, civic engagement, and macro-economic and political pressures. These changes can send a town's SE-EE trajectory in novel directions. Multiple interviewees in Robin, for instance, expressed doubt about the town's ability to control development in the near future. With many nearby towns now built-out, they anticipated that developers would, for the first time in decades, start to view construction in Robin as economically feasible, especially as the recession ended and the housing market rebounded. With changes in the federal estate tax, they fretted that Robin's farmers, who owned many of the town's remaining large parcels, would be forced to sell their land for development. Finally, they worried about changing demographics. Board membership was aging and uncharacteristically low. Of the young politicos, many did not seem to prioritize rural conservation and compromise the way the old-guard did, favoring instead personal ties and political patronage. This changeability underscores an ultimate lesson of this study. The social

and ecological life of a town is dynamic. There is no single prescription that will fit all towns at all times. Instead, I isolated critical factors that drive the system forward and stress that these factors must be combined, adapted, and applied as needed to fit a town's particular social and ecological context. Acknowledging the social nature of these drivers is essential, however. Policy content and the inherited decision-power structure are important, but care and attention must be invested in cultivating strategic and respectful social interactions. In an evolving world, maintaining conducive social conditions requires monitoring, recruitment, and constant vigilance.

Table 3.1. Final models used to test for inter-town differences in impacts to wetlands and buffers. Data derived from construction site plans.

Disturbance measure	Zero-inflated	Regression[a]	Variance Structure	Y Transformation
wetland area disturbed (m^2)	Y	logistic	na	na
		gls	1[b]	ln(y+1)
new impervious area in wetland (m^2)	Y	logistic	na	na
		gls	2[c]	$\sqrt[8]{}$
total impervious area in wetland (m^2)	Y	logistic	na	na
		gls	3[d]	$\sqrt[8]{}$
disturbed area in 30m buffer (m^2)	N	gls	1	$\sqrt[4]{}$
new impervious area in 30m buffer (m^2)	Y	logistic	na	na
		gls	2	ln(y+120.23)
total impervious area in 30m buffer (m^2)	Y	logistic	na	na
		gls	1	$\sqrt[8]{}$
disturbed area in 400m buffer (m^2)	N	gls	4[e]	$\sqrt[4]{}$
new impervious area in 400m buffer (m^2)	Y	logistic	na	na
		gls	1	ln(y+291.46)
total impervious area in 400m buffer (m^2)	Y	logistic	na	na
		gls	1	ln(y+1)
% wetland area disturbed	Y	logistic	na	na
		gls	3	ln(y+1)
% new impervious area in wetland	Y	logistic	na	na
		gls	1	none
% total impervious area in wetland	Y	logistic	na	na
		gls	1	none
% of 30m buffer disturbed	N	gls	2	none
% new impervious area in 30m buffer	N	gls	1	none
% total impervious area in 30m buffer	N	gls	5[f]	none
% of 400m buffer disturbed	N	gls	2	$\sqrt{}$
% new impervious area in 400m buffer	N	gls	1	none
% total impervious area in 400m buffer	N	gls	1	none
distance to the nearest new disturbance (m)	Y	logistic	na	na
		gls	4	$\sqrt[4]{}$
distance to the nearest new impervious area (m)	Y	logistic	na	na
		gls	1	none
edge density of disturbed area (m/ha)	N	gls	6[g]	$\sqrt[6]{}$

Table 3.1 continued.

edge density of new impervious area (m/ha)	N	gls	5	$^{6}\sqrt{}$
correlation length of disturbed area (m)	N	gls	2	$^{8}\sqrt{}$
correlation length of impervious area (m)	N	gls	none	$^{10}\sqrt{}$
type of project	NA	multinomial	na	na
wetland created	N	logistic	na	na
permanent wetland barrier	NA	logistic	na	na

[a] For all zero-inflated models, I used logistic regression with a log link to model zero values and generalized least squares regression (gls) to model the non-zero values.

[b] I assigned different variances to each town and to each project type.

[c] I assigned different variances to each project type.

[d] I assigned different variances to each town.

[e] I assigned different variances to each town; I also allowed variances to increase exponentially within each town as a function of the fitted values of the regression.

[f] I assigned different variances to each project type; within each town, I also allowed variances to increase exponentially as a function of the fitted values of the regression.

[g] I assigned different variances to each town; I also allowed variances to increase within each town as a power function of the fitted values of the regression.

Table 3.2. Interviewee demographic data

		Lark	Robin	Teal	Gannet	Developers & Consultants
interviewees		8	8	8	8	9
sex (F, M)		3,5	3,5	5,3	3,5	0,9
age (years)		61±4 (40-73)	60±4 (47-74)	63±2 (50-71)	56±2 (47-65)	57±3 (49-71)
years in town		27±6 (7-50)	32±7 (10-70)	33±6 (19-70)	27±4 (12-41)	26±4 (13-42)
highest educational degree	middle school	0	0	0	1	0
	high school	4	1	3	2	2
	associate's	1	1	3	1	1
	bachelor's	2	3	1	4	4
	master's	1	3	1	0	1
	NA	0	0	0	0	1
political ID	conservative	4	2	4	2	4
	independent	3	2	2	3	2
	liberal	1	4	2	2	0
	other	0	0	0	1	1
	NA	0	0	0	0	2
adults in household		2.0±0.0 (2-2)	1.9±0.2 (1-3)	2.1±0.2 (1-3)	1.9±0.1 (1-2)	2.0±0.0 (2-2)
kids in household		2.9±1.0 (0-6)	1.1±0.4 (0-3)	3.4±0.8 (1-7)	3.4±1.0 (0-9)	2.6±0.7 (0-7)
land area owned	≤ 0.4 ha	1	0	1	1	1
	0.4 – 2 ha	0	4	3	2	2
	2 – 4 ha	1	0	0	0	0
	> 4 ha	6	4	4	5	5
	NA	0	0	0	0	1

Notes: For categorical variables, all values are # of subjects; for continuous variables, mean ±SE and range are shown.

Table 3.3. Descriptive statistics summarizing project frequency across factor categories.

Factor	Factor Category	# of Projects
Town	Lark	49
	Robin	50
	Gannet	49
	Teal	46
Decade	1990s	79
	2000s	115
Project Type	ANRsubdivision[a]	6
	Assorted[b]	6
	Commercial	9
	Driveway	7
	SFH[c]	22
	SFHaccessory[d]	23
	SFHsubdivision[e]	68
	Septic	27
	Subdivision	13
	SubdivisionRoad[f]	5
	SubdivisionRoad+[g]	8
Inter-Wetland Barrier	N	72
	Y	114
Type of Inter-Wetland Barrier	Commercial	6
	Driveway	11
	Lawn	3
	Road	10
	SFHComb[h]	71
	SubdivisionComb[i]	13

[a.] ANRsubdivisions are subdivisions without a common road.
[b.] Assorted projects include activities such as utility work and beach fortification.
[c.] SFH is a single-family house.
[d.] SFHaccessory includes minor projects associated with an SFH (e.g., house renovations, swimming pools).
[e.] SFHsubdivision includes SFHs within conventional subdivisions.
[f.] SubdivisionRoad refers to a subdivision road and the associated grading.
[g.] SubdivisionRoad+ includes a subdivision road, plus associated grading and stormwater facilities.
[h.] SFHComb includes stand-alone SFHs and SFH within subdivisions.
[i.] SubdivisionComb includes the following project type categories: Subdivision (conventional), SubdivisionRoad, SubdivisionRoad+.

Table 3.4. Descriptive statistics detailing project-site characteristics and project impacts.

Project Metric	Mean	±	SE	Range		
Total Site Area (ha)	5.27	±	0.79	0.03	-	74.51
Lark	1.65		0.36	0.03		13.45
Robin	3.54	±	1.42	0.07	-	66.23
Teal	7.34		1.86	0.27		74.51
Gannet	8.81		2.00	0.07		57.47
On-site Wetland Area (ha)	0.74	±	0.16	0	-	8.30
On-site Upland Area (ha)	3.28	±	0.79	0.03	-	67.29
Disturbed Wetland (m^2)	155.19	±	46.54	0	-	5207.42
New Impervious Wetland (m^2)	60.26	±	23.31	0	-	3052.39
Total Impervious Wetland (m^2)	60.26	±	23.32	0	-	3052.39
Disturbed 30m (m^2)	2379.92	±	496.45	0	-	51493.51
New Impervious 30m (m^2)	741.50	±	203.65	-119.23	-	31475.66
Total Impervious 30m (m^2)	753.17	±	203.47	0	-	31475.66
Disturbed 400m (m^2)	5821.53	±	1415.20	0	-	223328.71
New Impervious 400m (m^2)	1760.43	±	401.98	-290.46	-	44138.26
Total Impervious 400m (m^2)	1798.30	±	401.67	0	-	44138.26
% Wetland Disturbed	2.01	±	0.43	0	-	8.25
% Wetland New Impervious	0.30	±	0.09	0	-	4.84
% Wetland Total Impervious	0.30	±	0.09	0	-	4.84
% 30m Disturbed	20.53	±	1.86	0	-	79.71
% 30m New Impervious	3.31	±	0.51	-18.62	-	31.80
% 30m Total Impervious	4.20	±	0.51	0	-	31.80
% 400m Disturbed	25.23	±	2.30	0	-	93.57
% 400m New Impervious	3.72	±	0.58	-26.07	-	35.51
% 400m Total Impervious	5.15	±	0.55	0	-	35.51
Distance to Nearest New Disturbance (m)	7.09	±	0.60	0	-	33.63
Distance to Nearest New Impervious (m)	11.10	±	0.97	0	-	63.91
Distance to Nearest New Road (m)	5.06	±	2.23	0	-	53.53
Disturbance Edge Density (m/ha)	10.43	±	1.30	0.21	-	90.93

Table 3.4 continued.

Impervious Edge Density (m/ha)	7.99	±	1.08	0.05	-	58.86
Disturbance Correlation Length (m)	121.23	±	20.19	3.77	-	1440.48
Impervious Correlation Length (m)	104.49	±	20.14	0.89	-	1211.58
Total Created Wetland (m^2)	79.69	±	42.16	0	-	1971.13
Created Wetland as % of Original Wetland	0.13	±	0.08	0	-	3.13
Created : Permanently Disturbed Wetland	0.26	±	0.09	0	-	3.20

Table 3.5. Results of regression models used to test for inter-town differences in impacts to wetlands and buffers. Only significant results are shown.

Impact Metric	Regression	Predictor	X^2 / F value$_{(df)}$[j]	z / t value$_{(df)}$[k]	Coefficient[l] ± SE
Disturbed Wetland (m^2)	logistic$_{(77\%)}$[a]	T_Robin[b]	$15.15_{(3)}^{*}$	-3.20^{*}	-1.44 ± 0.45
		T_Gannet		2.66^{*}	1.19 ± 0.45
		Project Type-R[c,d]	$36.60_{(5)}^{***}$		
	gls	T_Lark	$5.09_{(3,52)}^{*}$	$-2.20_{(60)}^{*}$	-0.97 ± 0.44
		T_Gannet		$3.57_{(60)}^{**}$	0.94 ± 0.26
		PT-R_SubdivisionComb[c,f]	$5.10_{(5,52)}^{**}$	$3.74_{(60)}^{**}$	-0.41 ± 0.39
		Intercept	$151.99_{(1,52)}^{***}$	$12.33_{(60)}^{***}$	3.90 ± 0.32
New Impervious Wetland (m^2)	logistic$_{(81\%)}$	Town*Decade[d,e]	$12.48_{(3)}^{*}$		
		Project Type-R[d]	$31.79_{(5)}^{***}$		
	gls	T_Robin	$2.82_{(3,45)}^{*}$	$-2.62_{(54)}^{*}$	-0.38 ± 0.14
		T_Gannet		$2.13_{(54)}^{*}$	0.19 ± 0.09
		Decade	$5.79_{(1,45)}^{*}$	$-2.41_{(54)}^{*}$	-0.28 ± 0.12
		PT-R_Assorted[g]	$9.45_{(5,45)}^{***}$	$-5.06_{(54)}^{*}$	-0.56 ± 0.11
		PT-R_SubdivisionComb		$3.66_{(54)}^{**}$	0.34 ± 0.09
		Intercept	$247.22_{(1,45)}^{***}$	$15.72_{(54)}^{***}$	1.53 ± 0.10
Total Impervious Wetland (m^2)	logistic$_{(84\%)}$	Town*Decade[d]	$11.77_{(3)}^{*}$		
		Project Type[d]	$54.30_{(10)}^{***}$		
	gls	T_Robin	$4.09_{(3,44)}^{*}$	$-2.91_{(53)}^{*}$	-0.32 ± 0.11
		T_Gannet		$2.23_{(53)}^{*}$	0.15 ± 0.07
		T_Teal		$2.24_{(53)}^{*}$	0.15 ± 0.06
		Decade	$4.66_{(1,44)}^{*}$	$-2.16_{(53)}^{*}$	-0.24 ± 0.11
		PT-R_Assorted	$8.77_{(5,44)}^{***}$	$-4.80_{(53)}^{***}$	-0.56 ± 0.12
		PT-R_SubdivisionComb		$3.54_{(53)}^{*}$	0.31 ± 0.09
		Intercept	$334.97_{(1,44)}^{***}$	$18.30_{(53)}^{***}$	1.54 ± 0.08

Table 3.5 continued.

Disturbed 30m (m^2)	gls	T_Robin*Decade	$3.66_{(3,176)}^{*}$	$-2.38_{(193)}^{*}$	-0.80	±	0.34
		T_Gannet*Decade		$2.76_{(193)}^{*}$	1.01	±	0.36
		T_Robin	$4.63_{(3,176)}^{*}$	$2.25_{(193)}^{*}$	0.59	±	0.26
		T_Gannet		$-3.24_{(193)}^{*}$	-1.01	±	0.31
		PT_Assorted	$12.67_{(10,176)}^{***}$	$-2.40_{(193)}^{*}$	-2.57	±	1.07
		PT_Commercial		$1.73_{(193)}^{\bullet}$	2.25	±	1.30
		PT_Septic		$-8.81_{(193)}^{***}$	-2.71	±	0.31
		PT_SFH[h]		$-2.84_{(193)}^{*}$	-1.03	±	0.36
		PT_SFHaccessory[i]		$-7.3_{(193)}^{***}$	-2.35	±	0.32
		PT_SFHsubdivision		$-2.91_{(193)}^{*}$	-0.89	±	0.31
		PT_Subdivision[f]		$3.03_{(193)}^{*}$	2.32	±	0.77
		PT_SubdivisionRoad[f]		$1.99_{(193)}^{*}$	2.30	±	1.15
		PT_SubdivisionRoad+[f]		$3.58_{(193)}^{**}$	3.24	±	0.91
		Intercept	$436.9_{(1,176)}^{***}$	$20.90_{(193)}^{***}$	5.79	±	0.28
New Impervious 30m (m^2)	$logistic_{(88\%)}$	T_Lark*Decade	$9.44_{(3)}^{*}$	2.54^{*}	2.12	±	0.84
		T_Robin*Decade		-1.98^{*}	-2.22	±	1.12
		T_Lark		-2.44^{*}	-1.65	±	0.68
		Project Type[d]	$68.83_{(10)}^{***}$				
	gls	T_Robin	$3.36_{(3,139)}^{*}$	$-3.11_{(152)}^{*}$	-.26	±	0.08
		T_Gannet		$2.00_{(152)}^{*}$	0.11	±	0.05
		PT_Assorted	$28.96_{(10,139)}^{***}$	$-10.26_{(152)}^{***}$	-1.36	±	0.13
		PT_Septic		$-6.67_{(152)}^{***}$	-1.19	±	0.18
		PT_SFH		$-2.48_{(152)}^{*}$	-0.45	±	0.18
		PT_SFHaccessory		$-7.79_{(152)}^{***}$	-1.17	±	0.15
		PT_SFHsubdivision		$-2.71_{(152)}^{*}$	-0.40	±	0.15
		PT_Subdivision		$2.89_{(152)}^{*}$	0.89	±	0.31
		PT_SubdivisionRoad		$2.70_{(152)}^{*}$	1.36	±	0.50
		PT_SubdivisionRoad+		$5.04_{(152)}^{***}$	1.88	±	0.37
		Intercept	$2277.32_{(1,139)}^{***}$	$47.72_{(152)}^{***}$	6.07	±	0.13

Table 3.5 continued.

Total Impervious 30m (m^2)	logistic$_{(89\%)}$	T_Lark*Decade	$7.55_{(3)}^{\bullet}$	2.10^{*}	1.88	±	0.90
		T_Robin*Decade		-2.11^{*}	-1.91	±	0.90
		Project Type-R[d]	$66.60_{(6)}^{***}$				
	gls	PT-R_ANRsubdivision	$18.91_{(5,153)***}$	$1.97_{(158)}^{\bullet}$	0.17	±	0.09
		PT-R_Assorted		$-5.59_{(158)}^{***}$	-0.85	±	0.15
		PT-R_Commercial		$2.98_{(158)}^{*}$	0.57	±	0.19
		PT-R_SFHComb		$-1.87_{(158)}^{\bullet}$	-0.12	±	0.06
		PT-R_SFHaccessory		$-3.98_{(158)}^{**}$	-0.28	±	0.07
		PT-R_SubdivisionComb		$5.65_{(158)}^{***}$	0.50	±	0.09
		Intercept	$1279.85_{(1,153)}^{***}$	$35.77_{(158)}^{***}$	1.90	±	0.05
Disturbed 400m (m^2)	gls	T_Robin	$7.89_{(3,180)}^{**}$	$4.14_{(193)}^{**}$	0.64	±	0.15
		T_Gannet		$-2.49_{(193)}^{*}$	-0.50	±	0.20
		PT_Assorted		$-10.43_{(193)}^{***}$	-4.68	±	0.45
		PT_Commercial	$34.20_{(10,180)}^{***}$	$4.04_{(193)}^{**}$	3.41	±	0.84
		PT_Driveway		$-8.55_{(193)}^{***}$	-3.08	±	0.36
		PT_Septic		$-9.90_{(193)}^{***}$	-2.82	±	0.28
		PT_SFH		$-3.78_{(193)}^{**}$	-1.28	±	0.34
		PT_SFHaccessory		$-11.04_{(193)}^{***}$	-2.97	±	0.27
		PT_SFHsubdivision		$-2.28_{(193)}^{*}$	-0.61	±	0.27
		PT_Subdivision		$5.03_{(193)}^{***}$	4.29	±	0.85
		PT_SubdivisionRoad		$2.83_{(193)}^{*}$	3.37	±	1.19
		PT_SubdivisionRoad+		$4.09_{(193)}^{**}$	4.08	±	1.00
		Intercept	$1107.34_{(1,180)}^{***}$	$33.28_{(193)}^{***}$	7.06	±	0.21

Table 3.5 continued.

New Impervious 400m (m^2)	$logistic_{(93\%)}$	Project Type[d]	$94.75_{(10)}^{***}$				
	gls	PT_Assorted	$57.85_{(10,\ 152)}^{***}$	$-13.88_{(162)}^{***}$	-1.33	±	0.10
		PT_Septic		$-11.74_{(162)}^{***}$	-1.27	±	0.11
		PT_SFH		$-4.79_{(162)}^{***}$	-0.61	±	0.13
		PT_SFHaccessory		$-5.59_{(162)}^{***}$	-1.38	±	0.25
		PT_SFHsubdivision		$-4.95_{(162)}^{***}$	-0.52	±	0.10
		PT_Subdivision		$4.38_{(162)}^{***}$	1.42	±	0.32
		PT_SubdivisionRoad		$3.70_{(162)}^{**}$	1.49	±	0.40
		PT_SubdivisionRoad+		$4.74_{(162)}^{***}$	1.74	±	0.37
		Intercept	$5383.96_{(1,152)}^{***}$	$73.38_{(162)}^{***}$	7.02	±	0.10
Total Impervious 400m (m^2)	$logistic_{(89\%)}$	T_Teal	$7.98_{(3)}^{*}$	-2.61^{*}	-1.46	±	0.56
		Project Type-R[d]	$52.62_{(5)}^{***}$				
	gls	T_Lark*Decade	$4.08_{(3,153)}^{*}$	$2.33_{(170)}^{*}$	0.57	±	0.24
		T_Robin*Decade		$2.10_{(170)}^{*}$	0.48	±	0.23
		T_Teal*Decade		$-2.75_{(170)}^{*}$	-0.96	±	0.35
		PT_ANRsubdivision	$31.78_{(10,153)}^{***}$	$2.65_{(170)}^{*}$	0.80	±	0.30
		PT_Assorted		$-6.05_{(170)}^{***}$	-4.36	±	0.72
		PT_Commercial		$6.02_{(170)}^{***}$	2.29	±	0.38
		PT_Septic		$-11.07_{(170)}^{***}$	-4.10	±	0.37
		PT_SFH		$-2.08_{(170)}^{*}$	-0.47	±	0.23
		PT_SFHaccessory		$-7.03_{(170)}^{***}$	-1.39	±	0.20
		PT_Subdivision		$4.14_{(170)}^{**}$	1.80	±	0.43
		PT_SubdivisionRoad		$6.81_{(170)}^{***}$	2.52	±	0.37
		PT_SubdivisionRoad+		$7.58_{(170)}^{***}$	2.79	±	0.37
		Intercept	$1548.79_{(1,153)}^{***}$	$39.35_{(170)}^{***}$	5.90	±	0.15

Table 3.5 continued.

% Wetland Disturbed	logistic$_{(84\%)}$	Town*Decade[d]	$6.78_{(3)}^{\bullet}$				
		Project Type-R[d]	$33.91_{(9)}^{***}$				
	gls	T_Lark	$6.44_{(3,25)}^{*}$	$-3.91_{(28)}^{**}$	-0.36	±	0.09
		T_Robin		$2.42_{(28)}^{*}$	-0.32	±	0.13
		T_Gannet		$1.92_{(28)}^{\bullet}$	0.35	±	0.18
		T_Teal		$1.99_{(28)}^{\bullet}$	0.33	±	0.16
		Intercept	$59.95_{(3,25)}^{***}$	$7.74_{(28)}^{***}$	0.66	±	0.08
% Wetland New Impervious	logistic$_{(86\%)}$	Town[d]	$13.13_{(3)}^{*}$				
		Project Type-R[d]	$28.30_{(4)}^{***}$				
	gls	Town-R_Robin[b]	$8.93_{(2,22)}^{*}$	$-3.97_{(24)}^{**}$	-0.65	±	0.16
		Intercept	$22.29_{(1,22)}^{**}$	$4.72_{(24)}^{**}$	0.72	±	0.15
% Wetland Total Impervious	logistic$_{(86\%)}$	Town[d]	$15.03_{(3)}^{*}$				
		Project Type-R[d]	$25.93_{(5)}^{***}$				
	gls	Town-R_Robin	$5.65_{(2,22)}^{*}$	$-2.91_{(24)}^{*}$	-0.53	±	0.18
		Intercept	$15.64_{(1,22)}^{**}$	$3.95_{(24)}^{**}$	0.65	±	0.16
% 30m Disturbed	gls	T_Lark	$31.16_{(3,106)}^{***}$	$1.76_{(109)}^{\bullet}$	4.37	±	2.49
		T_Robin		$7.23_{(109)}^{***}$	15.75	±	2.18
		T_Gannet		$-5.29_{(109)}^{***}$	-10.08	±	1.91
		T_Teal		$-6.61_{(109)}^{***}$	-10.04	±	1.52
		Intercept	$244.41_{(1,106)}^{*}$	$15.63_{(109)}^{***}$	18.54	±	1.19
% 30m New Impervious	gls	PT_Septic	$18.26_{(9,99)}^{***}$	$-5.34_{(108)}^{***}$	-3.70	±	0.69
		Intercept	$29.24_{(1,99)}^{***}$	$5.41_{(108)}^{***}$	3.74	±	0.69
% 30m Total Impervious	gls	T_Teal*Decade	$13.06_{(3,91)}^{***}$	$-3.10_{(107)}^{*}$	-2.30	±	0.74
		PT_Septic	$21.71_{(9,91)}^{***}$	$-6.63_{(107)}^{***}$	-4.86	±	0.73
		Intercept	$44.74_{(1,91)}^{***}$	$6.69_{(107)}^{***}$	4.86	±	0.73

Table 3.5 continued.

% 400m Disturbed	gls	T_Lark	$24.78_{(3,95)}^{***}$	$2.83_{(108)}^{*}$	1.02	±	0.36
		T_Robin		$5.33_{(108)}^{***}$	1.76	±	0.33
		T_Gannet		$-2.82_{(108)}^{*}$	-0.93	±	0.33
		T_Teal		$-6.28_{(108)}^{***}$	-1.85	±	0.29
		PT_Assorted	$4.54_{(10,95)}^{***}$	$-2.75_{(108)}^{*}$	-3.10	±	1.13
		PT_Commercial		$4.26_{(108)}^{***}$	3.13	±	0.73
		PT_Driveway		$-2.63_{(108)}^{*}$	-2.49	±	0.95
		PT_SFHsubdivision		$2.36_{(108)}^{*}$	0.88	±	0.37
		PT_SubdivisionRoad		$2.14_{(108)}^{*}$	0.96	±	0.45
		Intercept	$304.29_{(1,95)}^{***}$	$17.44_{(108)}^{***}$	4.12	±	0.24
% 400m New Impervious	gls	PT_ANRsubdivision	$33.80_{(9,98)}^{***}$	$-2.73_{(107)}^{*}$	-2.68	±	0.98
		PT_Commercial		$1.86_{(107)}^{\bullet}$	12.84	±	6.91
		PT_Driveway		$-3.12_{(107)}^{*}$	-2.81	±	0.90
		PT_Septic		$-5.78_{(107)}^{***}$	-4.58	±	0.79
		PT_SFHaccessory		$-2.63_{(107)}^{*}$	-2.71	±	1.03
		PT_Subdivision		$2.63_{(107)}^{*}$	2.58	±	0.98
		Intercept	$33.85_{(1,98)}^{***}$	$5.82_{(107)}^{***}$	4.61	±	0.79
% 400m Total Impervious	gls	T_Robin*Decade	$4.48_{(3,91)}^{*}$	$2.04_{(108)}^{*}$	1.99	±	0.98
		T_Teal*Decade		$-3.54_{(108)}^{**}$	-1.88	±	0.53
		PT_ANRsubdivision	$18.51_{(10,91)}^{***}$	$-2.98_{(108)}^{*}$	-2.50	±	0.84
		PT_Assorted		$-3.80_{(108)}^{**}$	-5.24	±	1.38
		PT_Commercial		$3.23_{(108)}^{*}$	16.48	±	5.10
		PT_Driveway		$-2.28_{(108)}^{*}$	-4.51	±	1.98
		PT_Septic		$-8.41_{(108)}^{***}$	-5.26	±	0.63
		Intercept	$73.44_{(1,91)}^{***}$	$8.57_{(108)}^{***}$	5.35	±	0.62

Table 3.5 continued.

Distance to Nearest Disturbance (m)	logistic$_{(82\%)}$	T_Robin	$12.07_{(3)}^{*}$	2.98^{*}	1.26	±	0.42
		T_Teal		$-1.75^{\bullet}$	-0.58	±	0.33
		Project Type-R[d]	$61.29_{(6)}^{***}$				
	gls	T_Gannet*Decade	$4.06_{(3,117)}^{*}$	$-3.23_{(127)}^{*}$	-0.32	±	0.10
		T_Lark	$5.83_{(3,117)}^{*}$	$-1.84_{(127)}^{\bullet}$	-0.24	±	0.13
		T_Gannet		$4.12_{(127)}^{**}$	0.36	±	0.09
		PT-R_SFHaccessory	$3.12_{(3,117)}^{*}$	$2.52_{(127)}^{*}$	0.28	±	0.11
		Intercept	$198.48_{(1,117)}^{***}$	$14.09_{(127)}^{***}$	1.54	±	0.11
Distance to Nearest Impervious (m)	logistic$_{(83\%)}$	Town*Decade[d]	$9.88_{(3)}^{*}$				
		Project Type-R[d]	$35.29_{(5)}^{***}$				
	gls	T_Robin	$7.51_{(3,111)}^{**}$	$1.85_{(114)}^{\bullet}$	2.92	±	1.58
		T_Teal		$-4.69_{(114)}^{***}$	-6.24	±	1.33
		Intercept	$278.39_{(1,111)}^{***}$	$16.68_{(114)}^{***}$	14.90	±	0.89
Disturbance Edge Density (m/ha)	gls	T_Lark*Decade	$3.53_{(3,92)}^{*}$	$-1.77_{(103)}^{\bullet}$	-0.09	±	0.05
		T_Gannet*Decade		$2.41_{(103)}^{*}$	0.14	±	0.06
		T_Teal*Decade		$-1.75_{(103)}^{\bullet}$	-0.12	±	0.07
		T_Lark	$7.07_{(3,92)}^{**}$	$3.38_{(103)}^{*}$	0.14	±	0.04
		T_Gannet		$-3.03_{(103)}^{*}$	-0.13	±	0.04
		PT-R_SFHComb	$5.72_{(4,92)}^{**}$	$-4.36_{(103)}^{***}$	-0.18	±	0.04
		PT-R_SFHaccessory		$-2.84_{(103)}^{*}$	-0.12	±	0.04
		PT-R_SubdivisionComb		$1.74_{(103)}^{\bullet}$	0.11	±	0.06
		Intercept	$2038.75_{(1,92)}^{***}$	$45.15_{(103)}^{***}$	1.46	±	0.03
Impervious Edge Density (m/ha)	gls	T_Lark*Decade	$4.75_{(3,82)}^{*}$	$-3.50_{(93)}^{**}$	-0.23	±	0.07
		T_Lark	$3.78_{(3,82)}^{*}$	$3.01_{(93)}^{*}$	0.17	±	0.06
		T_Robin		$-1.67_{(93)}^{\bullet}$	-0.08	±	0.05
		T_Teal		$-1.81_{(93)}^{\bullet}$	-0.08	±	0.05
		PT-R_Commercial	$15.21_{(4,82)}^{***}$	$3.90_{(93)}^{**}$	0.17	±	0.04
		PT-R_SFHComb		$-5.46_{(93)}^{***}$	-0.19	±	0.03
		PT-R_SFHaccessory		$-5.81_{(93)}^{***}$	-0.22	±	0.04
		PT-R_SubdivisionComb		$2.79_{(93)}^{*}$	0.15	±	0.06
		Intercept	$2121.53_{(1,82)}^{***}$	$46.06_{(93)}^{***}$	1.39	±	0.03

Table 3.5 continued.

Disturbance Correlation Length (m)	gls	PT-R_Commercial	$36.19_{(4,99)}^{***}$	$1.89_{(103)}^{\bullet}$	0.11	±	0.06
		PT-R_SFHComb		$-3.67_{(103)}^{**}$	-0.09	±	0.03
		PT-R_SFHaccessory		$-10.66_{(103)}^{***}$	-0.31	±	0.03
		PT-R_SubdivisionComb		$6.56_{(103)}^{***}$	0.31	±	0.05
		Intercept	$6097.04_{(1,99)}^{***}$	$78.08_{(103)}^{***}$	1.77	±	0.02
Impervious Correlation Length (m)	gls	T_Robin*Decade	$4.69_{(3,82)}^{*}$	$3.40_{(93)}^{*}$	0.15	±	0.04
		T_Teal*Decade		$-2.11_{(93)}^{*}$	-0.09	±	0.04
		T_Robin	$6.88_{(3,82)}^{**}$	$-3.69_{(93)}^{**}$	-0.12	±	0.03
		T_Teal		$2.63_{(93)}^{*}$	0.10	±	0.04
		PT_SFHComb	$27.62_{(4,82)}^{***}$	$-2.98_{(93)}^{*}$	-0.07	±	0.02
		PT_SFHaccessory		$-8.71_{(93)}^{***}$	-0.24	±	0.03
		PT_SubdivisionComb		$6.53_{(93)}^{***}$	0.20	±	0.03
		Intercept	$3534.70_{(1,82)}^{***}$	$59.45_{(93)}^{***}$	1.54	±	0.03
Permanent Inter-Wetland Barrier	$\text{logistic}_{(75\%)}$	T_Robin	$10.27_{(3)}^{*}$	-2.85^{*}	-0.95	±	0.33
		T_Teal		$1.74^{\bullet}$	0.60	±	0.35
		Decade	$3.47_{(1)}^{\bullet}$	$1.85^{\bullet}$	0.71	±	0.38
		Project Type-R[d]	$47.01_{(7)}^{***}$				
Total Created Wetland (m^2)	$\text{logistic}_{(88\%)}$	T_Lark	$19.11_{(3)}^{***}$	2.06^{*}	1.90	±	0.92
		T_Robin		2.72^{*}	2.59	±	0.95
		T_Gannet		-1.97^{*}	-2.12	±	1.08
		T_Teal		-2.29^{*}	-2.36	±	1.03
		Project Type-R[d]	$10.17_{(3)}^{*}$				

[a] Percent of cases correctly classified by the logistic model.

[b] "T" and "T-R" = Town and Town-Reduced, respectively. I used Town-Reduced as a predictor where I had to exclude Lark from the analysis due to a lack of cases for Lark. I compared the towns using deviation contrasts.

[c] "PT" and "PT-R" = Project Type and Project Type-Reduced, respectively. I used Project-Type-Reduced where I had to condense Project Type categories because of data quasi-separation. I compared project types using deviation contrasts.

[d] Persistent quasi-separation of the data for this predictor. Overall predictor p values are reliable, but estimated coefficients and standard errors are unreliable. Thus, I do not list coefficients and standard errors for this predictor.

[e] Dummy variable. Coded: 0 = 1990s and 1 = 2000s.

[f] Subdivision = conventional subdivision; SubdivisionRoad = subdivision road and associated grading only; SubdivisionRoad+ = subdivision road, associated grading, and associated stormwater facilities only; SubdivisionComb = Subdivision, SubdivisionRoad, and SubdivisionRoad+ combined.

[g] Assorted = miscellaneous projects (e.g., utility work; beach replenishment).

[h] SFH = stand-alone single-family house; SFHsubdivision = SFH within a subdivision; SFHComb = SFH and SFHsubdivision combined.

[i] SFHaccessory = projects accessory to a SFH, includes driveways where I had insufficient cases to use Driveway as an independent category.

[j] Results from the X^2 or F test (for the logistic and gls regressions, respectively) assessing overall significance of each variable. Results provided just once for each categorical variable.

[k] Results from the z or t test (for the logistic and gls regressions, respectively), used to determine significance of individuals dummy variable coefficients.

[l] Coefficients are for transformed variables, where applicable. See Table 3.1.

• $0.05 \leq p < 0.1$

* $p < 0.05$

** $p < 0.001$

*** $p < 0.0001$

Table 3.6. Multinomial regression results detailing differences in project-type frequency across towns and decades. Coefficients are log odds ratios, with septic projects as the reference project type. Only significant results are shown.

	$X^2_{(df)}$
Town	$87.26_{(24)}^{***}$
Decade	$17.14_{(8)}^{*}$

Project Type	**T_Lark**			**T_Robin**			**T_Gannet**			**T_Teal**			**Decade**			**Intercept**		
	Coef.	**±**	**SE**	**Coef.**	**±**	**SE**	**Coef.**	**±**	**SE**	**Coef.**	**±**	**SE**	**Coef.**	**±**	**SE**	**Coef.**	**±**	**SE**
Commercial	2.8^{***}	±	0.8	-		-	4.8^{***}	±	0.6	4.1^{***}	±	0.7	-		-	-4.6^{***}	±	0.58
Assorted	3.1^{***}	±	0.8	-		-	4.8^{***}	±	0.6	3.5^{***}	±	0.8	-2.4^{*}	±	1.2	-4.5^{***}	±	0.57
SFHsubdivision	-		-	1.9^{**}	±	0.6	-1.9^{***}	±	0.6	-		-	-		-	0.9^{*}	±	0.43
SubdivisionComb	-2.2^{**}	±	0.8	1.5^{*}	±	0.7	-		-	1.1^{*}	±	0.5	-		-	-		-

* $p < 0.05$
** $p < 0.001$
*** $p < 0.0001$

Table 3.7. Property-rights ethics across case towns.

Observed property ethics	**Description**	**Lark**	**Robin**	**Teal**	**Gannet**
autonomy	landowner totally controls land-use; includes libertarians	√*	√	√*	√*
autonomous conservation	landowner pursues permanent conservation as personally preferred land-use				√
autonomous stewardship	landowner pursues land stewardship as personally preferred land-use			√	
balance	stakeholders value and try to balance private autonomy and environmental conservation		√*		
economic balance	landowner uses land to reap its economic investment value	√*	√	√	√
economic balance + environmental bias	stakeholders recognize land investment value, but are somewhat biased towards wetland protection	√			
necessary ill	stakeholders recognize the social benefits of environmental regulations and tolerate restrictions despite autonomy preference			√*	
neighbor control	landowner controls some aspect (e.g., aesthetics) of neighbor's land		√	√	
regulatory control	regulations should limit land-use as needed to protect public welfare		√		
regulatory control: deviant	regulations should limit land-use in order to arrest development	√			√
social obligation	landowners accept limitations on land-use to protect public welfare	√	√*		
zoning autonomy	landowner controls land-use within constraints outlined in zoning code		√		
Strength of property ethics	1 = most strong; 4 = least strong	3	4	2	1
Takings influence	degree to which wetland decisions are influenced by the potential for takings litigation; 1 = most strong; 4 = least strong	3	4	2	3

Notes: √ = property ethic observed in town; * = dominant property ethic in town.

Table 3.8. Education and wealth measures[a] for case towns.

	Lark	Robin	Teal	Gannet
Education[b]				
% ≥ high-school degree	96	96	96	91
% ≥ bachelor's degree	35	48	37	23
Wealth				
% unemployed	7.5	5.0	5.0	11.0
% poverty	6.0	3.0	5.0	16.0
Median household income 1999	$56,000	$87,000	$69,000	$50,000
mean: 2008-2012	$82,000	$109,000	$108,000	$69,000

[a] Data are rounded to obscure town identity.

[b] Data are from the following source: U.S. Census Bureau; generated by J. Veysey Powell; using American FactFinder; <http://factfinder2.census.gov>; (4 April 2014).

Table 3.9. Potential positive outcomes associated with wetland, construction, and permitting-specific training and outreach, as identified in each case town.

	Lark	Robin	Teal	Gannet
Knowledgeable permitting boards leads to:				
Efficient, consistent, predictable, acceptable permit-decisions.	√		√	
Unbiased, ethical permit-decisions and behavior at public hearings.	√	√	√	
More accurate and consistent enforcement.		√	√	√
Improved inter-board understanding and communication.			√	√
A knowledgeable public leads to:				
Less resistance from landowners and applicants who can anticipate the time and effort required to obtain permits.	√	√	√	√
Less animosity from developers who understand permit-policies do not prohibit wetland disturbance.				√
Better board accountability.			√	
Enhanced sense of community and town identity.		√		√
Knowledgeable boards and publics:				
Understand, value, and support wetland policies and conservation.	√	√	√	√

Table 3.10. Sampling of strategies that facilitate social and ecological effectiveness.

Factor	Strategy
communication	
site walks	• use site walks to obtain site-specific information, demonstrate commitment, build relationships, and educate and communicate with stakeholders
inter-board	• use joint-board meetings to coordinate and share information • seek CC input early in the planning process • mandate CC review of building, planning, and zoning permits • use cross-board technical review committees • institute training on the purpose and policies of other town boards
extra-hearing	• encourage extra-hearing meetings where abutters, applicants, and other stakeholders iron out differences and work towards mutual interests
public relations	• cultivate public-relation skills among board members and staff; project a helpful, reasonable, caring attitude • target key landowners with interpersonal communication • develop a strategy for communicating conservation initiatives to the public; make strategy implementation a priority
organizational field	• network with relevant non-profit organizations and government agencies to gain access to novel funding, education, support, and facilitative services
capacity	
board training	• require mandatory training in wetland ecology, land-use planning, communication, and stormwater management; contact the state Association of Conservation Commissions and similar organizations for training opportunities • encourage training in meeting management and governance ethics • seek to populate boards with complementary expertise, including in ecology, planning, engineering, communications, and land conservation
social capital	• build relationships across social groups to understand community interests, enhance political power, and improve permitting efficiency
longevity	• encourage longevity among informed, capable board members, but discourage longevity among ignorant, politically-motivated, or non-participative members: used well, longevity enhances institutional memory and builds credibility
education	
novel educators	• train real-estate agents to inform prospective buyers about on-site wetlands and wetland-permits, and to describe wetlands as positive amenities that provide ecosystem services
public databases	• create a national database of exemplary development projects, including both positive and negative examples of work near wetlands and examples of current and novel stormwater technologies (to be used as a reference for regulators, developers, and other stakeholders) • create databases of community GIS layers, including parcel maps, environmental features, infrastructure, and proposed/permitted projects (to increase accessibility and efficiency of information-sharing; can be state or community-sponsored) • create database of land-use-permit applications, inclusive of federal, state, and local permits; should include both application forms and completed applications (to enhance efficiency of permit application and review) • create state websites documenting road-kill locations for wetland-dependent wildlife species (to be used in determining mortality hotspots and designing policies to enhance wildlife connectivity)
outreach	• target developers and landowners • address wetland ecology, land-use policies, conservation options, and the link between conservation and lower taxes • use exposure to nature and examples of different development projects to engender care for the environment and an understanding that wetland policies condition, but don't prohibit development • explain hearing process at the start of public meetings to level stakeholder expectations

Table 3.10 continued.	
structure	
board agents	• hire a conservation agent to improve communication between the conservation commission and the public, enhance conservation outreach, and improve enforcement • hire a town planner to improve the efficiency and technical basis of planning board reviews, hold pre-hearing meetings with applicants, and mediate interactions between the planning board and applicants • require that agents and town planners be trained in wetland science and land-use policies • have an advocate available to guide citizens through the permit process and provide them with unbiased information about their rights and potential courses of action • use a regional agent/planner/advocate to save costs to any individual town
liaisons	• formalize inter-board liaison positions to enhance communication and increase prominence of conservation interests
sub-committees	• use sub-committees to focus attention and human capital on particular subjects, especially technical permit review and conservation planning
physical proximity	• have conservation, planning, zoning, and/or board of health staff share office space to enhance inter-board communication • have a local land-trust representative attend land-use hearings to facilitate early conversations about permanent land conservation with project applicants
code enforcement officer	• hire two code enforcement officers: one who enforces environmental policies and a second who enforces building code matters (e.g., electrical) • consider a code-enforcement board, instead of a single officer, to reduce any subjectivity associated with enforcement • use the enforcement officer for wetlands enforcement, to minimize animosity towards the boards making wetland-permit and policy decisions
tactics	
town identity	• strategically build a town identity around preserving the town's rural character, which is a broadly-appealing objective • appoint/elect board members who support this strategy • institute strict zoning and wetland bylaws as early as possible to support this rural norm • market this identity to businesses and homeowners who value natural amenities
land conservation	• pursue permanent land conservation as a relatively apolitical path to wetland conservation • focus on exposure to nature as a recruiting technique • use open-space subdivisions to connect conserved parcels
open-space subdivisions	• use conservation subdivisions to achieve multiple goals, including: protecting sensitive environmental features, retaining significant design authority and economic return for the landowner, and consolidating remaining open-space under one landowner • promote open-space subdivisions as part of the municipal communications strategy
implementation	
be reasonable	• do not use wetland policies as an anti-development tool • work with applicants to meet mutual interests
inter-personal	• to develop trust with the regulated community: pursue face-to-face interactions whenever possible; and strive to be accessible, empathetic, and honest
options + autonomy	• to encourage compliance and buy-in, do not deny permits outright; instead outline several equally acceptable permit conditions and allow regulated party to choose between the alternatives
enforcement	• do not rely on deed restrictions; place sensitive lands under conservation easement, held by a third party, where possible
authority	
CC authority	• increase the authority of conservation commissions to enhance enforcement and ecological effectiveness • facilitate early and continuous expression of conservation interests during the project-design process

Table 3.10 continued.	
PB authority	• divest planning boards of economic-development responsibilities, to avoid conflicts of interest with their conservation duties
courage to deny	• do not be afraid to deny permits for projects that fail to meet legally established standards
benevolent dictator	• work with, rather than against, opposing interest groups; prioritize mutual interests and community well-being

Figure 3.1. Predicted odds that a construction project would disturb wetlands, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

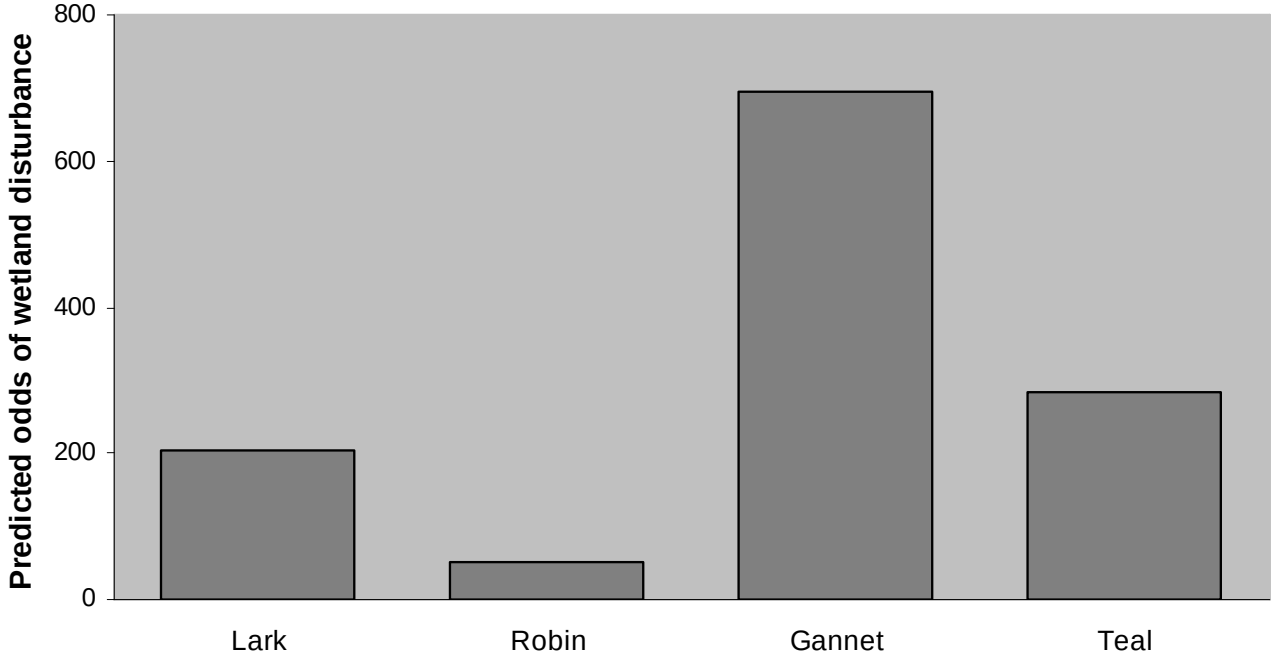


Figure 3.2. Per-project mean (±1SE) area of permanently disturbed wetland, for those projects where wetlands were disturbed, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

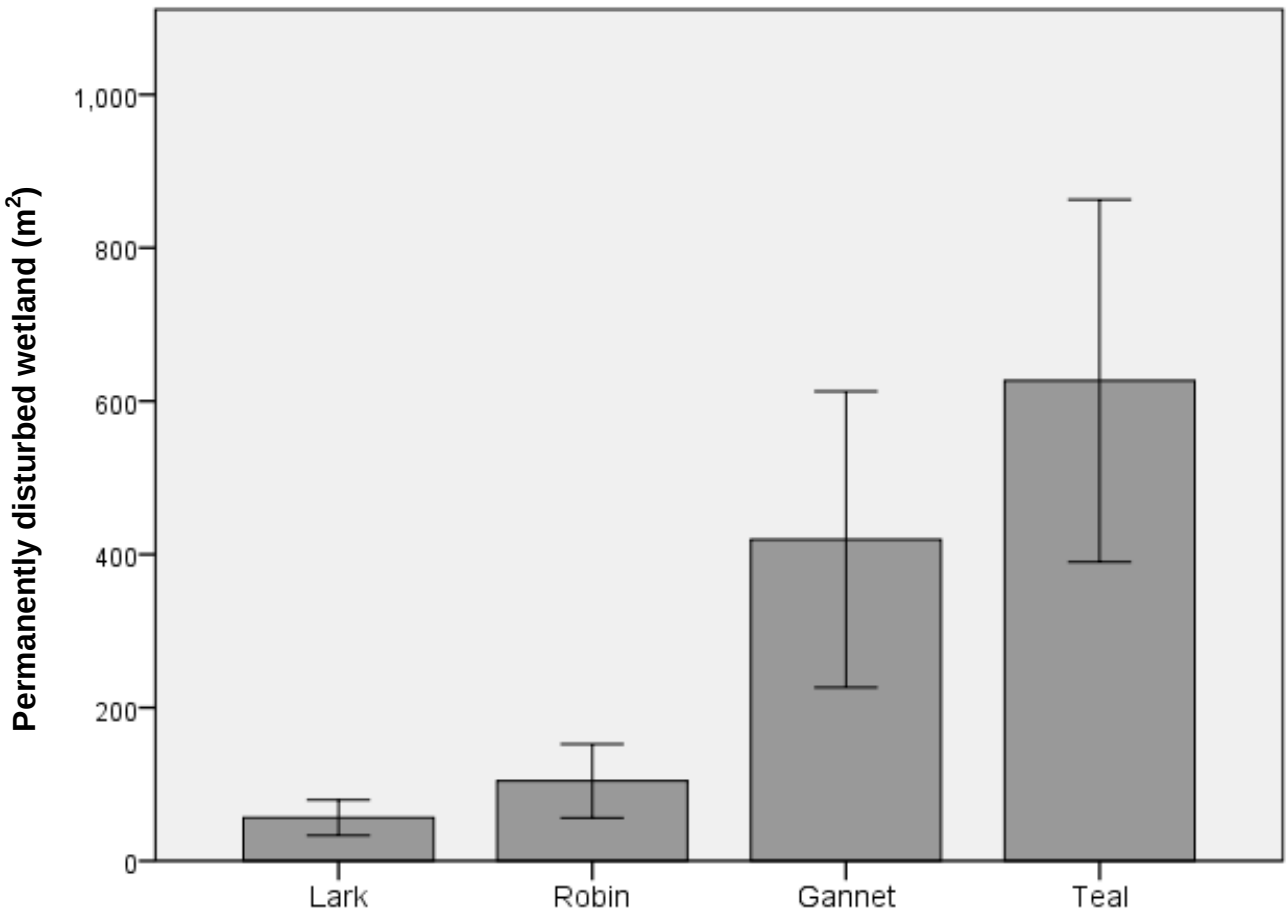


Figure 3.3. Per-project mean (±1SE) total area of impervious surface located in wetlands, for those projects with impervious surface in wetlands, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

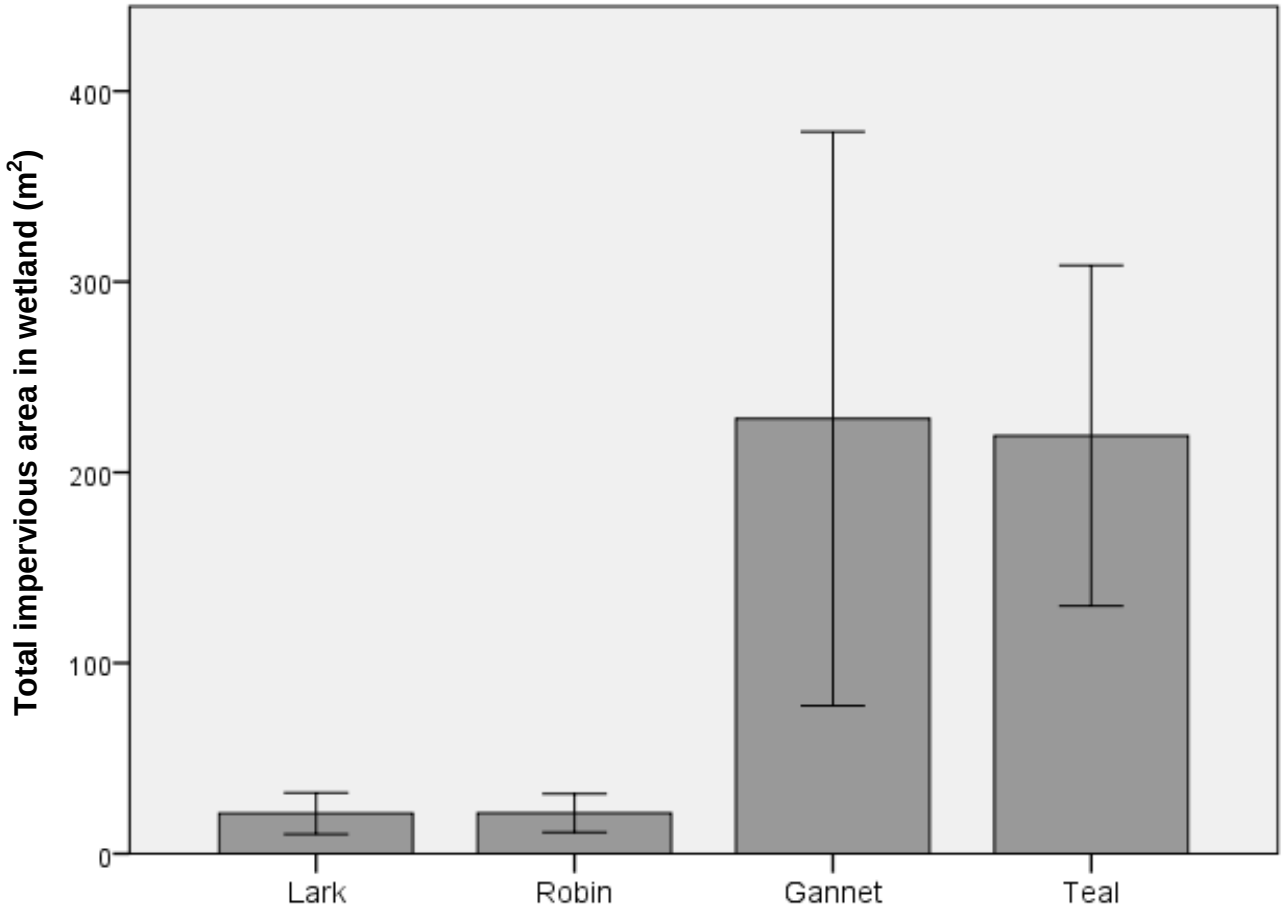


Figure 3.4. Per-project mean (±1SE) of the fourth-root of disturbed area in the 30m buffer, for two Massachusetts and two New Hampshire exurban towns, in the 1990s versus the 2000s.

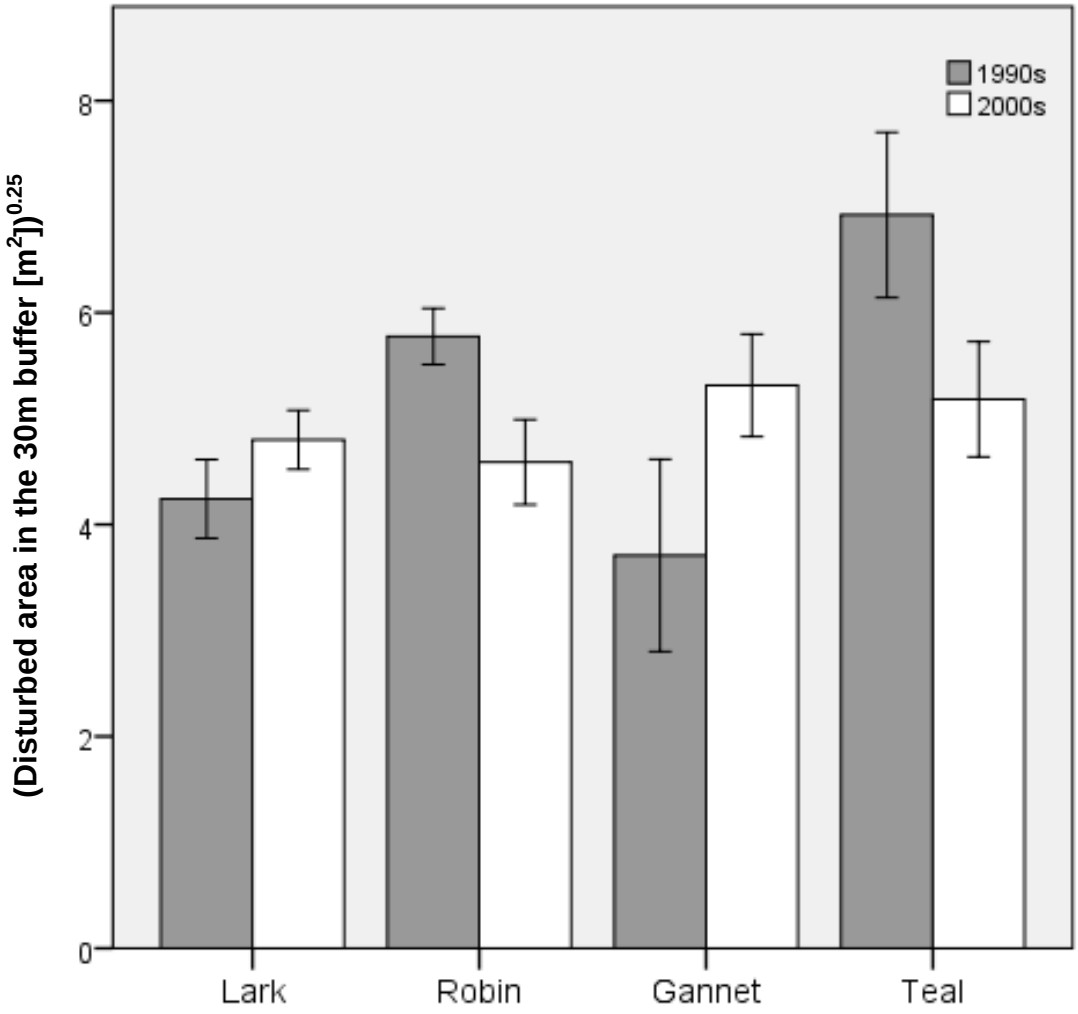


Figure 3.5. Mean (±1SE) percent of the 30m buffer disturbed per project, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

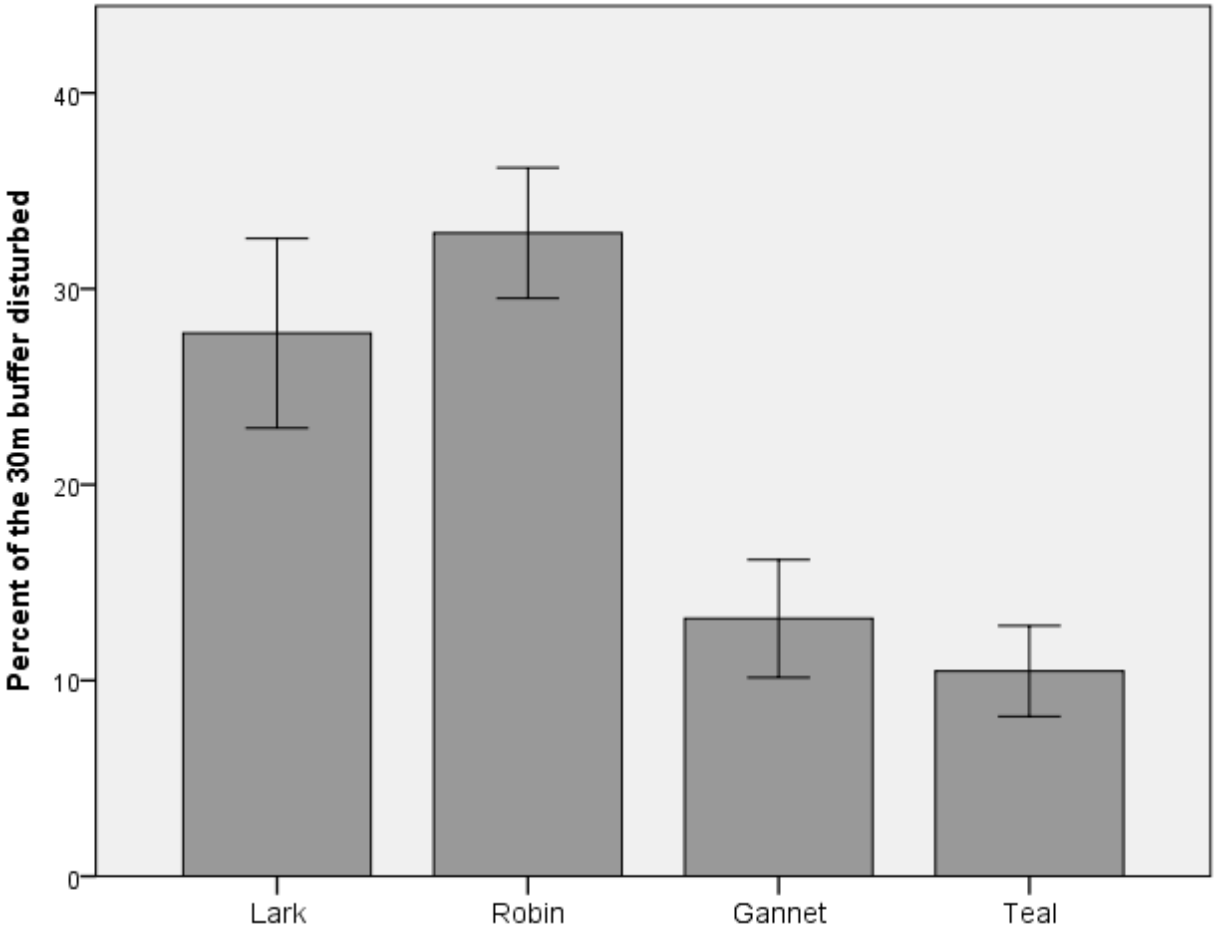


Figure 3.6. Predicted odds that a construction project would create new impervious area in the 30m buffer, in two Massachusetts and two New Hampshire exurban towns, in the 1990s versus the 2000s.

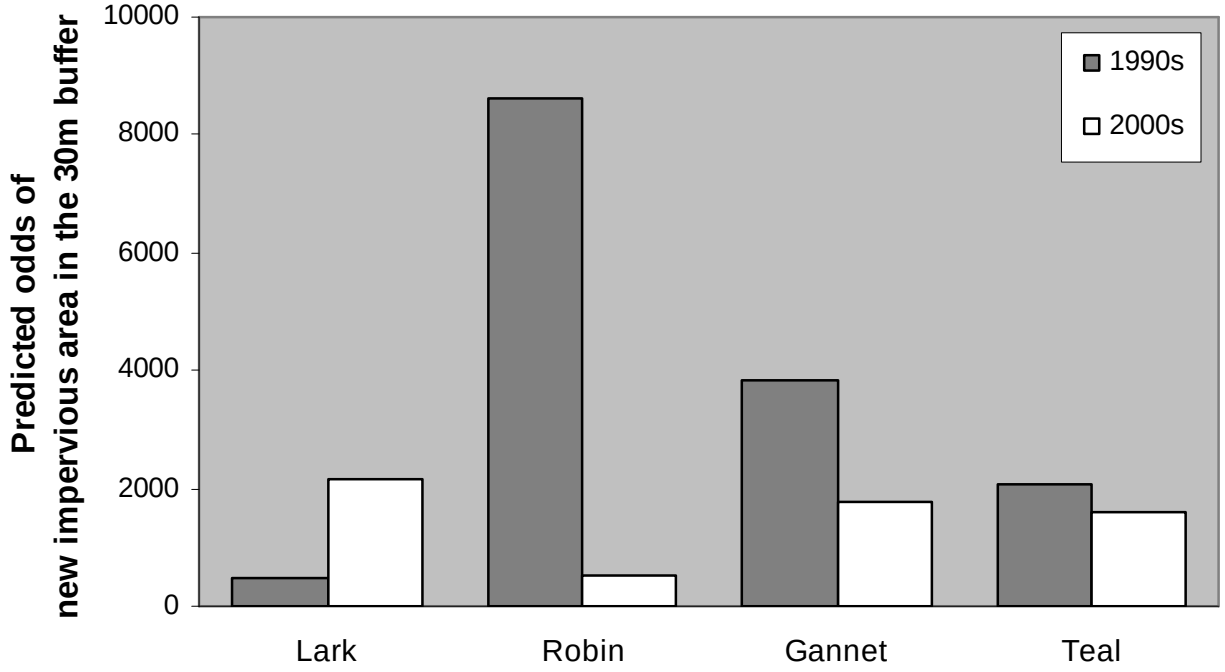


Figure 3.7. Per-project mean (±1SE) area of new impervious surface in the 30m buffer, for projects with new impervious surfaces in the 30m buffer, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

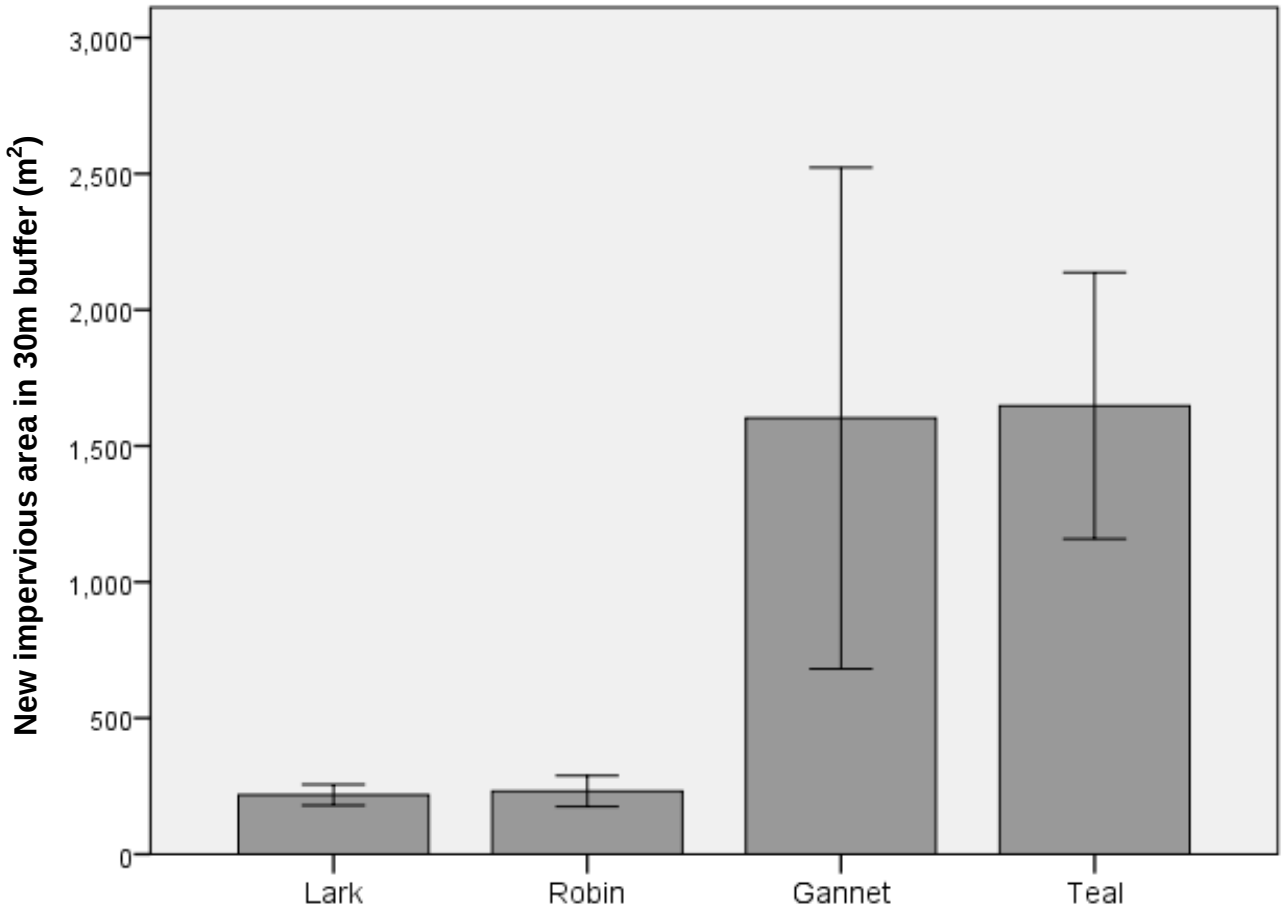


Figure 3.8. Per-project mean (±1SE) of disturbed area in the 400m buffer, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

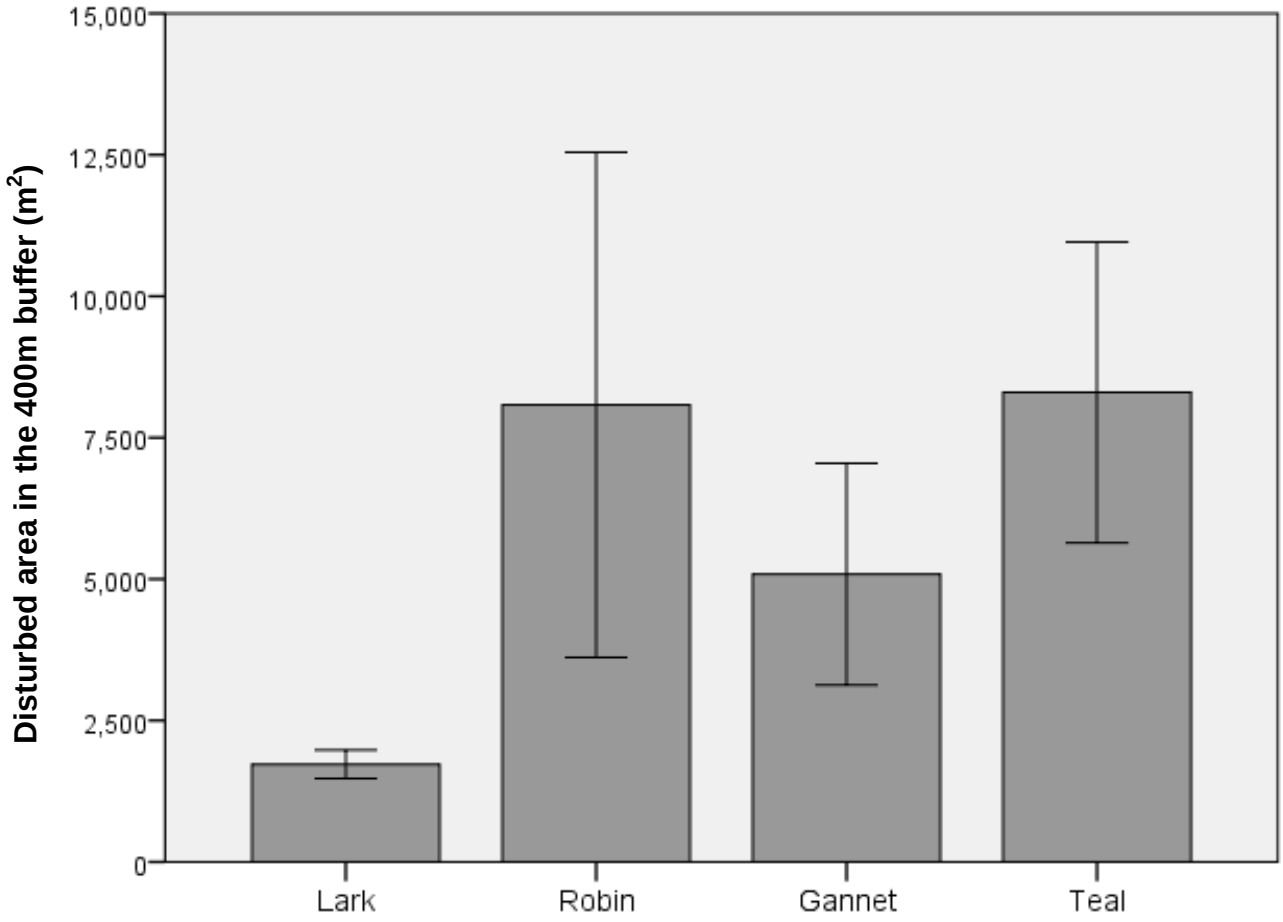


Figure 3.9. Per-project mean (±1SE) of (ln (total impervious area in the 400m buffer)+1), for projects with impervious surface in the 400m buffer, in two Massachusetts and two New Hampshire exurban towns, in the 1990s versus the 2000s.

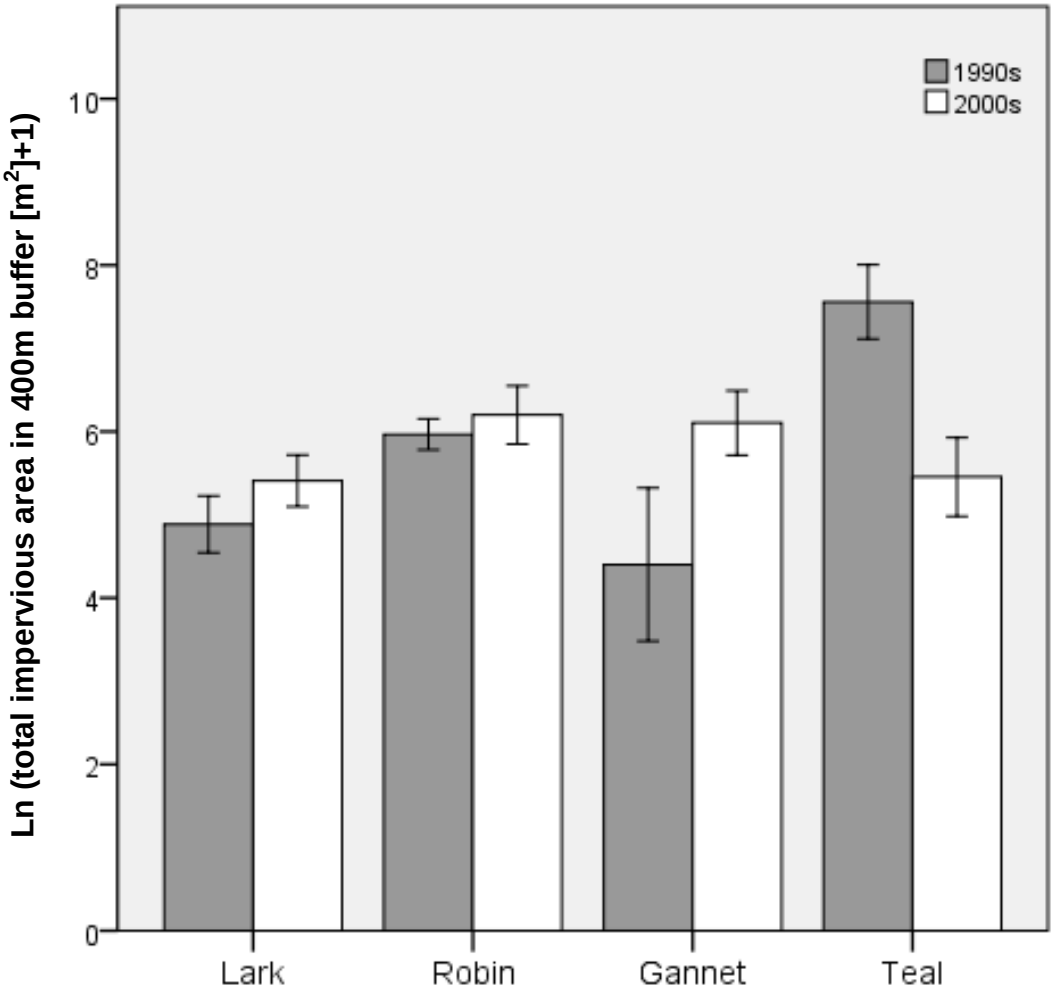


Figure 3.10. Predicted odds that a construction project would be set-back from the wetlands, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

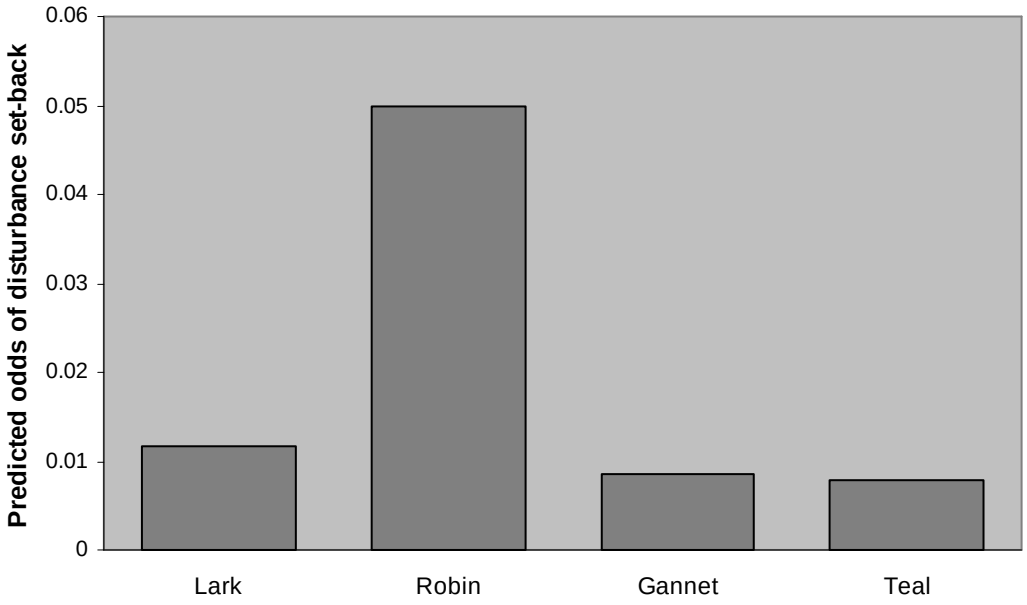


Figure 3.11. Mean (±1SE) project buffer width for those projects that buffered wetlands against disturbance, in two Massachusetts and two New Hampshire exurban towns, in the 1990s versus the 2000s.

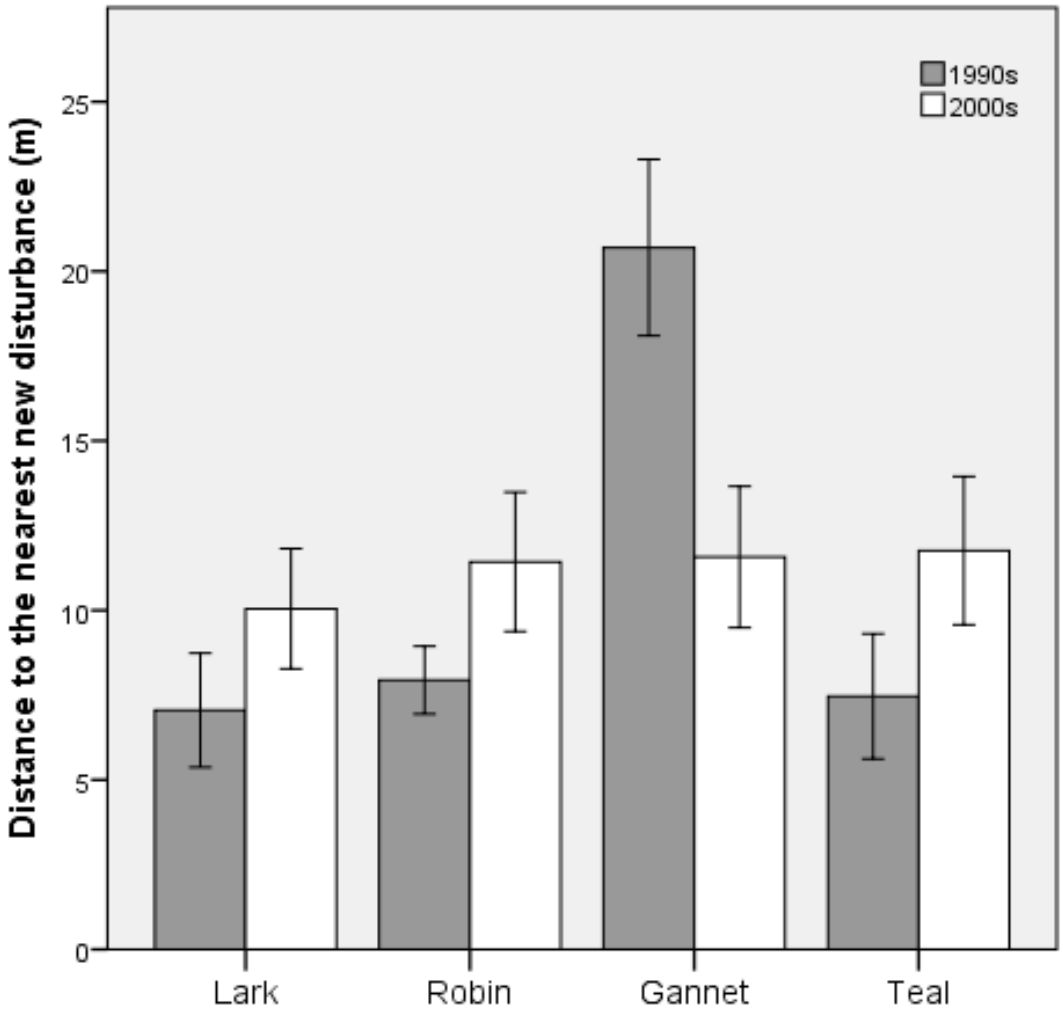


Figure 3.12. Mean (±1SE) project buffer width for those projects that buffered wetlands against new impervious surfaces, in two Massachusetts and two New Hampshire exurban towns, between 1990 and 2011.

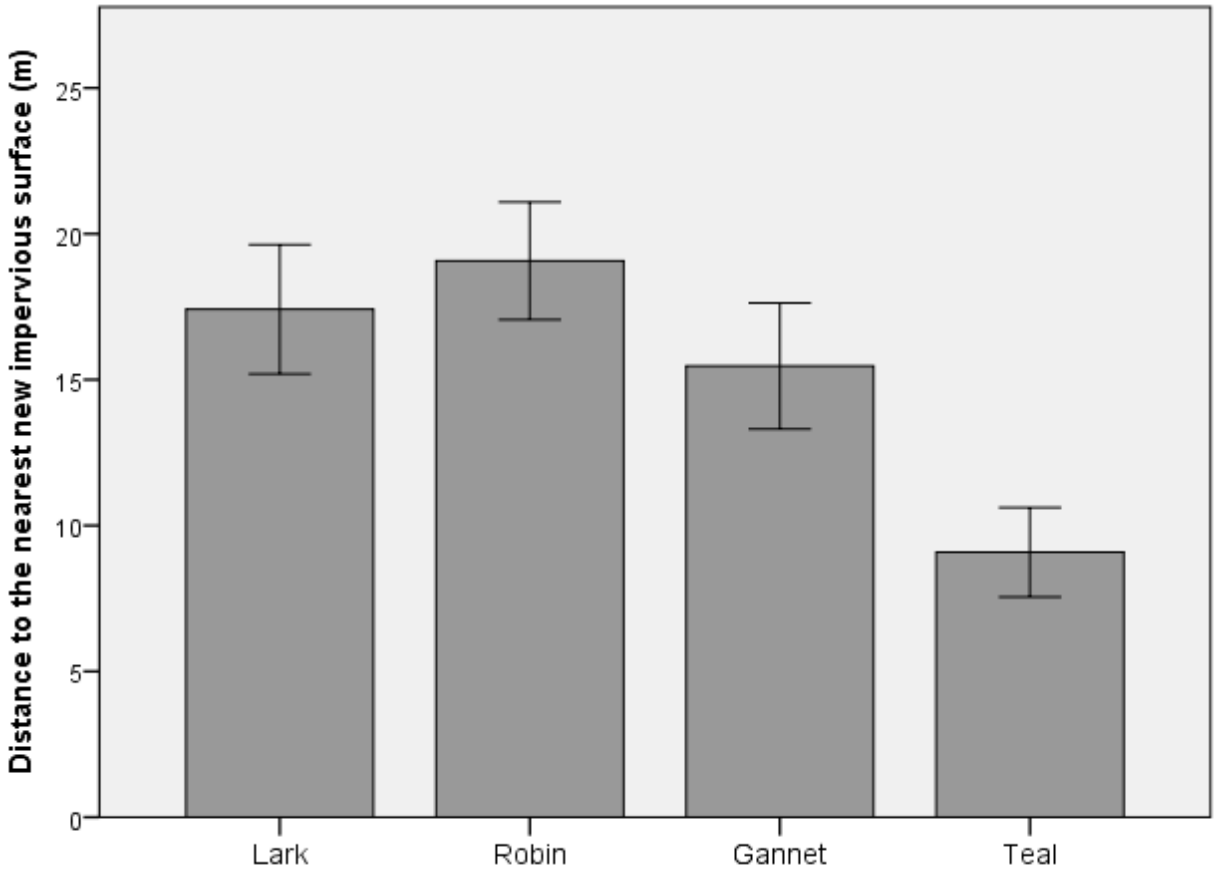


Figure 3.13. Mean (±1SE) per-project area of total impervious surface in wetlands, for those projects with impervious surface in wetlands, in the 1990s versus the 2000s, across the four case towns.

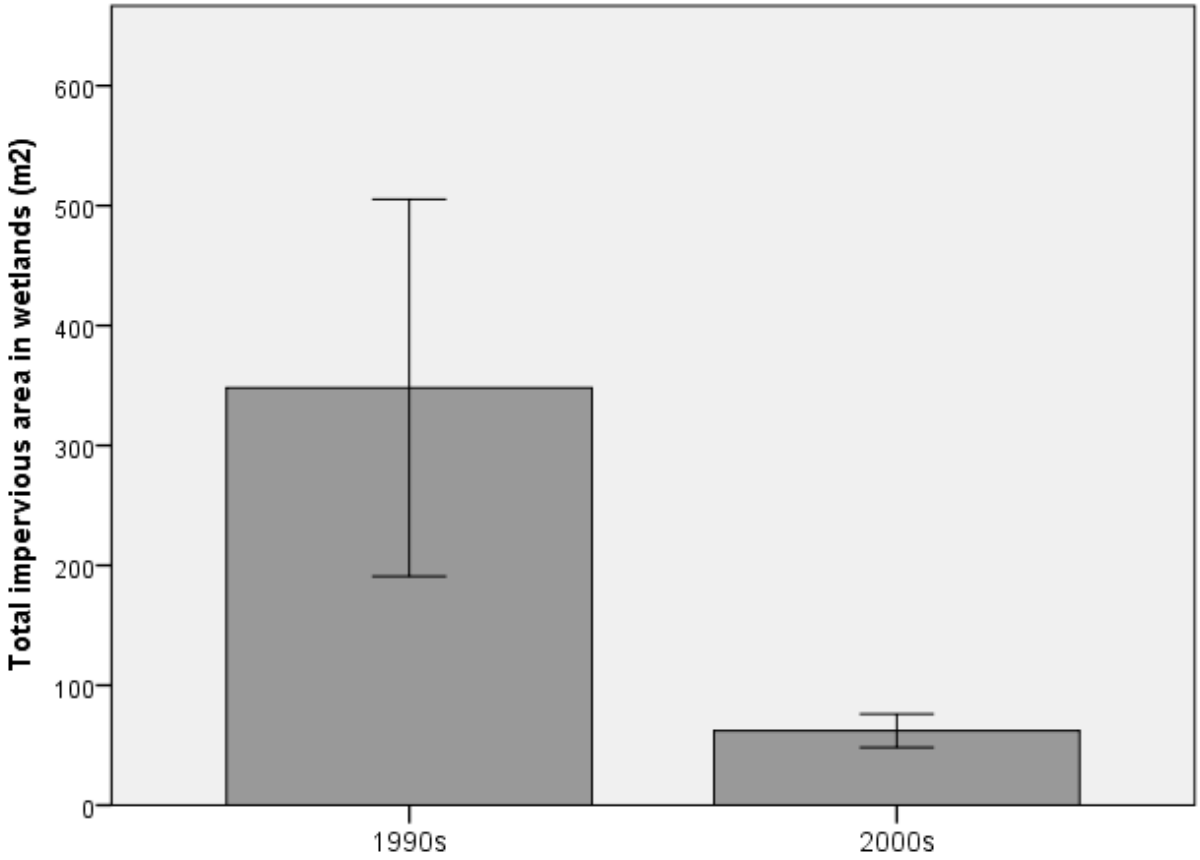
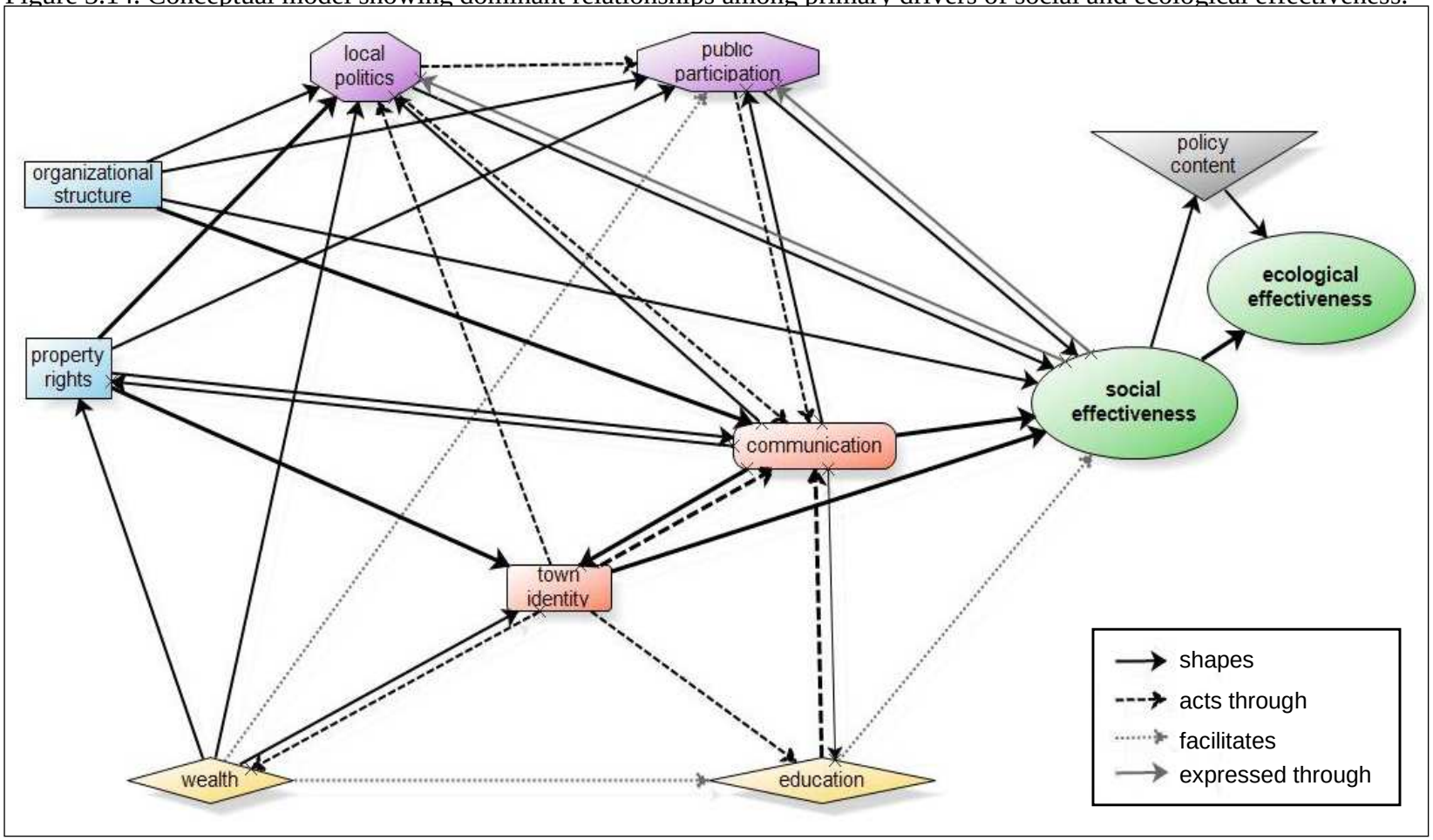


Figure 3.14. Conceptual model showing dominant relationships among primary drivers of social and ecological effectiveness.



CHAPTER 4

SYNTHESIS

Rationale

Since the mid-1970s, buffers have emerged as a preferred tool for protecting wetlands. Massachusetts was an early adopter, instituting a state-wide jurisdictional buffer in 1983. Slowly, many northeastern towns followed suit (Meyer and Konisky 2007a; Sims and Schuetz 2009). Capitalizing on the rising popularity of decentralized governance, towns viewed buffers as a simple tool that could enhance and guarantee strong local wetland protection (Denters and Rose 2005b; Meyer and Konisky 2007a). Many pushed for wider buffers than required under state and federal law, citing wildlife-habitat needs as a primary reason (Meyer and Konisky 2007a; Sims and Schuetz 2009). The buffer trend seemed well-founded in scientific evidence. Research from this period showed that buffers effectively protected wetland water quality (Castelle et al. 1994; Broadmeadow 2004; Mayer et al. 2007) and provided vital habitat to some wetland-dependent wildlife species (Semlitsch and Bodie 2003; Veysey et al. 2009; Marczak et al. 2010). Research further demonstrated that towns had smaller disturbances in wetlands and adjacent uplands when they had local buffers in place (Meyer and Konisky 2007b). But important research gaps remained, undermining arguments for wide wildlife buffers. Foremost were questions about how narrow buffers could be without causing irreparable harm to wildlife populations. It was also unclear why, among towns with buffers, there was still such variability in the amount of disturbance to wetland ecosystems. As conflict over the legal and moral grounds of restricting land-use in upland buffers mounted, questions about the social sustainability of buffers also arose. Despite buffers' popularity, many states and towns refrained from implementing regulatory

buffers and even shied away from voluntary buffers in policies like forestry best management practices.

Summary

This study helps fill these gaps, extending empirical knowledge about the functional, geographic, and social implications of wetland buffers. This study is unique because it probes both the ecological and social effectiveness (EE and SE) of a locally-implemented environmental policy tool. I pursued these objectives with a two-part design. First, I used a landscape-scale experiment to examine the effects of differential buffer widths on adult amphibian demography[1]. I conducted this research in a working forest in rural New England, where wetland protection was principally governed by voluntary forestry best management practices. Second, I used case-study methods to compare the EE and SE of municipal wetland programs in four exurban New England towns. The experimental work demonstrates how two wetland-dependent wildlife species react to buffered disturbance in a relatively unfragmented, naturalistic landscape. It thus provides a baseline for expectations about wildlife impacts, which could reasonably be expected to increase in severity as land-use and landscape fragmentation intensify. The case-study work builds on the experiment, showing how social interactions influence the content, evolution, and actual outcomes of buffer policies in an exurban setting, where land development and conservation vie for control of a fragmenting landscape.

The buffer experiment showed that disturbance near wetlands can have strong, negative, sublethal effects on wetland-dependent amphibians, but that wider buffers mitigate the severity

[1] The experimental results presented in my dissertation are but one piece of a much larger project to which many individuals contributed. To simplify this chapter, however, I use a first-person, singular narrative throughout.

and duration of impacts. Adult spotted salamanders and wood frogs were generally smaller, had lower energy reserves, produced less biomass, and were recaptured in fewer numbers at vernal pools with the narrower 30-m buffers than at pools with 100-m buffers or undisturbed pools. Some of these metrics recovered during the decade following disturbance, but other metrics persisted or worsened. I did observe some negative impacts at 100m pools. For instance, female salamanders were less abundant over time at both the 100m and 30m treatments. Also, hydrologically stressed 100m pools produced less biomass and fewer salamanders than 100m pools with longer hydroperiods. Overall, these results suggest that 30-m buffers may not be wide enough to maintain resilient populations of these two amphibian species in a forestry context. Though total abundance was not reduced at the 30m pools, the sublethal effects likely weakened the 30m populations' ability to resist or recover from additional stressors that might arise, like disease or development. By contrast, 100-m buffers seem sufficiently wide in a forestry setting, except where wetland hydroperiod is particularly short.

The case-study research showed that wetland-ecosystem disturbance varied significantly across the exurban towns and was principally a function of social effectiveness and policy content. SE was driven by multiple interacting factors, with no single SE prescription fitting all towns. Nevertheless, eight core drivers strongly influenced SE. Having a conservation-based town identity and being able to communicate about wetland permitting were key factors driving positive SE. Property-rights and town organizational structure were critical contextual factors that shaped stakeholder attitudes about wetland-permitting. Education and wealth enabled, but were not essential to, positive SE. Finally, stakeholders used public participation and local politics as tools to express SE, thus shaping wetland decisions. The case towns indicate that local control, founded on a wetland-buffer policy, can effectively protect the spatial extent of wetlands

if the necessary social factors are aligned. When social factors do not align, however, stakeholder malcontent can weaken EE and destabilize social relations.

Wetland buffers embodied this interactive EE-SE relationship. Wider buffers were generally correlated with better EE, but not always. Some of the widest buffers were not fully implemented because decision-makers were intimidated or influenced by stakeholder opposition. Notably, even the largest municipal buffers were smaller than 100-m wide. In fact, only two buffers were greater than 30 m and both were limited in scope; these included: a 76-m buffer for hazardous materials and snow stockpiles and a 46-m natural-vegetation buffer (with some cutting allowed), which was frequently ignored in practice. Otherwise, buffers ranged from 8 to 30-m wide and usually allowed some disturbance. If I interpret these results in light of my experimental work, I might conclude that, while local buffer programs can protect wetlands' spatial extent and likely even water quality, these programs are probably less effective at supporting resilient populations of wetland-dependent amphibians and other similar species.

The case-study results also highlight a more fundamental weakness of buffer policies. Robin consistently buffered wetlands against disturbances, kept impervious areas farthest from wetlands, and successfully reduced the size of permitted impacts in the 30m buffer from the 1990s to the 2000s. In effect, Robin increased its actual buffer width over time. There is, however, an inherent trade-off to buffer enlargement. In fortifying the practical strength of its 30-m buffer, Robin allowed greater impacts in its 400-m buffer and less compact projects overall. Thus, wider buffers may benefit wetland communities and proximate wildlife habitat (i.e., within 30 m), but come at a cost to upland habitat generally and may result in sprawling development. This suggests that buffers need to be part of a larger landscape-management strategy which includes tactics that address wildlife connectivity across upland patches.

Significance

This research is valuable for theoretical and practical reasons that encompass, but also extend beyond, the wetland-buffer debate. Theoretically, the case-study work advances understanding of decentralized environmental structures generally and local regulatory processes in particular. It is one of the first studies to analyze both the social and ecological effectiveness of a decentralized environmental structure and to show how these two measures interact. Previous research in this field focused on the social benefits of collaborative watershed governance and assumed that when stakeholders were satisfied with a collaborative process, ecological benefits would follow (Lubell et al. 2005). I found that SE and EE were often positively correlated, but this pattern was not universal. I also found that public participation, a foundational component of collaborative processes, was often used to sabotage attempts to improve EE in the local regulatory programs. More generally, SE was a main driver of EE. This point is an important contribution of my work, especially because it means that decision-makers in local regulatory regimes may not easily achieve environmental goals if stakeholders are dissatisfied.

This research is even more useful from a practical perspective. The amphibian work is the first landscape-scale experiment to test how buffers of different widths affect the demographic responses of vernal-pool-dependent species to upland disturbance. This experiment provides empirical data on two buffer widths that complement and help refine the management recommendations of previous observational and modeling research. These data can most readily be used to update forestry policies, but also inform expectations about how these species might respond to buffered disturbances in more developed landscapes.

The case-study work is also highly applied. I present a number of strategies and policy changes that towns and other stakeholders could use to improve the SE and EE of municipal wetland programs. Some recommendations are simple and could be instituted immediately. Others require time to incubate and implement. Many support cultivation of town identity and communication: the two factors I identified as most important to achieving positive SE. For instance, I recommend that towns build support for wetland conservation by framing their recruiting message in terms of preserving their town's rural character because rurality appeals to a broader swath of stakeholders than do wetlands alone. This same logic could be applied to a region, instead of just one town. I also suggest structural changes that support improved communication, including: requiring liaisons between the conservation commission and planning board; investing in a conservation agent, town planner, or environmental code enforcement officer; encouraging joint-board meetings; and mandating early conservation input during project-planning. Other recommendations, such as encouraging extra-hearing meetings between stakeholders, are meant to build relationships and mutual understanding, and sometimes respect for nature, as with site walks.

My research is not just useful to towns, but also suggests steps that state and federal environmental agencies and non-profit groups might take to support local wetland programs. For instance, I recommend mandatory training in wetland science, permitting procedure, landscape planning, and communication for conservation, planning, and (in New Hampshire) zoning board members. Such training would nurture skills that local officials need to produce scientifically sound and socially acceptable wetland decisions. State and federal agencies or non-profit groups could be critical partners in executing this recommendation. These entities could provide or coordinate such training or organize a training-certification program. Likewise, such entities

could host a website that serves as a repository for information about, and examples of, development designs, trends, and technologies. Regulators, developers, and other stakeholders could use this website as a reference or education tool, or for design inspiration.

Finally, the case-study research offers insights into how specific policy formulations and social conditions interact to either facilitate or inflame local wetland-conservation efforts. For instance, buffer policies that exceed state requirements (e.g., in width or which prohibit certain kinds of activities) are more likely to succeed in towns where citizens want to balance private and public land rights than in towns where most citizens want unfettered autonomy over their land. This example highlights the important point that policy content may need to be tailored to social context. I return to the subject of policy formulation in the final section of this chapter.

Limitations

Despite its theoretical and applied contributions, my study had some limitations and the results should be extrapolated cautiously. For the experiment, the logistical constraints inherent in a landscape-scale experiment meant I could only study two of many possible buffer widths, so I cannot precisely isolate an optimal buffer width for each species. Logistics also limited my ability to study mechanisms driving the observed negative effects. Finally, I conducted the experiment in a particular landscape on two particular species. I assume the negative effects observed in the working forest would be similar or worse in a more developed landscape where habitat connectivity is diminished, but cannot say for certain. Likewise, other species may, but do not necessarily, react similarly to clear cutting or other disturbances in upland habitat.

The municipal research was also, by design, limited in extent. The purpose of case-study research is to study a few places in depth, to discover the nuances that make a place function.

Though I found some cross-town patterns, my results may not adequately represent wetland programs in other towns, especially those outside my region (i.e., north-central Massachusetts and south-central New Hampshire) that may be subject to different economic, cultural, or ecological forces. My exurban EE assessment was also somewhat limited in scope. I analyzed two EE measures: the spatial extent of wetland-ecosystem disturbances caused by individual construction projects and key stakeholders' perceived EE. Though reliable and precise due its quantitative nature, the first metric did not measure cumulative impacts within a town or functional changes in wetland ecosystems (including changes to inter-habitat connectivity). Perceived EE encompassed cumulative, functional, and spatial impacts, but may have been biased by observer experience and values. Finally, I focused primarily on local processes and found that towns strongly shaped SE and EE, but acknowledge that state and federal programs also influence wetland ecosystems at the local scale.

Future Research

Such limitations restrict my study's inference sphere, but also provide fertile ground for future research. At a macro-level, it would be useful to know whether my results are replicable in landscapes with different amounts of fragmentation and development or types of disturbance, wetland policies, governing structures, or cultural priorities. For instance, at what point on a rural-urban gradient would one observe changes in total breeding-adult abundance with a 30-m buffer in place? When would one observe sublethal effects, like diminished size, with a 100-m buffer in place? How would stakeholders react to a 100-m buffer, given that it is wider than any current buffers in my case towns? Would the reaction be different in conservative northern New

England, where the economy is based on tourism and natural resources, versus the densely-populated, information-based economies of southern New England?

The experiment also inspires questions about species and buffer specificity. For instance, how do spotted salamanders and wood frogs react to other buffer widths? Are they umbrella species whose habitat needs encompass those of other wetland-dependent wildlife (e.g., fairy shrimp, four-toed salamanders)? How do species' responses change if disturbance is allowed in the buffer, as often occurs on construction sites? At a micro-level, it would be helpful to understand what mechanisms drive the observed buffer-treatment effects. For instance, did size reductions result from over-crowding and increased resource competition or from pool-switching, delayed breeding, or higher mortality among the largest animals? What are the effects of being chronically small? What triggers allocation between growth and reproduction? What happens to the offspring of small individuals? Do their eggmasses or metamorphs suffer in size or quality?

A natural offshoot of the municipal research is to confirm whether spatial EE is an adequate proxy for functional EE and if not, how local policy content and social interactions influence wetland-ecosystem functions, like water purification and wildlife-habitat provision. It is also important to investigate, using quantitative measures, whether the case-study results apply broadly to other towns in exurban landscapes. It could also be informative to explore the dimensions and determinants of SE-EE feedback lags and how municipal programs evolve over time, both in response to macro-contextual changes (e.g., the end of the recession; demographic transitions) and to implementation of some of my recommendations for improving such programs. Finally, stakeholders from all four towns seemed more willing to protect wetlands through permanent land conservation than through permitting for individual projects. One MA interviewee went so far as to ascribe this preference to the whole state of New Hampshire.

Discovering the rationale behind such preferences could provide insight into how to improve permit programs, whether by enhancing the appeal of project-based conservation or by increasing opportunities for large-scale conservation within the permit process.

Buffer Policy

Pulling together all that we know about buffers from this and previous research, I conclude that buffers are a necessary, but not sufficient, wetland-protection tool. Buffers are needed because they protect wetland water quality, slow flood waters, and provide some essential habitat for certain species. Local buffer policies can be more effective at achieving these goals than state or federal policies. And having buffers can normalize protection of the wetland proper (Meyer and Konisky 2007b). But buffers alone cannot provide all of the habitat that wetland-dependent wildlife need to maintain viable populations (Harper et al. 2008; Bauer et al. 2010a; Freeman et al. 2012). In particular, buffers ignore that some species' require permeable, connected migratory habitat between wetlands. In some locations, buffers also contribute to more dispersed development. Local control may exacerbate this sprawl and contribute to inter-town class stratification if some towns have strict bylaws and plentiful open space which inflate property values, while other towns allow near unrestricted development (Clingermayer 2004; Glaeser and Ward 2009; Gibbs and Krueger 2011). Robin may successfully protect its wetlands and buffers, but at the cost of displaced development, loss of regional greenspace, and forgone economic opportunities. Also, buffers can cause social conflict, be ignored or abused, or increase the economic costs of land-use.

For these reasons, buffers must be but one part of a landscape-management approach to wetland conservation, which focuses not just on site-specific details, but also addresses

cumulative impacts, consciously trades-off land use and conservation across many sites, and offers management alternatives for situations where buffers are politically unfeasible. One critical component of such an approach will be ensuring that total disturbance on the landscape does not surpass specific thresholds. For vernal-pool-dependent amphibians in New England, that threshold likely occurs when forest cover falls below 30 – 50 % of the landscape (Gibbs 1998; Homan et al. 2004; Herrmann et al. 2005). Similarly, water and wildlife habitat quality degrade significantly once about 10% of a watershed is impervious (Moglen and Kim 2007; Schiff and Benoit 2007; Randhir and Ekness 2009). Disturbance configuration is another important element to consider. Buffers, thresholds, and configuration will be more important in some landscapes than others, however, so the particular plan must vary with location.

Where the landscape is largely undeveloped and disturbances are temporary, as in working forests, wetland-dependent wildlife may maintain connectivity even where buffers are narrow (Veysey et al. 2009; Freidenfelds et al. 2011; Coster et al. *in review*). In such landscapes, minimal buffers may be adequate and forest managers might focus mostly on controlling the amount of disturbance in the landscape, the disturbance-return interval, and rotating disturbance across the landscape so that vernal pools with medium-to-long hydroperiods can recover between cuttings. In such settings, 30 m seems a reasonable standard buffer width, though bigger or smaller buffers may be warranted at particular sites, depending on wetland hydroperiod, wetland density, cutting regimes, and climate conditions, or if future research shows other buffer widths to be more appropriate.

Buffers will be increasingly important as additional stressors are added or disturbances become permanent, as in exurbia and suburbia. In these landscapes, buffers wider than 30 m are warranted, not only to handle the greater pollutant loads and edge effects generated by more

intense land use, but also because upland habitat will be scarcer and buffers may need to support larger proportions of wetland-dependent species' populations. But land is a more valuable commodity and buffers may be least politically feasible in such developed landscapes. Moreover, species still need permeable upland migratory habitat, even amidst development.

One alternative to uniformly wide buffers is to set a goal for total conserved upland in the landscape, require minimal buffers (i.e., 30 m), and then divide the remainder of the conserved-upland quota between additional buffer area and permanently preserved habitat parcels in the inter-wetland matrix. While the conservation goal would apply to the whole landscape, decisions about how to apportion conserved land between buffers and generalized open space could be made at a smaller scale (e.g., individual project sites) with input from developers, local officials, and abutters. Recent models suggest this approach could be both ecologically and economically effective (Bauer et al. 2010a; Freeman and Bell 2011; Bauer and Swallow 2013). Providing developers with a choice between buffers and open space could also satisfy their desire for autonomy (Bauer et al. 2010b; Freeman and Bell 2011; Freeman et al. 2012).

Land-use configuration is also more important in developed landscapes. Paved roads, for example, can block wildlife dispersal (Cushman et al. 2009; Veysey et al. 2011; Gabrielsen et al. 2013), are a major source of amphibian mortality (Fahrig et al. 1995; Carr and Fahrig 2001; Gibbs and Shriver 2005), and should be intentionally located on the landscape. Where possible, wide buffers (i.e., 100+ m) should separate roads and wetlands, road density within 1 km of a wetland should be minimized, and roads should not isolate wetlands or wetland clusters (Gibbs and Shriver 2005; Karraker and Gibbs 2011; Veysey et al. 2011). Despite other benefits, local permit programs are ill-suited to planning land-use configuration and disturbance thresholds on a landscape scale. Like buffers, local control is important, but insufficient, and should be

supported by regional or state initiatives that coordinate and facilitate landscape planning. To this end, conservation-subdivision design and smart growth could be essential tools because both encourage broad-scale consideration of landscape composition and configuration, but can also be attentive to site-level details and stakeholder preferences.

Conclusion

Ultimately, buffers are necessary to wetland-ecosystem integrity and the evidence suggests that wider buffers are needed than those currently used in exurban and suburban landscapes. But buffers alone will not be enough to maintain viable populations of wetland-dependent wildlife species in these developed landscapes and will not be socially feasible in some locations. To address these short-comings, a tri-partite strategy should be applied. First, buffer planning should be subsumed within a larger landscape-management approach that also attends to total landscape disturbance and landscape configuration. Where wider buffers are not possible, at least not in the short-term, two complementary tactics should be pursued. A sustained effort should be made to increase the social acceptability of wider buffers and make buffers generally seem normal. At a basic level, this campaign should be run by skilled communicators and should aim to: increase stakeholder knowledge about wetland science and policy; cultivate interpersonal relationships between conservationists and community power holders; rally the town or region around a rural or green identity; and insert collaborative components into the regulatory structure. While these educational and community-building efforts are underway, alternative and apolitical approaches to wetland conservation should be actively implemented. Conservationists should temporarily accept narrow buffers and instead focus on voluntary and regulatory methods for conserving uplands across the broader landscape.

APPENDIX A

Variance-covariance structure[a, b] of size-metric regression models.

Species & Capture Status	Sex	Biomass (g)	SVL/SUL (mm)[e]	Mass (g)	Body Condition Index[h]
Ambystoma maculatum					
recapture	F	varIdent(1|wetland)	varIdent(1|year)	varFixed(mean.hydro); corARMA(q=1)	varExp(sd.hydro|year); corAR1()
	M	varIdent(1|wetland)	varExp(fitted)	varPower(fitted|year)	varPower(sd.hydro|year); corAR1()
new-capture	F	varExp(fitted|year)	varPower(sd.hydro|trt)[f]	varExp(fitted); corAR1()	varExp(fitted|year); corARMA(p=1,q=1)
	M	varExp(fitted|year)	varExp(fitted); corAR1()	varIdent(1|wetland); corAR1()	varPower(fitted|year); corAR1()
Lithobates sylvaticus					
recapture	F	varExp(fitted|trt)[c]	NA	varExp(cut.year)[g]	varIdent(1|wetland); corAR1()
	M	varIdent(1|trt)	varIdent(1|wetland); corAR1()	varExp(cut.year|trt); corAR1()	varIdent(1|year); corARMA(p=2)
new-capture	F	NA	varPower(sd.hydro|trt); corAR1()	varPower(mean.hydro|trt); corARMA(p=1,q=1)	varPower(sd.hydro|year); corAR1()
	M	varFixed(mean.hydro)[d]	varPower(mean.hydro|trt); corARMA(p=1,q=1)	varPower(mean.hydro|trt); corAR1()	varPower(fitted|wetland); corARMA(p=1,q=1)

[a] See Pinheiro and Bates (2000) for descriptions of the possible variance-covariance structures.
[b] If no structure listed, that component of the variance-covariance structure was not needed.
[c] Trt = cutting treatment, a categorical variable with three levels: reference, 30m buffer, 100m buffer.
[d] Mean.hydro = mean pool hydroperiod (days)
[e] SVL = snout-vent length; SUL = snout-urodyle length.
[f] Sd.hydro = standard deviation of the mean pool hydroperiod (a measure of pool hydroperiod variability, in days)
[g] Cut.year = dummy variable representing the difference between the reference treatment and the two cut treatments, over the six study years.
[h] Index is a measure of relative energy reserves and is calculated as the residuals of an ordinary least squares regression of mass on SVL/SUL. Mass and SVL/SUL were square-root transformed for salamanders and log-transformed for frogs, prior to the regression.

APPENDIX B

Indicators used to assess social effectiveness of municipal wetland-permit programs in the case towns.

Indicator Type	**Indicator**	
Knowledge		**Can the interviewee describe…**
	wetland knowledge	…what wetlands are and how they function?
	connectivity knowledge	…the ecological connections between wetlands and the surrounding landscape?
	wildlife knowledge	…the habitat needs of wetland-dependent wildlife?
	wetland-policy knowledge	…the rationale behind and content of wetland-permit policies?
	permit-process knowledge	…the parties involved and various stages of the wetland-permit process?
Attitude		**What is the interviewee's opinion about…**
	wetlands	…wetlands? Does she value wetlands? Why?
	wetland policies	…wetland policies? Does she value wetland policies? Why?
	program ecological effectiveness	…whether wetland programs are ecologically effective?
	satisfaction	…the overall permit-process? Was she satisfied? Frustrated?
	access	…the accessibility of the permit-process? Were permit officials and information readily available? Were public hearings useful participation venues?
	influence	…her ability to influence the permit-process?
	empathy	…other stakeholders? Did she express empathy for their interests?
Action		**Has/will the interviewee…**
	voting	…voted for/against a policy that affects wetlands?
	policy-making	…engaged in wetland-policy crafting or revision?
	political action	…lobbied for/against a wetland-policy or political figure with known opinions about wetlands?
	public comment	…argued for/against a wetland-permit application at a public hearing?
	permit appeal	…appealed or litigated a wetland-permit decision?
	compliance	…violated a permit condition?
	deterrence	…decided not to work or live in a town because of its wetland program?
	education	…attended meetings or classes to learn about wetlands or wetland policy?
	extra-hearing meetings	…utilized extra-hearing venues to resolve differences with other stakeholders?
	opinion change	…changed her opinion about wetlands?
	behavior change	…changed how she treats wetlands?
	other actions	…engaged in other actions that supported or opposed a municipal wetland-program?

APPENDIX C

Case town demographic and land-use policy summary.

		Lark	Gannet	Robin	Teal
State		MA	NH	MA	NH
Population:	1990[a]	5400[e]	4900	2200	2700
	2000[b]	5500	5500	2800	3800
	2010	6000	6000	3200	4800
Population density (persons/km^2):	1990	54	51	52	40
	2000	55	57	66	56
	2010	61	63	74	71
Population change:	1970 – 1990	1900 (56%)	2800 (127%)	940 (73%)	1300 (95%)
	1990 – 2000	100 (2%)	500 (10%)	600 (27%)	1100 (41%)
	2000 – 2010	500 (9%)	500 (9%)	400 (14%)	1000 (26%)
Median household income:	1999	$56,000	$50,000	$87,000	$69,000
	mean for 2008-2012	$82,000	$69,000	$109,000	$108,000
Town area (ha)		10015	9601	4286	6742
% Wetland area[c]		15.9	20.1	13.9	8.8
% Developed area[d]		10	Nav[g]	15	11.6
# Land-use bylaws		7	8	5	7
Prime wetlands		Nap[f]	No	Nap	No
Wetland provision		Yes	Yes	Yes	Yes
Vernal pool provision		Yes	Yes	No	Yes
Floodplain provision		Yes	Yes	Yes	Yes
Aquifer provision		Yes	Yes	No	Yes
Shoreland provision		NAp	Yes	NAp	No
Zoning bylaw		Yes	Yes	Yes	Yes
Subdivision bylaw		Yes	Yes	Yes	Yes
Open-space subdivision provision		Yes	Yes	Yes	Yes
Growth-management provision		Yes	Yes	Yes	Yes
Impact-fee provision		No	Yes	No	Yes
TDR provision		No	No	No	No
Other innovative land-use controls		Yes	Yes	Yes	Yes
Planning board		Yes	Yes	Yes	Yes
Conservation commission		Yes	Yes	Yes	Yes

Appendix C continued.				
Buffer provision				
Jurisdictional buffer:	• wetlands: 30m; perennial streams: 61m	• wetlands: 8m for fertilizer, 15m for septic pipes, 30m for septic systems; 76m for hazmats or snow piles; major water bodies: 8-23m for excavation	• wetlands: 30m	• wetlands: 23-30m for septic, 23m for hazmats; vernal pools: 30m for septic
Impervious buffer:	• may be required	• 15m	• 19m	• wetlands: 23m for buildings, 15m for roads; vernal pools: 30m for buildings & roads
Impervious buffer exemptions:	• yes, for different types of small impervious areas	• yes, for lot access if runoff is controlled	• yes, up to $9m^2$ of impervious area	• yes, for lot access
Natural vegetation buffer:	• may be required	• surface waters: 46m; wetlands: 15m; some cutting allowed	• 7m (informal)	• wetlands and streams: 8m; vernal pools: 15m

[a] 1970 and 1990 population data sources =
NH: New Hampshire Economic and Labor Market Information Bureau. (Feb. 2014). *New Hampshire Community Profiles*. Retrieved from: http://www.nhes.nh.gov/elmi/products/cp/index.htm.
MA: Boston Region Metropolitan Planning Organization. *Massachusetts Population by Town, 1980, 1990, 2000, 2010*. Retrieved from: http://www.ctps.org/datacatalog_share/content/massachusetts-population-town-1980-1990-2000-and-2010 (29 Sept. 2014)

[b] Income and 2000 to 2012 population data source = U.S. Census Bureau; generated by J. Veysey Powell; using American FactFinder; http://factfinder2.census.gov (4 April 2014).

[c] Data sources = NH: U.S. Fish and Wildlife Service. *National Wetlands Inventory*. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Retrieved from: http://www.granit.sr.unh.edu/data/downloadfreedata/category/databycategory.html (2 Feb. 2010); MA: U.S. Fish and Wildlife Service. *National Wetlands Inventory*. U.S. Department of the Interior, Fish and Wildlife Service, Washington D.C. Retrieved from: http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/nwi.html (2 Feb. 2010).

[d] Data sources = NH: NH GRANIT. (2001). *New Hampshire Land Cover Assessment – 2001*. Retrieved from: http://www.granit.sr.unh.edu/data/downloadfreedata/alphabetical/databyalpha.html (22 Oct. 2014); MA: MassGIS. (1999). *Land Use Summary Statistics*. Retrieved from: http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/landusestats.html (22 Oct. 2014)

[e] Data are rounded to obscure town identity.

[f] Not applicable.

[g] Not available.

APPENDIX D

Sample introductory letter sent to interview candidates.

20 August 2013

Dear Subject Name,

You have been suggested as a person who has applied for and received a permit to build near wetlands in Gannet, State. I am a PhD student in the Department of Natural Resources and the Environment at the University of New Hampshire. For my doctoral research, I am comparing the social and ecological effectiveness of wetland-permitting programs among towns in New Hampshire and Massachusetts, in order to help communities develop better methods for balancing human needs and wetland protection.

I would like to speak with you about your experiences developing land in Gannet. A typical interview takes 30-90 minutes. Should you agree to participate, the interview would be conducted at a time and place convenient for you.

Please email or call me to schedule an interview or if you have any questions. If I don't hear from you, I will call within the next few days to see if you are willing to participate in this research.

Thank you for your time and consideration.

Sincerely,

Jessica Veysey Powell
Doctoral Candidate
Department of Natural Resources and the Environment
University of New Hampshire

Email: jss4@wildcats.unh.edu
Telephone: (603) 659-2980

APPENDIX E

Interview Guides

Municipal Official Interview Guide

Knowledge

Wetland Science

1) When I say "wetland," what are the first three words that come to mind?
2) Would you name three different types of wetlands?
3) Would you name three different species that use wetlands (plants or animals)?
4) If you had to define the outer limit (or boundary) of a wetland "ecosystem," would it be:
    a) At the water's edge b) Within a few feet of the water's edge
    c) Several yards from the water's edge d) Other (Clarify)
5) I define a wetland buffer as "a piece of land next to a wetland that is undisturbed, protects wetland water quality, and provides wildlife habitat."
    a) Do you agree with this definition? If not, how would you define a wetland buffer?
6) Can land development impact wetlands? (Y/N/Sometimes) Could you provide two examples?

Wetland Policy

7) Is it legal to build in wetlands? (Y/N/Sometimes)
8) What two laws do you think most influence how wetlands are used in [TOWN]?
9) Who decides whether a landowner can build in wetlands or not?
10) Does [TOWN] protect any land outside the wetland itself? Distance?

Attitude

Wetland Science

1) On a scale of 1 to 10, how important do you think it is to protect wetlands? (1 = not important; 10 = extremely important). Why?
2) Which of the following do you associate with wetlands? (Circle all that apply).
    a) Agricultural opportunities b) Bad smells c) Conservation
    d) Development obstacles e) Development opportunities f) Disease source
    g) Flood control h) Flood source i) Mosquito breeding ground
    j) Pollution prevention k) Recreation opportunities l) Scenic vistas
    m) Unattractive vistas n) Water supply o) Wildlife habitat
3) Which one of the above is most important to you?

Wetland Policy

4) What is an "effective" wetland-permit policy? How do you define "effective"?
    a. Probe re: both social and environmental aspects.
5) Do you think [TOWN]'s current wetland-protection policy is effective? Why?
    a. What are the pros and cons of [TOWN]'s wetland-permit process?
6) Do you think [STATE]'s current wetland-permitting policy is effective? Why?
    a. What are the pros and cons of [STATE]'s wetland-permit process?
7) Do you think [TOWN] is more or less effective at protecting wetlands than other [STATE] towns? Why?
8) Has your opinion about wetlands or wetland policies changed over time? How? Why?

Experience / Organization/ Actions

1) Why are you a member of [BOARD]?
2) When you first joined [BOARD]:
    a. How much did you know about wetlands? (None, not much, some, a lot).
        i. Have you learned more about wetlands since then? How?
    b. How much did you know about wetland-permit policies? (None, not much, etc).
        i. Have you learned more about wetland-permit policies since then? How?

3) You've just learned a project is proposed in or near wetlands in [TOWN]. Please walk me through your typical thoughts and actions in response to this news.

Use the following questions as prompts to explore question (4).

Information Gathering

4) How do you typically find out there is a project proposed in/near wetlands?
5) Where do you go / who do you contact to get more information about:
    a. Project details?
    b. The landowner / developer's reputation?
    c. Community reaction to proposed projects?
    d. Ecological impact of the project on wetlands?
    e. Whether the project complies with [local and state] wetland-permit policies?
    f. Status of a [DES] application?
6) Is the information usually understandable? Thorough? Helpful? Easy to access?
7) Are you confident that consultants / developers / board members provide accurate:
    a. Scientific information? b. Legal information?
8) Do wetland site plans typically show the proposed work in enough detail for you to understand how the project will impact wetlands? Explain.
    a. Do the plans show enough of the project site and adjacent lots for you to understand how the project relates to current and past work in the neighborhood?
    b. Do proposed site plans accurately reflect as-built work?
    c. Has site plan quality changed over time? Why?
9) Does [BOARD] ever adopt wetland-protection policies or strategies from other towns?
    a. Who do you go to for information about wetland governance in other towns?
10) How many hours per month would you say you spend on [BOARD] business?

Priorities and Change

11) How would you rank the [BOARD]'s priorities in making wetland-permit decisions?
    a) Adequate infrastructure b) Economic development c) Implement the Master Plan
    d) Minimize conflict e) Open space conservation f) Public safety
    g) Rare species protection h) Satisfy the landowner i) Satisfy the public
    j) Stormwater management k) Treat applicants equally l) Water quality
    m) Wetland protection
12) Have [BOARD]'s priorities changed over time? How? Why?
13) Have [BOARD]'s strategies for protecting wetlands changed over time? How? Why?
    a. For example, maybe [BOARD] used to try to minimize wetland fill, but now it focuses on minimizing impervious area. (Or something else)?
    b. Has [BOARD] made a conscious effort to promote specific types of development?
    c. R: How did R develop its policy on isolated wetlands (dni <3000 ft2, except vps)?

d. Does [BOARD] try to balance or trade-off bigger wetland impacts at one location with smaller impacts at another location (either within a project or across different projects in town)?

14) Have wetland ecosystems changed in [TOWN] over time? How?
    a. Have you noticed any differences in which species you see in wetlands?
    b. Have you noticed any differences in wetland water quality?
15) Has public reaction to development in/near wetlands changed over time? Why/how?
16) How has the growth rate in [TOWN[changed over time?

Public Hearings and Permits

17) How would you describe [BOARD] discussions during public hearings?
    a. Are they: (e.g.) Superficial? Stilted? Open? Do you speak freely?
18) By the end of a hearing, if [BOARD] is uncertain about a technical aspect of the application, what typically happens?
    a. Does [BOARD] continue the hearing? Or make a decision anyways?
    b. Does [BOARD] rely on the applicant to provide the technical information?
    c. How long does it typically take the [BOARD] to get that information?
19) Does information gained at public hearings influence how you vote on permit applications?
20) How does [BOARD] react when arguments arise at public hearings? Example?
    a. How are arguments typically resolved?
    b. How do arguments influence [BOARD]:
        i. Decisions? ii. Perceptions of the involved persons?
    c. How do these arguments make you feel?
21) Which person(s) or board has the most influence on the fate of a permit? Why?
22) Which person(s) or board has the most influence on the spatial layout of construction plans, specifically the distance between construction and wetlands?
23) Have you ever observed a [BOARD] member or agent take some action that you felt abused her/his authority as a [BOARD] member? Please describe.
24) Do you think there is a representative mix of professional backgrounds on the PB/ZBA/CC?
25) Are any board members or citizens particularly:
    a. Obstructionist (Try to block projects and/or don't offer constructive criticism)?
    b. Skilled at balancing development needs with wetland protection (Open to compromise and/or offer constructive advice)?
    c. Skilled at mediating arguments at permit hearings?
26) What is the role of the [BOARD] agent?
    a. Does the agent influence [BOARD] decisions? How?
    b. Does [BOARD] consult with the agent on wetland decisions?
    c. Has [BOARD] ever censored the agent's comments or ignored her advice? Describe.
27) How strictly do you think [BOARD] follows [local wetland policy]?
28) Does [BOARD] use any unwritten rules to decide wetland permit conditions?
29) Do you think the public has sufficient opportunity to express its opinions at hearings?
30) Do you think [BOARD] treats all applicants/citizens equally? Why?

Relations with Other Boards

31) Please describe the nature of communications between [BOARD] and [OTHER BOARDS].
    a. Who? How? When? How often?
    b. How does [BOARD] get information about [OTHER BOARDS]' wetland decisions?
    c. Are [BOARD]'s relationships with [OTHER BOARDS] positive or negative? Why?
32) [NH/MA]: What role does the CC/PB play in the permitting process?

33) Do you think [OTHER BOARDS] effectively balance land development and wetland protection? Or do their decisions allow too much development or wetland protection?
34) [MA] Does splitting authority for wetland permitting between the PB and CC impact how much wetland disturbance is allowed during development projects?
35) How does [BOARD] deal with violations of [local wetland policy]?

Other Actions

36) How does [BOARD] generate support for proposed wetland-protection measures (e.g., prime wetlands, policy revision)? How effective are these methods? Why?
37) What part of [local code] do you think is [TOWN]'s strong wetland protection tool? (e.g., buffers, minimum lot size, open-space subdivisions). Why?

Home Rule

1) Do you think wetland permits should be issued by the state, town, or another entity? Why?
2) Do you think [TOWN] has the expertise and resources it needs to administer an effective wetland-permit program?

Property Rights

1) Do you think [TOWN] has the right to restrict activities on private land? Why? Which?
2) Who should decide what work can occur in or around wetlands located on private land?
3) Do you think your understanding of PRs is typical of other officials/citizens in [TOWN]?
4) Have you observed changes in your own or others' understanding of PRs over time?
5) Have you heard of the "takings rule"? How do you feel about the takings rule?

Overall

1) Could you make three suggestions to improve the wetland-permit process in [TOWN]?
2) Overall, would you say that exempt and expedited projects have a positive or negative impact on wetland conservation? Why? How might we better address cumulative impacts?
3) Do you think [wetland policy] adequately protects habitat for wildlife species that depend on both wetlands and adjacent uplands to complete their life cycles?
    a. What policy measures could we adopt to better provide habitat for these species?
4) Do you think [wetland policy] adequately protects ecological connections between wetlands? E.g. Does [wetland policy] provide enough habitat for wildlife to move between wetlands?
    a. What policy measures could we adopt to better promote inter-wetland connectivity?
5) How can we adapt [state policy] to reduce landowner frustration with the permit process?
6) Is there anything we missed that is critical to understanding wetland permitting in [TOWN]?

Demographics

1) In what year were you born?
2) In what town do you currently live? For how many years have you lived there?
3) How many adults live in your household? How many children?
4) Do you currently own land?
    a. To the best of your knowledge, does it include any wetlands?
5) What is your current occupation? Have you worked in other occupations?
6) What is the highest degree you've received? Major?
7) How would you describe yourself politically?
8) Do you have any hobbies or belong to any organizations or other community groups?

Can I contact you with follow-up questions I may have?

Landowner Interview Guide

Introduction

1) Please tell me a bit about your property.
    a. To the best of your knowledge, does it include any wetlands?

Knowledge

Wetland Science

1) When I say "wetland," what are the first three words that come to mind?
2) Would you name three different types of wetlands?
3) Would you name three different species that use wetlands (plants or animals)?
4) If you had to define the outer limit (or boundary) of a wetland "ecosystem," would it be:
    a. At the water's edge b) Within a few feet of the water's edge
    c) Several yards from the water's edge d) Other (Clarify)
5) I define a wetland buffer as "a piece of land next to a wetland that is undisturbed, protects wetland water quality, and provides wildlife habitat."
    a. Do you agree with this definition? If not, how would you define a wetland buffer?
6) Can land development impact wetlands? (Y/N/Sometimes) Could you provide two examples?

Wetland Policy

7) Is it legal to build in wetlands? (Y/N/Sometimes)
8) What two laws do you think most influence how wetlands are used in [TOWN]?
9) Who decides whether a landowner can build in wetlands or not?
10) Does [TOWN] protect any land outside the wetland itself? Distance?

Attitude

Wetland Science

1) On a scale of 1 to 10, how important do you think it is to protect wetlands? (1 = not important; 10 = extremely important). Why?
2) Which of the following do you associate with wetlands? (Circle all that apply).
    a) Agricultural opportunities b) Bad smells c) Conservation
    d) Development obstacles e) Development opportunities f) Disease source
    g) Flood control h) Flood source i) Mosquito breeding ground
    j) Pollution prevention k) Recreation opportunities l) Scenic vistas
    m) Unattractive vistas n) Water supply o) Wildlife habitat
3) Which one of the above is most important to you?

Wetland Policy

4) What is an "effective" wetland-permit policy? How do you define "effective"?
    a. Probe re: both social and environmental aspects.
5) Do you think [TOWN]'s current wetland-protection policy is effective? Why?
    a. What are the pros and cons of [TOWN]'s wetland-permit process?
6) Do you think [STATE]'s current wetland-permitting policy is effective? Why?
    a. What are the pros and cons of [STATE]'s wetland-permit process?
7) Has your opinion about wetlands or wetland policies changed over time? How? Why?

Experience / Organization

1) Please tell me about your experience with the wetland-permit process in [TOWN].

Use the following questions as prompts to explore question (1). Tailor to applicants and abutters.

Information Gathering

2) How did you learn that you had wetlands on your land? How did you react?
3) Did you hire a developer or consultant to help you with the project? Why?
4) Who did you contact to get information about:
    a. What work you could do in or near wetlands?
    b. Which wetland-application to submit?
    c. The status of your application?
    d. Whether community members were receptive to your project?
5) Was this information understandable? Thorough? Helpful? Trust-worthy? Easy to access?

Public Hearings and Permits

6) Did you attend the public hearings for your permit application? Why?
7) Was there community opposition to your project? Please describe.
    a. How did you react to this opposition?
    b. How was the opposition resolved?
    c. Do you think this opposition influenced the outcome of your project?
8) Which person or group had the most influence on the fate of your permit? Why?
9) Besides you, which person or group had the most influence on the spatial layout of your construction plans, specifically the proposed distance between construction and wetlands?
10) Was there a representative mix of professional backgrounds on the PB? ZBA? CC?
11) Were there any board members or citizens who were particularly:
    a. Obstructionist (Tried to block your project and/or didn't offer constructive criticism)?
    b. Skilled at balancing your development needs with wetland protection (Open to compromise and/or offered constructive advice)?
    c. Skilled at mediating arguments at your permit hearings?
12) Was it easier to get a wetland-permit from [DES] or from [TOWN]? Why?
13) Was it easier to get support for a wetland-permit from [TOWN] PB, ZBA, or CC? Why?
14) [NH]: What role did the CC play in the permitting process?
15) Were you aware of any unwritten rules used in deciding whether to issue you a permit?
16) Have you ever received an enforcement order? Why? How was it resolved?
17) For abutters: Did your other neighbors attend the hearings? Why?

Overall Experience

18) Overall, did you achieve your project goals?
19) Do you think wetlands were effectively protected?
20) Were you able to fully express yourself at the hearings? Was your opinion respected?
21) Did you feel you were treated with fairness? How do you define "fairness"?
22) Have you ever applied for a wetland permit in a different town or state?
23) How was the permit process different in [TOWN/STATE] versus other [towns or states]?

<u>Home Rule</u>

1) Do you think wetland permits should be issued by the state, towns, or another entity? Why?
2) Do you think [TOWN] has the expertise and resources needed to administer an effective wetland-permit program?
3) Imagine that wetland permits are only issued by: a) [STATE] or b) [TOWN].
    a. In which scenario would your ability to achieve your development goals be greatest?
    b. Would wetland protection be most effective?

Property Rights

1) What were you most concerned about when deciding what to do with your land?
   a) Aesthetics
   b) Balancing development & conservation
   c) Building a home
   d) Keeping the land in your family
   e) Making a profit
   f) Maximizing property value
   g) Minimizing property taxes
   h) Providing commercial opportunities
   i) Wetland protection
   j) Wildlife habitat
2) Can you think of any activities that should be restricted on your land?
3) Who should decide what work can occur in or around wetlands located on your land?
4) Do you think that your understanding of PRs is typical of other landowners in [TOWN]?
5) Have you observed changes in your own or others' understanding of PRs over time?
6) Have you ever heard of the "takings rule"? How do you feel about the takings rule?

Overall

1) Have wetland ecosystems changed in [TOWN] since you moved here? How? Why?
   a. Have you noticed any differences in which species you see in wetlands?
   b. Have you noticed any differences in wetland water quality?
2) How has the growth rate in [TOWN] changed over time?
3) Have you noticed any changes in how [BOARD] treats landowners over time?
4) Have you noticed any changes in citizen attitude towards wetlands or permitting over time?
5) Could you suggest two ways to improve the wetland-permit process in [TOWN]?
6) Is there anything we missed that is critical to understanding wetland permitting in [TOWN]?

Demographics

1) In what year were you born?
2) In what town do you currently live? For how many years have you lived there?
3) How many adults live in your household? How many children?
4) What is your current occupation? Have you worked in other occupations?
5) What is the highest degree you've received? Major?
6) How would you describe yourself politically?
7) Do you have any hobbies or belong to any organizations or community groups?

Can I contact you with follow-up questions I may have?

Developer / Consultant Interview Guide

Introduction

1) Would you tell me briefly about the company you work for/your professional background?

Knowledge

Wetland Science

1) When I say "wetland," what are the first three words that come to mind?
2) Would you name three different types of wetlands?
3) Would you name three different species that use wetlands (plants or animals)?
4) If you had to define the outer limit (or boundary) of a wetland "ecosystem," would it be:
    a. At the water's edge b) Within a few feet of the water's edge
    c) Several yards from the water's edge d) Other (Clarify)
5) I define a wetland buffer as "a piece of land next to a wetland that is undisturbed, protects wetland water quality, and provides wildlife habitat."
    a. Do you agree with this definition? If not, how would you define a wetland buffer?
6) Can land development impact wetlands? (Y/N/Sometimes) Could you provide two examples?

Wetland Policy

7) Is it legal to build in wetlands? (Y/N/Sometimes)
8) What two laws do you think most influence how wetlands are used in [TOWN]?
9) Who decides whether a landowner can build in wetlands or not?
10) Does [TOWN] protect any land outside the wetland itself? Distance?

Attitude / Values

Wetland Science

1) On a scale of 1 to 10, how important do you think it is to protect wetlands? (1 = not important; 10 = extremely important). Why?
2) Which of the following do you associate with wetlands? (Circle all that apply).
    a) Agricultural opportunities b) Bad smells c) Conservation
    d) Development obstacles e) Development opportunities f) Disease source
    g) Flood control h) Flood source i) Mosquito breeding ground
    j) Pollution prevention k) Recreation opportunities l) Scenic vistas
    m) Unattractive vistas n) Water supply o) Wildlife habitat
3) Which one of the above is most important to you?

Wetland Policy

4) What is an "effective" wetland-permit policy? How do you define "effective"?
    a. Probe re: both social and environmental aspects.
5) Do you think [TOWN]'s current wetland-protection policy is effective? Why?
    a. What are the pros and cons of [TOWN]'s wetland-permit process?
    b. Is [TOWN] more or less effective at protecting wetlands than other towns? Why?
6) Do you think [STATE]'s current wetland-permitting policy is effective? Why?
    a. What are the pros and cons of [STATE]'s wetland-permit process?
7) How would describe the type of construction that you normally do? (e.g. SFHs; high density)
8) When designing a project, how would you rank the following priorities and concerns?
    a) Energy efficiency b) Green energy c) Innovative technology/design
    d) Profit e) Proximity to town center f) Proximity to open space
    g) Public safety h) Stormwater management i) Total impervious area

j) Wetland protection k) Wildlife habitat

9) Has your opinion about wetlands or wetland policies changed over time? How? Why?

Experience / Organization

1) Do you normally attend public hearings for your development projects? Why?
2) Do you generally expect community opposition to your development projects?
    a. If so, what strategies do you use to deal with community opposition?
    b. Do you downsize projects/make them more environmentally-friendly from the start?
    c. Do you oversize projects, so that after revisions, they are what you originally wanted?
    d. Do you trade-off impacts between projects? For example, have more impacts at one site in exchange for lesser impacts at another site?
    e. Do you use other strategies? (e.g., PR, lobby boards, pre-planning)
3) Have your strategies for designing developments near wetlands changed over time? How?
    a. What motivated these changes? (e.g., wetland policies, people/groups)
    b. Do your development strategies differ between [TOWN] and other towns? How?
    c. Do your development strategies differ between NH and MA? How?
4) Please tell me about your experiences with the wetland-permit process in [TOWN].

Use the following questions as prompts to explore question (4). Tailor to developers and consultants.

5) Who do you contact to get information about:
    a. Rules governing work in or near wetlands? b. Which application to submit?
    c. How your project might impact wetlands? d. The status of your application?
6) Is this information understandable? Thorough? Helpful? Trust-worthy? Easy to access?
7) How do you figure out whether community members will be receptive to your project?
8) Which person or group has the most influence on whether you receive a permit? Why?
9) Besides you, which person or group has the most influence on the spatial layout of your construction plans, specifically the proposed distance between construction and wetlands?
10) Is there a representative mix of professional backgrounds on the PB? ZBA? CC?
11) Are there any board members or citizens who are particularly:
    a. Obstructionist (Try to block your projects and/or rarely offer constructive criticism)?
    b. Skilled at balancing your development needs with wetland protection (Open to compromise and/or offer constructive advice)?
    c. Skilled at mediating arguments that arise at permit hearings?
10) Have you ever been involved in an argument during a public hearing? Describe.
    a. Did this argument help you achieve your development goals?
    b. Did the argument change how receptive the board/citizens were to your project?
    c. How did this argument make you feel?
    d. How was the argument resolved?
11) Have you noticed any changes over time in how [BOARD] treats applicants?
12) Have you noticed changes over time in abutter attitudes towards your projects or permitting?
13) Is it easier to get a wetland-permit from [DES] or from [TOWN]? Why?
14) Is it easier to get a wetland permit from [TOWN] or other towns in [STATE]? Why?
15) Is it easier to get support for a wetland-permit from [TOWN] PB, ZBA, or CC? Why?
16) [NH]: What role does the CC play in the permitting process?
17) Are you aware of any unwritten rules [BOARD] uses to make wetland-permit decisions?
18) Overall, how would you describe your experience working in [TOWN]?
19) Were your project development goals achieved?

20) Do you think wetlands were effectively protected?
21) Did you feel that you were treated with fairness? How do you define "fairness"?

Home Rule

1) Do you think wetland permits should be issued by the state, towns, or another entity? Why?
2) Do you think [TOWN] has the expertise and resources needed to administer an effective wetland-permit program?
3) Imagine that wetland permits are only issued by a) the state or b) the town. In which scenario would your ability to achieve your development goals be greatest?

Property Rights

1) Think about land that you own or might own in the future.
    a. Are there any activities that you think should be restricted on your land? Why?
    b. Who should decide what work can occur in or around wetlands located on your land?
2) Do you think your understanding of PRs is typical of other [DEVELOPERS]?
3) Have you observed changes over time in your own or others' understanding of PRs?
4) Have you ever heard of the "takings rule"? How do you feel about the takings rule?

Overall

1) Could you make two suggestions to improve the wetland-permit process in [TOWN]?
2) Is there anything we missed that is critical to understanding wetland permitting in [TOWN]?

Demographics

1) In what year were you born?
2) In what town do you currently live? For how many years have you lived there?
3) How many adults live in your household? How many children?
4) Do you currently own land? In which towns?
    a. To the best of your knowledge, do your parcels include wetlands?
5) What is the highest degree you've received? Major?
6) How would you describe yourself politically?
7) Do you have any hobbies or belong to any organizations or community groups?

Can I contact you with follow-up questions I may have?

State & Federal IV Guide

Effectiveness

1) What is an "effective" wetland-permit policy? How do you define "effective"?
    a. Probe re: both social and environmental aspects.
2) Do you think [STATE]'s current wetland-permitting policy is effective? Why?
    a. What are the pros and cons of [STATE]'s wetland-permit process?
3) Do you think MA or NH is more effective at protecting wetlands? Why? How?
    a. Has this pattern changed over time? How?
4) How much do municipal decisions impact the extent of development in/near wetlands?
5) Do you think [TOWN] protects wetlands more or less effectively than [other towns]? Why?
    a. Is this different than in the past? How?
6) How much variation have you observed in wetland-protection effectiveness across towns?
7) Why are some towns better at protecting wetlands?
8) During local wetland-permit hearings, why are [BOARDS] in some towns more likely to experience conflict with applicants and/or citizens than boards in other towns? By conflict I mean, e.g.: strong arguments, visible frustration.
9) Why are [BOARDS] in some towns better at reaching permit decisions that are acceptable to all stakeholders (i.e., the BOARD, applicant, and citizens), while boards in other towns tend to make decisions that are unsatisfactory to multiple stakeholders?

Experience / Organization

General

1) What types of things stand out for you about the wetland-permit process in [TOWNS]?

People and Groups

2) Which person or group has the most influence on the fate a wetland permit? Why?
3) Which person or group has the most influence on the spatial layout of construction plans, specifically the distance between construction and wetlands?
4) Are any [DES] employees, [TOWN] officials, or [TOWN] citizens particularly:
    a. Obstructionist (Try to block projects and/or don't offer constructive criticism)?
    b. Skilled at balancing development and wetland protection (Open to compromise and/or offer constructive advice)?
    c. Skilled at mediating arguments about permit applications?

Fairness and Conflict

5) How strictly do you think [DES] follows [state wetland policy]?
6) Are you aware of any unwritten rules [DES] uses to decide wetland-permit conditions?
7) Do you think [state wetland law] is applied uniformly to all applicants? Towns? Why?
8) Imagine a scenario where an applicant or abutter strongly objects to a [DES] decision. This person phones you and vocally expresses anger about the [DES] permit conditions.
    a. How do you typically react?
    b. How is such conflict typically resolved?
    c. Does such active displeasure ever influence the outcome of permit decisions, either by you, your peers, or the [COUNCIL]?

[NH only]

9) Why do you think there is no state-wide buffer in NH?
    a. What are the pros and cons of having different buffer policies in each town?

b. Do you personally think there should be a state-wide buffer in NH?

10) What do you think about the prime wetlands program?
    a. Do prime wetlands lead to more effective wetland protection?
    b. Why are some citizens so opposed to prime wetlands?
    c. What or who motivated the recent changes to the prime wetlands policy?
11) [NH]: What role does the CC play in the permitting process?

Process Details

12) When you have a permit application for a project in [TOWN],
    a. Do you mostly communicate with applicants, abutters, or [TOWN] personnel? Who?
    b. How do you develop a sense of on-the-ground site conditions?
    c. Do you trust information provided by abutters / applicants / consultants?
    d. How knowledgeable are [TOWN] personnel about wetland science / policy?
13) Think of [TOWN] officials that you interact with during your job. What traits make officials easy to work with? Difficult? Facilitate your job? Inhibit your job? Why?
14) How does [DES] deal with information about violations of [state wetland policy]?
    a. What percent of violations are pursued?
    b. What characteristics of a violation make it more likely to be pursued?
    c. How are violations typically resolved?

System Changes

15) Have wetland ecosystems in [part of STATE] changed since you came to [DES]? Why/how?
16) Has public attitude towards wetlands/permitting changed since you came to [STATE]? Why/how?
17) Has public perception of [DES] changed since you came to [DES]? Why/how?
18) Have [DES]'s priorities / strategies for wetland permitting changed since you arrived? Why/how?

Home Rule

1) In your personal opinion, do you think wetland permits should be issued by the state, town, or another entity? Why?
    a. Do you think your answer to this question is typical of citizens in [STATE]? How?
2) Do you think [TOWN] has the expertise and resources it needs to administer an effective wetland-permit program?
    a. If not, how can we balance desire for local governance with resource scarcity?
3) Which organizational model do you think more effectively protects wetlands:
    a. NH model: with local authority concentrated at the PB?
    b. MA model: with local authority split between the CC and PB?

Property Rights

1) Do you think most [TOWN/STATE] citizens believe that development in or near wetlands should or should not be restricted? (What %)?
2) Have you observed changes in your own or others' understanding of PRs over time?
3) Have you heard of the "takings rule"? Do you think the takings rule influences wetland permit decisions? How?

Overall

1) Could you suggest three ways to improve the wetland-permit process in [STATE]?
2) What is your perception of the impact of exempt and expedited projects? Cumulatively?

    a. How might we better address cumulative impacts?
3) Do you think [state wetland policy] adequately protects habitat for wildlife species that depend on wetlands and adjacent uplands to complete their life cycles?
    a. What policy measures could we adopt to better provide habitat for these species?
4) Do you think [state wetland policy] adequately promotes ecological connections between wetlands (for wildlife dispersal and gene flow)?
    a. What policy measures could we adopt to better promote inter-wetland connectivity?
5) How can we adapt [wetland policy] to reduce landowner frustration with the permit process?
6) Is there anything we missed that is critical to understanding wetland permitting in [STATE]?

Demographics

1) In what year were you born?
2) In what town do you currently live? For how many years have you lived there?
3) How many adults live in your household? How many children?
4) Do you currently own land?
    a. To the best of your knowledge, does it include any wetlands?
5) Have you worked in other occupations? Which?
6) What is the highest degree you've received? Major?
7) How would you describe yourself politically?
8) Do you have any hobbies or belong to any organizations or other community groups?

Can I contact you with follow-up questions I may have?

APPENDIX F

Institutional Animal Care and Use Committee approvals

UNIVERSITY of NEW HAMPSHIRE

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

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

UNIVERSITY of NEW HAMPSHIRE

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.

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

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

APPENDIX G

Institutional Review Board approval

University *of* New Hampshire

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

26-May-2010

Veysey, Jessica
NREN, James Hall
223 S. Main Street, Apt. 5
Newmarket, NH 03857

IRB #: 4897
Study: Comparative Analysis of the Social and Ecological Effectiveness of Freshwater Wetland Policies in Massachusetts and New Hampshire
Approval Date: 25-May-2010

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Exempt as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 101(b). Approval is granted to conduct your study as described in your protocol.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* (This document is also available at http://www.unh.edu/osr/compliance/irb.html.) Please read this document carefully before commencing your work involving human subjects.

Upon completion of your study, please complete the enclosed Exempt Study Final Report form and return it to this office along with a report of your findings.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie F. Simpson
Manager

cc: File
Babbitt, Kimberly

LIST OF REFERENCES

Abrams, JB, and H Gosnell. 2012. The politics of marginality in Wallowa County, Oregon: contesting the production of landscapes of consumption. Journal of Rural Studies **28**: 30-37.

Abrams, JB, H Gosnell, NJ Gill, and PJ Klepeis. 2012. Re-creating the rural, reconstructing nature: an international literature review of the environmental implications of amenity migration. Conservation and Society **10**: 270-284.

Addison, JA, and KN Barber. 1997. Response of soil invertebrates to clear-cutting and partial cutting in a boreal mixedwood forest in Northern Ontario. Infor. Rep. GLC-X-1. Sault Ste. Marie, Ontario, Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, 29 pp.

Adger, WN, and C Luttrell. 2000. Property rights and the utilisation of wetlands. Ecological Economics **35**: 75-89.

Adler, JH, KD Connolly, RC Gardner, SM Johnson, and M Latham. 2007. The Supreme Court and the Clean Water Act: Five Essays. Vermont Journal of Environmental Law **56**: 99 pp.

Allen, SC, CE Moorman, MN Peterson, GR Hess, and SE Moore. 2012. Overcoming socio-economic barriers to conservation subdivisions: a case-study of four successful communities. Landscape and Urban Planning **106**: 244-252.

AmphibiaWeb. 2014. *Information on amphibian biology and conservation*. [web application]. AmphibiaWeb, Berkeley, California. Available from http://amphibiaweb.org/amphibian/speciesnums.html (accessed 31 Oct. 2014).

Anderson, BT, K Hayhoe, and XZ Liang. 2010. Anthropogenic-induced changes in twenty-first century summertime hydroclimatology of the Northeastern US. Climatic Change **99**: 403-423.

Anholt, S. 2008. Place branding: Is it marketing, or isn't it? Place branding and public diplomacy **4**: 1-6.

Ardia, DR. 2005. Super size me: an experimental test of the factors affecting lipid content and the ability of residual body mass to predict lipid stores in nestling European Starlings. Functional Ecology **19**: 414-420.

Arnold, SJ. 1976. Sexual behavior, sexual interference, and sexual defense in the salamanders *Ambystoma maculatum*, *Ambystoma tigrinum*, and *Plethodon jordani*. Zeitschrift fur Tierpsychologie **42**: 247-300.

Ashworth, GJ. 2011. Place branding: glocal, virtual and physical identities, constructed, imagined and experienced. Tourism Management **32**: 702-703.

Aubry, KB. 2000. Amphibians in managed, second-growth Douglas-fir forests. Journal of Wildlife Management **64**: 1041-1052.

Babbitt, KJ, MJ Baber, and TL Tarr. 2003. Patterns of larval amphibian distribution along a wetland hydroperiod gradient. Canadian Journal of Zoology **81**: 1539-1552.

Baber, MJ, E Fleishman, KJ Babbitt, and TL Tarr. 2004. The relationship between wetland hydroperiod and nestedness patterns in assemblages of larval amphibians and predatory macroinvertebrates. Oikos **107**: 16-27.

Baldwin, RF, AJK Calhoun, and PG deMaynadier. 2006a. Conservation planning for amphibian species with complex habitat requirements: a case study using movements and habitat selection of the wood frog *Rana sylvatica*. Journal of Herpetology **40**: 442-453.

Baldwin, RF, AJK Calhoun, and PG deMaynadier. 2006b. The significance of hydroperiod and stand maturity for pool-breeding amphibians in forested landscapes. Canadian Journal of Zoology **84**: 1604-1615.

Bancila, RI, T Hartel, R Plaiasu, J Smets, and D Cogalniceanu. 2010. Comparing three body condition indices in amphibians: a case study of yellow-bellied toad *Bombina variegata*. Amphibia-Reptilia **31**: 558-562.

Bates, D, M Maechler, and B Bolker. 2011. lme4: Linear mixed-effects models using S4 classes (R package version 0.999375-39).

Bauer, DM, PWC Paton, and SK Swallow. 2010a. Are wetland regulations cost effective for species protection? A case study of amphibian metapopulations. Ecological Applications **20**: 798-815.

Bauer, DM, and SK Swallow. 2013. Conserving metapopulations in human-altered landscapes at the urban–rural fringe. Ecological Economics **95**: 159-170.

Bauer, DM, SK Swallow, and PWC Paton. 2010b. Cost-effective species conservation in exurban communities: A spatial analysis. Resource and Energy Economics **32**: 180-202.

Beck, CW, and JD Congdon. 2000. Effects of age and size at metamorphosis on performance and metabolic rates of southern toad, *Bufo terrestris*, metamorphs. Functional Ecology **14**: 32-38.

Beese, WJ, BG Dunsworth, and NJ Smith. 2005. Variable-retention adaptive management experiments: testing new approaches for managing British Columbia's coastal forests. Pages 55-64 *in* CE Peterson, and DA Maguire, editors. Balancing ecosystem values: innovative experiments for sustainable forestry: proceedings of a conference. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Begon, M, J Harper, and C Townsend. 1996. Ecology (3rd ed.). Cambridge, Massachusetts, Blackwell Science LTD, xii + 1068 pp.

Beierle, TC, and J Cayford. 2002. Democracy in Practice: Public Participation in Environmental Decisions. Washington DC, Resources for the Future, viii + 149 pp.

Beierle, TC, and DM Konisky. 2000. Values, conflict, and trust in participatory environmental planning. Journal of Policy Analysis and Management **19**: 587-602.

Beierle, TC, and DM Konisky. 2001. What are we gaining from stakeholder involvement? Observations from environmental planning in the Great Lakes. Environment and Planning C-Government and Policy **19**: 515-527.

Bellis, ED. 1962. The influence of humidity on wood frog activity. American Midland Naturalist **68**: 139-148.

Bennett, AF, T Garland, and PL Else. 1989. Individual correlation of morphology, muscle mechanics, and locomotion in a salamander. American Journal of Physiology - Regulatory, Integrative and Comparative Physiology **256**: R1200-R1208.

Benton, TG, and DE Bowler. 2012. Dispersal in invertebrates: influences on individual decisions. Pages 43-49 *in* J Clobert, M Baguette, TG Benton, and JM Bullock, editors. Dispersal Ecology and Evolution. Oxford University Press, Oxford.

Berven, K. 1982. The genetic basis of altitudinal variation in the wood frog *Rana sylvatica*. I. An experimental analysis of life history traits. Evolution **36**: 962-983.

Berven, KA. 1981. Mate choice in the wood frog, *Rana sylvatica*. Evolution **35**: 707-722.

Berven, KA. 1988. Factors affecting variation in reproductive traits within a population of wood frogs (*Rana sylvatica*). Copeia **1988**: 605-615.

Berven, KA. 1990. Factors affecting population fluctuations in larval and adult stages of the wood frog (*Rana sylvatica*). Ecology **71**: 1599-1608.

Berven, KA. 1995. Population regulation in the wood frog, *Rana sylvatica*, from 3 diverse geographic localities. Australian Journal of Ecology **20**: 385-392.

Berven, KA. 2009. Density dependence in the terrestrial stage of wood frogs: evidence from a 21-year population study. Copeia **2009**: 328-338.

Berven, KA, and DE Gill. 1983. Interpreting geographic variation in life-history traits. American Zoologist **23**: 85-97.

Berven, KA, and TA Grudzien. 1990. Dispersal in the wood frog (*Rana sylvatica*): implications for genetic population-structure. Evolution **44**: 2047-2056.

Beuschel, V, and TK Rudel. 2010. Can real-estate developers be "green"?: Sprawl, environmental rhetoric, and land use planning in a New Jersey community. Society & Natural Resources **23**: 97-110.

Blanchard, FN. 1933. Late autumn collections and hibernating situations of the salamander *Hemidactylium scutatum* (Schlegel) in southern Michigan. Copeia **1933**: 216.

Blaustein, AR. 1994. Chicken Little or Nero's fiddle? A perspective on declining amphibian populations. Herpetologica **50**: 85-97.

Blaustein, AR, and JM Kiesecker. 2002. Complexity in conservation: lessons from the global decline of amphibian populations. Ecology Letters **5**: 597-608.

Blomquist, SM, and ML Hunter. 2007. Externally attached radio-transmitters have limited effects on the antipredator behavior and vagility of *Rana pipiens* and *Rana sylvatica*. Journal of Herpetology **41**: 430-438.

Bonte, D, and E De la Pena. 2009. Evolution of body condition-dependent dispersal in metapopulations. Journal of Evolutionary Biology **22**: 1242-1251.

Bowman, T, and J Thompson. 2009. Barriers to implementation of low-impact and conservation subdivision design: Developer perceptions and resident demand. Landscape and Urban Planning **92**: 96-105.

Bowman, T, J Thompson, and J Colletti. 2009. Valuation of open space and conservation features in residential subdivisions. Journal of Environmental Management **90**: 321-330.

Bredahl Jacobsen, J, and N Hanley. 2009. Are there income effects on glocal willingness to pay for biodiversity conservation? Environmental and Resource Economics **43**: 137-160.

Brepson, L, Y Voituron, and T Lengagne. 2013. Condition-dependent ways to manage acoustic signals under energetic constraint in a tree frog. Behavioral Ecology **24**: 488-496.

Broadmeadow, S, and TR Nisbet. 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. Hydrology and Earth System Science **8**: 286-305.

Brodeur, JC, RP Suarez, GS Natale, AE Ronco, and ME Zaccagnini. 2011. Reduced body condition and enzymatic alterations in frogs inhabiting intensive crop production areas. Ecotoxicology and Environmental Safety **74**: 1370-1380.

Brodman, R. 1996. Effects of intraguild interactions on fitness and microhabitat use of larval Ambystoma salamanders. Copeia **1996**: 372-378.

Brody, SD. 2003. Examining the effects of biodiversity on the ability of local plans to manage ecological systems. Journal of Environmental Planning and Management **46**: 817-837.

Brown, SC, and PLM Veneman. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, USA. Wetlands **21**: 508-518.

Bunce, M. 1998. Thirty years of farmland preservation in North America: discourses and ideologies of a movement. Journal of Rural Studies **14**: 233-247.

Bunnell, FL. 2005. Adaptive management for biodiversity in managed forests - it can be done. Pages 3-11 *in* CE Peterson, and DA Maguire, editors. Balancing ecosystem values: innovative experiments for sustainable forestry. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Calhoun, A, and PG deMaynadier. 2002. Forestry habitat management guidelines for vernal pool wildlife in Maine. Orono, Maine, University of Maine, Maine Department of Inland Fisheries and Wildlife, Maine Audubon, and Maine Department of Conservation, 38 pp.

Calhoun, AJK, JS Jansujwicz, KP Bell, and ML Hunter. 2014. Improving management of small natural features on private lands by negotiating the science-policy boundary for Maine vernal pools. Proceedings of the National Academy of Sciences **111**: 11002-11006.

Cariveau, AB, DC Pavlacky, AA Bishop, and TG LaGrange. 2011. Effects of surrounding land use on playa inundation following intense rainfall. Wetlands **31**: 65-73.

Carr, LW, and L Fahrig. 2001. Effect of Road Traffic on Two Amphibian Species of Differing Vagility. Conservation Biology **15**: 1071-1078.

Carruthers, BG, and L Ariovich. 2004. The sociology of property rights. Annual Review of Sociology **30**: 23-46.

Castelle, AJ, AW Johnson, and C Conolly. 1994. Wetland and stream buffer size requirements - a review. Journal of Environmental Quality **23**: 878-882.

Chandler, CH, and KR Zamudio. 2008. Reproductive success by large, closely related males facilitated by sperm storage in an aggregate breeding amphibian. Molecular Ecology **17**: 1564-1576.

Chang, C, JC Allen, SE Dawson, and GE Madsen. 2012. Network analysis as a method for understanding the dynamics of natural resource management in rural communities. Society & Natural Resources **25**: 203-208.

Charmaz, K. 2006. Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis. Washington DC, Sage, xiv + 208 pp.

Chase, VP, LS Deming, and F Latawiec. 1997. Buffers for wetlands and surface waters: a guidebook for New Hampshire municipalities. 2nd edition. Concord, Audubon Society of New Hampshire, 82 pp.

Chazal, AC, and PH Niewiarowski. 1998. Responses of mole salamanders to clearcutting: using field experiments in forest management. Ecological Applications **8**: 1133-1143.

Chen, J, SC Saunders, TR Crow, RJ Naiman, KD Brosofske, GD Mroz, BL Brookshire, and JF Franklin. 1999. Microclimate in forest ecosystem and landscape ecology. BioScience **49**: 288-297.

Church, DR, LL Bailey, HM Wilbur, WL Kendall, and JE Hines. 2007. Iteroparity in the variable environment of the salamander *Ambystoma tigrinum*. Ecology **88**: 891-903.

Clark, TW. 2002. The Policy Process: a Practical Guide for Natural Resources Professionals. New Haven, Connecticut, Yale University Press, xii + 215 pp.

Cline, BB, and ML Hunter. 2014. Different open-canopy vegetation types affect matrix permeability for a dispersing forest amphibian. Journal of Applied Ecology **51**: 319-329.

Clingermayer, JC. 2004. Heresthetics and happenstance: intentional and unintentional exclusionary impacts of the zoning decision-making process. Urban Studies **41**: 377-388.

Cole, EC, WC McComb, M Newton, CL Chambers, and JP Leeming. 1997. Response of amphibians to clearcutting, burning, and glyphosate application in the Oregon Coast Range. The Journal of Wildlife Management **61**: 656-664.

Collins, J, and R Ober. 2009. New Hampshire: Common Ground. Pages 87-123 *in* CHW Foster, editor. Twentieth Century New England Land Conservation: a Heritage of Civic Engagement. Harvard University Press, Cambridge, MA.

Colocousis, CR. 2013. The biophysical dimension of community economic addiction: examining the emergence of biomass energy in a Northern Forest community. Society & Natural Resources **26**: 688-701.

Cooperman, MD, JM Reed, and LM Romero. 2004. The effects of terrestrial and breeding densities on corticosterone and testosterone levels in spotted salamanders, Ambystoma maculatum. Canadian Journal of Zoology **82**: 1795-1803.

Corn, PS, and RB Bury. 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology and Management **29**: 39-57.

Coster, SS. 2013. Landscape genetics of pond-breeding amphibians in a managed forest. University of New Hampshire, Durham, NH, 173 pp.

Coster, SS, AI Kovach, and KJ Babbitt. *in review*. High genetic connectivity in wood frogs (*Lithobates sylvaticus*) and spotted salamanders (*Ambystoma maculatum*) in a commercial forest. Herpetological Conservation and Biology.

Cotton, S, and C Wedekind. 2009. Population consequences of environmental sex reversal. Conservation Biology **23**: 196-206.

Crawford, JA, and RD Semlitsch. 2007. Estimation of core terrestrial habitat for stream-breeding salamanders and delineation of riparian buffers for protection of biodiversity. Conservation Biology **21**: 152-158.

Creighton, J. 2005. The Public Participation Handbook - Making Better Decisions Through Citizen Involvement. San Francisco, Jossey-Bass, 261 pp.

Crump, ML. 2010. Amphibian diversity and life history. Pages 3-20 *in* C Dodd Jr, editor. Amphibian Ecology and Conservation. Oxford University Press, New York.

Cushman, S, B Compton, and K McGarigal. 2009. Habitat fragmentation effects depend on complex interactions between population size and dispersal ability: modeling influences of roads, agriculture, and residential development across a range of life-history characteristics. Pages 369-387 *in* SA Cushman, and F Huettman, editors. Spatial Complexity, Informatics, and Wildlife Conservation. Springer, Tokyo.

Dahl, T. 1990. Wetlands: Losses in the United States: 1780's to 1980's. Washington DC, US Department of the Interior, Fish and Wildlife Service, 13 pp.

Dahl, T. 2011. Status and Trends of Wetlands in the Conterminous United States 2004 to 2009. Washington DC, US Department of the Interior, Fish and Wildlife Service, 108 pp.

Dale, L, and AK Gerlak. 2007. It's all in the numbers: acreage tallies and environmental program evaluation. Environmental Management **39**: 246-260.

Daniels, SE, and GB Walker. 1996. Collaborative learning: improving public deliberation in ecosystem-based management. Environmental Impact Assessment Review **16**: 71-102.

Davic, RD, and HH Welsh, Jr. 2004. On the ecological role of salamanders. Annual Review of Ecology, Evolution, and Systematics **35**: 405-434.

De Meester, L, S Declerck, R Stoks, G Louette, F Van De Meutter, T De Bie, E Michels, and L Brendonck. 2005. Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. Aquatic Conservation: Marine and Freshwater Ecosystems **15**: 715-725.

Degraaf, RM, and M Yamasaki. 2001. New England Wildlife: Habitat, Natural History, and Distribution. Hanover, New Hampshire, University Press of New England, 496 pp.

Deichmann, JL, WE Duellman, and GB Williamson. 2008. Predicting biomass from snout-vent length in new world frogs. Journal of Herpetology **42**: 238-245.

deMaynadier, PG, and JE Houlahan. 2008. Conserving vernal pool amphibians in managed forests. Page 392 *in* AJK Calhoun, and PG deMaynadier, editors. Science and conservation of vernal pools in northeastern North America. CRC Press, Boca Raton, FL.

deMaynadier, PG, and ML Hunter Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Reviews **3**: 230-261.

deMaynadier, PG, and ML Hunter. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology **12**: 340-352.

Denters, B, and LE Rose. 2005a. Local governance in the third millennium: a brave new world? Pages 1-11 *in* B Denters, and LE Rose, editors. Comparing Local Governance: Trends and Developments. Palgrave MacMillan, New York.

Denters, B, and LE Rose. 2005b. Towards Local Governance? Pages 246-262 *in* B Denters, and LE Rose, editors. Comparing Local Governance: Trends and Developments. Palgrave Macmillan, New York.

DeSantis, VS, and D Hill. 2004. Citizen participation in local politics: evidence from New England town meetings. State & Local Government Review **36**: 166-173.

Devine-Wright, P. 2009. Rethinking NIMBYism: the role of place attachment and place identity in explaining place-protective action. Journal of Community & Applied Social Psychology **19**: 426-441.

Donahue, B, J Burke, M Anderson, A Beal, T Kelly, M Lapping, H Ramer, R Libby, and L Berlin. 2014. A New England food vision: healthy food for all, sustainable farming and fishing, thriving communities. Durham, NH, Food Solutions New England, 48 pp.

Douglas, GCC. 2012. Cultural expectations and urban development: the role of "cultural sensitivity" and "cultural sincerity" in local growth politics. Sociological Perspectives **55**: 213-236.

Dryzek, J. 1997. The Politics of the Earth: Environmental Discourses. Oxford, England, Oxford University Press, 276 pp.

Ducey, PK, and P Ritsema. 1988. Intraspecific aggression and responses to marked substrates in *Ambystoma maculatum* (Caudata: Ambystomatidae). Copeia **1988**: 1008-1013.

Dupuis, L, and D Steventon. 1999. Riparian management and the tailed frog in northern coastal forests. Forest Ecology and Management **124**: 35-43.

DuShane, GP, and C Hutchinson. 1944. Differences in size and developmental rate between eastern and midwestern embryos of *Ambystoma maculatum*. Ecology **25**: 414-423.

Dutcher, D, J Finley, A Luloff, and J Johnson. 2004. Landowner perceptions of protecting and establishing riparian forests: a qualitative analysis. Society and Natural Resources **17**: 319-332.

Egan, RS, and PWC Paton. 2004. Within-pond parameters affecting oviposition by wood frogs and spotted salamanders. Wetlands **24**: 1-13.

Eggert, C, and R Guyetant. 2003. Reproductive behaviour of spadefoot toads (*Pelobates fuscus*): daily sex ratios and males' tactics, ages, and physical condition. Canadian Journal of Zoology **81**: 46-51.

Emel, JL, and E Brooks. 1988. Changes in form and function of property-rights institutions under threatened resource scarcity. Annals of the Association of American Geographers **78**: 241-252.

Emerson, SB. 1978. Allometry and jumping in frogs: helping the twain to meet. Evolution **32**: 551-564.

Enge, KM, and WR Marion. 1986. Effects of clearcutting and site preparation on herpetofauna of a North Florida flatwoods. Forest Ecology and Management **14**: 177-192.

Erwin, K. 2009. Wetlands and global climate change: the role of wetland restoration in a changing world. Wetlands Ecology and Management **17**: 71-84.

Faccio, SD. 2003. Postbreeding emigration and habitat use by Jefferson and spotted salamanders in Vermont. Journal of Herpetology **37**: 479-489.

Fahrig, L, JH Pedlar, SE Pope, PD Taylor, and JF Wegner. 1995. Effect of road traffic on amphibian density. Biological Conservation **73**: 177-182.

FAO. 2012. State of the World's Forests 2012. Rome, United Nations, Food and Agriculture Organization, 60 pp.

Ferner, JW. 2010. Measuring and marking post-metamorphic amphibians. Pages 123-141 *in* C Dodd Jr, editor. Amphibian Ecology and Conservation: A Handbook of Techniques. Oxford University Press, New York.

Ficetola, GF, E Padoa-Schioppa, and F De Bernardi. 2009. Influence of Landscape Elements in Riparian Buffers on the Conservation of Semiaquatic Amphibians. Conservation Biology **23**: 114-123.

Finkler, MS. 2013. Sexual dimorphism in visceral organ mass and hematology in spotted salamanders, *Ambystoma maculatum*, before and after breeding. Copeia **2013**: 338-345.

Finkler, MS, MT Sugalski, DL Claussen, and SJ Beaupre. 2003. Sex-related differences in metabolic rate and locomotor performance in breeding spotted salamanders (*Ambystoma maculatum*). Copeia **2003**: 887-893.

Flageole, S, and R Leclair, Jr. 1992a. Etude demographique d'une population de salamandres (Ambystoma maculatum) a l'aide de la methode squeletto-chronologique. Canadian Journal of Zoology **70**: 740-749.

Flageole, S, and R Leclair, Jr. 1992b. Etude démographique d'une population de salamandres (*Ambystoma maculatum*) à l'aide de la méthode squeletto-chronologique. Canadian Journal of Zoology **70**: 740-749.

Focht, W, and Z Trachtenberg. 2005. A trust-based guide to stakeholder participation. Pages 85-135 *in* P Sabatier, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock, editors. Swimming Upstream: Collaborative Approaches to Watershed Management. The MIT Press, Cambridge, Massachusetts.

Foster, CHW. 2009. Environmental Conservation in Massachusetts: a Twentieth Century Overview. Pages 175-215 *in* CHW Foster, editor. Twentieth Century New England Land Conservation: a Heritage of Civic Engagement. Harvard University Press, Cambridge, MA.

Fraley, JM. 2011. The Political Rhetoric of Property and Natural Resource Ownership: A Meditation on Chance, Taxation and Appalachia. Society & Natural Resources **25**: 127-140.

Franzen, A, and D Vogl. 2013. Two decades of measuring environmental attitudes: A comparative analysis of 33 countries. Global Environmental Change-Human and Policy Dimensions **23**: 1001-1008.

Freeman, RC, and KP Bell. 2011. Conservation versus cluster subdivisions and implications for habitat connectivity. Landscape and Urban Planning **101**: 30-42.

Freeman, RC, KP Bell, AJK Calhoun, and CS Loftin. 2012. Incorporating economic models into seasonal pool conservation planning. Wetlands **32**: 509-520.

Freidenfelds, NA, JL Purrenhage, and KJ Babbitt. 2011. The effects of clearcuts and forest buffer size on post-breeding emigration of adult wood frogs (*Lithobates sylvaticus*). Forest Ecology and Management **261**: 2115-2122.

Fretwell, SD. 1972. Populations in a Seasonal Environment. Princeton, Princeton University Press, 224 pp.

Freyfogle, E. 1998. Owning the land: Four contemporary narratives. Journal of Land Use and Environmental Law **13**: 279-307.

Freyfogle, ET. 1995. The Owning and Taking of Sensitive Lands. UCLA Law Review **43**: 77-138.

Friedland, AJ, RT Jones, TF Gross, and SD Blackmer. 2004. Towards a sustainable northern forest. Journal of Sustainable Forestry **18**: 1-22.

Gabrielsen, CG, AI Kovach, KJ Babbitt, and WH McDowell. 2013. Limited effects of suburbanization on the genetic structure of an abundant vernal pool-breeding amphibian. Conservation Genetics **14**: 1083-1097.

Gamble, LR, K McGarigal, CL Jenkins, and BC Timm. 2006. Limitations of regulated "buffer zones" for the conservation of marbled salamanders. Wetlands **26**: 298-306.

Garner, TWJ, JM Rowcliffe, and MC Fisher. 2011. Climate change, chytridiomycosis or condition: an experimental test of amphibian survival. Global Change Biology **17**: 667-675.

Gelissen, J. 2007. Explaining popular support for environmental protection - A multilevel analysis of 50 nations. Environment and Behavior **39**: 392-415.

Gervasi, S, and J Foufopoulos. 2008. Costs of plasticity: responses to desiccation decrease post-metamorphic immune function in a pond-breeding amphibian. Functional Ecology **22**: 100-108.

GFGS. 2009. Good Forestry in the Granite State: August 24, 2009 Minutes. Good Forestry in the Granite State: Steering Committee Minutes. K Ferrare, editor. University of New Hampshire Cooperative Extension, Durham, NH. Available from http://goodforestry.pbworks.com/w/page/14870035/August%2024%2C%202009%20Minutes (accessed 29 August 2013).

Gibbons, JW, CT Winne, DE Scott, JD Willson, X Glaudas, KM Andrews, BD Todd, LA Fedewa, L Wilkinson, RN Tsaliagos, SJ Harper, JL Greene, TD Tuberville, BS Metts, ME Dorcas, JP Nestor, CA Young, T Akre, RN Reed, KA Buhlmann, J Norman, DA Croshaw, C Hagen, and BB Rothermel. 2006. Remarkable amphibian biomass and abundance in an isolated wetland: implications for wetland conservation. Conservation Biology **20**: 1457-1465.

Gibbs, D, and R Krueger. 2011. Fractures in meta-narratives of development: an interpretive institutionalist account of land use development in the Boston city-region. International Journal of Urban and Regional Research **36**: 363-380.

Gibbs, JP. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. Landscape Ecology **13**: 263-268.

Gibbs, JP, and WG Shriver. 2005. Can road mortality limit populations of pool-breeding amphibians? Wetlands Ecology and Management **13**: 281-289.

Gill, DE. 1985. Interpreting breeding patterns from census data: a solution to the Husting dilemma. Ecology **66**: 344-354.

Glaeser, EL. 2007. Restricting Residential Construction. Pages 38-62 *in* GK Ingram, and Y Hong, editors. Land Policies and Their Outcomes. Lincoln Institute of Land Policy, Cambridge, MA.

Glaeser, EL, and BA Ward. 2009. The causes and consequences of land use regulation: evidence from Greater Boston. Journal of Urban Economics **65**: 265-278.

Goater, CP, RD Semlitsch, and MV Bernasconi. 1993. Effects of body size and parasite infection on the locomotory performance of juvenile toads, *Bufo bufo*. Oikos **66**: 129-136.

Goates, MC, KA Hatcha, and DL Eggett. 2007. The need to ground truth 30.5 m buffers: a case study of the boreal toad (*Bufo boreas*). Biological Conservation **138**: 474-483.

Gober, P, KL Larson, R Quay, C Polsky, H Chang, and V Shandas. 2013. Why land planners and water managers don't talk to one another and why they should! Society & Natural Resources **26**: 356-364.

Göçmen, ZA. 2013. Barriers to successful implementation of conservation subdivision design: A closer look at land use regulations and subdivision permitting process. Landscape and Urban Planning **110**: 123-133.

Graeter, GJ, BB Rothermel, and JW Gibbons. 2008. Habitat selection and movement of pond-breeding amphibians in experimentally fragmented pine forests. Journal of Wildlife Management **72**: 473-482.

Grayson, KL, SP De Lisle, JE Jackson, SJ Black, and EJ Crespi. 2012. Behavioral and physiological female responses to male sex ratio bias in a pond-breeding amphibian. Frontiers in Zoology **9**: 24.

Green, AJ. 2001. Mass/length residuals: measures of body condition or generators of spurious results? Ecology **82**: 1471-1483.

Guerry, AD, and ML Hunter. 2002. Amphibian distributions in a landscape of forests and agriculture: an examination of landscape composition and configuration. Conservation Biology **16**: 745-754.

Gulsrud, NM, S Gooding, and CCK van den Bosch. 2013. Green space branding in Denmark in an era of neoliberal governance. Urban Forestry & Urban Greening **12**: 330-337.

Hall, RH, and PS Tolbert. 2005. Organizations: Structures , Processes, and Outcomes (Ninth ed.). Upper Saddle River, New Jersey, Pearson Prentice Hall, xv + 292 pp.

Hambleton, R, and J Howard. 2013. Place-based leadership and public service innovation. Local Government Studies **39**: 47-70.

Hanna, KS, A Dale, and C Ling. 2009. Social capital and quality of place: reflections on growth and change in a small town. Local Environment **14**: 31-44.

Hanna, S, and J Rowley. 2008. An analysis of terminology use in place branding. Place Branding and Public Diplomacy **4**: 61-75.

Hannon, SJ, CA Paszkowski, S Boutin, J DeGroot, SE Macdonald, M Wheatley, and BR Eaton. 2002. Abundance and species composition of amphibians, small mammals, and songbirds in riparian forest buffer strips of varying widths in the boreal mixedwood of Alberta . Canadian Journal of Forest Research **32**: 1784.

Hansen, AJ, RL Knight, JM Marzluff, S Powell, K Brown, PH Gude, and K Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications **15**: 1893-1905.

Harmon, J. 2005. Live free (or die trying). Southwest Review **90**: 503-532.

Harper, CA, and DC Guynn Jr. 1999. Factors affecting salamander density and distribution within four forest types in the Southern Appalachian Mountains. Forest Ecology and Management **114**: 245-252.

Harper, EB, TAG Rittenhouse, and RD Semlitsch. 2008. Demographic consequences of terrestrial habitat loss for pool-breeding amphibians: Predicting extinction risks associated with inadequate size of buffer zones. Conservation Biology **22**: 1205-1215.

Harper, EB, and RD Semlitsch. 2007. Density dependence in the terrestrial life history stage of two anurans. Oecologia **153**: 879-889.

Harpole, DN, and CA Haas. 1999. Effects of seven silvicultural treatments on terrestrial salamanders. Forest Ecology and Management **114**: 349-356.

Hart, DD, and AJK Calhoun. 2010. Rethinking the role of ecological research in the sustainable management of freshwater ecosystems. Freshwater Biology **55**: 258-269.

Hawkes, VC, and PT Gregory. 2012. Temporal changes in the relative abundance of amphibians relative to riparian buffer width in western Washington, USA. Forest Ecology and Management **274**: 67-80.

Hawkins, C. 2011. Electoral support for community growth management policy. Social Science Quarterly **92**: 268-284.

Hawkins, CV. 2014. Landscape conservation through residential subdivision bylaws: Explanations for local adoption. Landscape and Urban Planning **121**: 141-148.

Hayhoe, K, CP Wake, TG Huntington, L Luo, MD Schwartz, J Sheffield, E Wood, B Anderson, J Bradbury, A DeGaetano, TJ Troy, and D Wolfe. 2007. Past and future changes in climate and hydrological indicators in the US Northeast. Climate Dynamics **28**: 381-407.

Heatwole, H. 1961. Habitat selection and activity of the wood frog, Rana sylvatica Le Conte. American Midland Naturalist **66**: 301-313.

Hector, KL, and S Nakagawa. 2012. Quantitative analysis of compensatory and catch-up growth in diverse taxa. Journal of Animal Ecology **81**: 583-593.

Heinen, JT, and JN Mehta. 2000. Emerging issues in legal and procedural aspects of buffer zone management with case studies from Nepal. The Journal of Environment & Development **9**: 45-67.

Herrmann, HL, KJ Babbitt, MJ Baber, and RG Congalton. 2005. Effects of landscape characteristics on amphibian distribution in a forest-dominated landscape. Biological Conservation **123**: 139-149.

Hesse-Biber, S, and P. Leavy. 2004. Approaches to Qualitative Research. New York, Oxford University Press, pp.

Hocking, D, and KJ Babbitt. 2014. Amphibian contributions to ecosystem services. Herpetological Conservation and Biology **9**: 1-17.

Homan, RN, BS Windmiller, and J Michael Reed. 2007. Comparative life histories of two sympatric *Ambystoma* species at a breeding pond in Massachusetts. Journal of Herpetology **41**: 401-409.

Homan, RN, BS Windmiller, and JM Reed. 2004. Critical thresholds associated with habitat loss for two vernal pool-breeding amphibians. Ecological Applications **14**: 1547-1553.

Homyack, JA. 2010. Evaluating habitat quality of vertebrates using conservation physiology tools. Wildlife Research **37**: 332-342.

Homyack, JA, CA Haas, and WA Hopkins. 2011. Energetics of surface-active terrestrial salamanders in experimentally harvested forest. Journal of Wildlife Management **75**: 1267-1278.

Howard, RD, and AG Kluge. 1985. Proximate mechanisms of sexual selection in wood frogs. Evolution **39**: 260-277.

Humfeld, SC. 2013. Condition-dependent signaling and adoption of mating tactics in an amphibian with energetic displays. Behavioral Ecology **24**: 859-870.

Hurley, JM, C Ginger, and DE Capen. 2002. Property concepts, ecological thought, and ecosystem management: a case of conservation policymaking in Vermont. Society & Natural Resources **15**: 295-312.

Husting, EL. 1965. Survival and breeding structure in a population of *Ambystoma maculatum*. Copeia **1965**: 352-362.

Irland, LC. 1999. The Northeast's Changing Forest. Cambridge, MA, Harvard University Press, 432 pp.

Ivakhiv, A. 2010. From frames to resonance machines: the neuropolitics of environmental communication. Environmental Communication **4**: 109-121.

Jackson-Smith, D, U Kreuter, and RS Krannich. 2005. Understanding the multidimensionality of property rights orientations: evidence from Utah and Texas ranchers. Society and Natural Resources **18**: 587-610.

Jacobs, HM. 2004. The future of an American ideal. Pages 171-184 *in* HM Jacobs, editor. Private Property in the 21st Century. Edward Elgar Publishing, Inc., Northhampton, MA.

Jacobs, HM, and K Paulsen. 2009. Property rights: the neglected theme of 20th-century American planning. Journal of the American Planning Association **75**: 134-143.

Jacobson, SK. 2009. Communication Skills for Conservation Professionals (2nd ed.). Washington DC, Island Press, xiii + 461 pp.

Janin, A, J-P Lena, and P Joly. 2011. Beyond occurrence: body condition and stress hormone as integrative indicators of habitat availability and fragmentation in the common toad. Biological Conservation **144**: 1009-1016.

Jansujwicz, JS, AJK Calhoun, JE Leahy, and RJ Lilieholm. 2013a. Using mixed methods to develop a frame-based private landowner typology. Society & Natural Resources **26**: 945-961.

Jansujwicz, JS, AJK Calhoun, and RJ Lilieholm. 2013b. The Maine Vernal Pool Mapping and Assessment Program: engaging municipal officials and private landowners in community-based citizen science. Environmental Management **52**: 1369-1385.

Jeon, SB, P Olofsson, and CE Woodcock. 2012. Land use change in New England: a reversal of the forest transition. Journal of Land Use Science **9**: 105-130.

Jimenez, BS. 2014. Separate, unequal, and ignored? Interjurisdictional competition and the budgetary choices of poor and affluent municipalities. Public Administration Review **74**: 246-257.

Johansson, M. 2012. Place branding and the imaginary: the politics of re-imagining a garden city. Urban Studies **49**: 3611-3626.

Johansson, M, J Rahm, and M Gyllin. 2013. Landowners' participation in biodiversity conservation examined through the value-belief-norm theory. Landscape Research **38**: 295-311.

John, D. 1994. Civic Environmentalism: Alternatives to Regulation in States and Communities. Washington DC, CQ Press, xvi + 347 pp.

John, D. 2000. Good cops, bad cops. Pages 61-64 *in* C Sabel, A Fung, and B Karkkainen, editors. Beyond Backyard Environmentalism. Beacon Press, Boston.

John-Alder, HB, and PJ Morin. 1990. Effects of larval density on jumping ability and stamina in newly metamorphosed *Bufo woodhousii fowleri*. Copeia **1990**: 856-860.

Johnston, B, and L Frid. 2002. Clearcut logging restricts the movements of terrestrial Pacific giant salamanders (*Dicamptodon tenebrosus* Good). Canadian Journal of Zoology **80**: 2170-2177.

Johst, K, and R Brandl. 1997. Body size and extinction risk in a stochastic environment. Oikos **78**: 612-617.

Joyal, LA, M McCollough, and ML Hunter Jr. 2001. Landscape ecology approaches to wetland species conservation : a case study of two turtle species in southern Maine. Conservation Biology **15**: 1755-1762.

Kahn, ME. 2002. Demographic change and the demand for environmental regulation. Journal of Policy Analysis and Management **21**: 45-62.

Kaplan, RH, and SN Salthe. 1979. The allometry of reproduction: an empirical view in salamanders. The American Naturalist **113**: 671-689.

Kaplowitz, MD, and J Kerr. 2003. Michigan residents' perceptions of wetlands and mitigation. Wetlands **23**: 267-277.

Kardynal, KJ, JL Morissette, SL Van Wilgenburg, EM Bayne, and KA Hobson. 2011. Avian responses to experimental harvest in southern boreal mixedwood shoreline forests: implications for riparian buffer management. Canadian Journal of Forest Research **41**: 2375-2388.

Karraker, NE, and JP Gibbs. 2011. Contrasting road effect signals in reproduction of long-versus short-lived amphibians. Hydrobiologia **664**: 213-218.

Karraker, NE, and HH Welsh, Jr. 2006. Long-term impacts of even-aged timber management on abundance and body condition of terrestrial amphibians in Northwestern California. Biological Conservation **131**: 132-140.

Kerwin, C. 2003. Rulemaking: How Government Agencies Write Laws and Make Policies (3rd ed.). Washington DC, CQ Press, xi + 300 pp.

Kettlewell, CI, V Bouchard, D Porej, M Micacchion, JJ Mack, D White, and L Fay. 2008. An assessment of wetland impacts and compensatory mitigation in the Cuyahoga River watershed, Ohio, USA. Wetlands **28**: 57-67.

Klenner, W, A Arsenault, EG Brockerhoff, and A Vyse. 2009. Biodiversity in forest ecosystems and landscapes: A conference to discuss future directions in biodiversity management for sustainable forestry. Forest Ecology and Management **258**: S1-S4.

Knapp, SM, CA Haas, DN Harpole, and RL Kirkpatrick. 2003. Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. Conservation Biology **17**: 752-762.

Knox, CB. 1999. Wood Frog. Pages 111-118 *in* ML Hunter, Jr., AJK Calhoun, and M McCollough, editors. Maine Amphibians and Reptiles. The University of Maine Press, Orono, Maine.

Komoroski, MJ, RD Nagle, and JD Congdon. 1998. Relationships of lipids to ovum size in amphibians. Physiological Zoology **71**: 633-641.

Kondo, MC, R Rivera, and S Rullman. 2012. Protecting the idyll but not the environment: second homes, amenity migration and rural exclusion in Washington state. Landscape and Urban Planning **106**: 174-182.

Kraft, M. 2009. Cleaning Wisconsin's waters: from command and control to collaborative decision making. Pages 115-140 *in* D Mazmanian, and M Kraft, editors. Toward Sustainable Communities: Transition and Transformations in Environmental Policies (2nd ed.). The MIT Press, Cambridge, Massachusetts.

Kraft, ME, and DA Mazmanian. 2009. Conclusions: Towards Sustainable Communities. Pages 317-334 *in* DA Mazmanian, and ME Kraft, editors. Toward Sustainable Communities: Transition and Transformations in Environmental Policy (2nd ed.). The MIT Press, Cambridge, MA.

Lautzenheiser, T, J Collins, EH Ricci, and J Clarke. 2014. Losing Ground: Planning for Resilience. Lincoln, MA, Massachusetts Audubon Society, Inc, 32 pp.

Leach, W, and P Sabatier. 2005. Are trust and social capital the keys to success? Watershed partnerships in California and Washington. Pages 232-258 *in* P Sabatier, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock, editors. Swimming Upstream: Collaborative Approaches to Watershed Management. The MIT Press, Cambridge, Massachusetts.

Leach, WD, and NW Pelkey. 2001. Making watershed partnerships work: a review of the empirical literature. Journal of Water Resources Planning and Management **127**: 378-385.

Lee, CW. 2011. The politics of localness: scale-bridging ties and legitimacy in regional resource management partnerships. Society & Natural Resources **24**: 439-454.

Lee, P, C Smyth, and S Boutin. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management **70**: 165-180.

Levi, JH, DJ Gehring, and R Groethe. 1976. Application of municipal ordinances to special purpose districts and regulated industries: a home rule approach. Urban Law Annual Review **77**: 77-123.

Lewicka, M. 2011. Place attachment: how far have we come in the last 40 years? Journal of Environmental Psychology **31**: 207-230.

Lobao, L, and D Kraybill. 2009. Poverty and local governments: economic development and community service provision in an era of decentralization. Growth & Change **40**: 418-451.

Lochmiller, RL, and C Deerenberg. 2000. Trade-offs in evolutionary immunology: just what is the cost of immunity? Oikos **88**: 87-98.

Lokocz, E, RL Ryan, and AJ Sadler. 2011. Motivations for land protection and stewardship: exploring place attachment and rural landscape character in Massachusetts. Landscape and Urban Planning **99**: 65-76.

Lovell, ST, and WC Sullivan. 2006. Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. Agriculture Ecosystems & Environment **112**: 249-260.

Lubell, M, WD Leach, and PA Sabatier. 2009. Collaborative watershed partnerships in the epoch of sustainability. Pages 255-288 *in* D Mazmanian, and M Kraft, editors. Toward Sustainable Communities: Transition and Transformation in Environmental Policy (2nd ed.). The MIT Press, Cambridge, Massachusetts.

Lubell, M, P Sabatier, A Vedlitz, W Focht, Z Trachtenberg, and M Matlock. 2005b. Conclusions and recommendations. Pages 261-296 *in* P Sabatier, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock, editors. Swimming Upstream: Collaborative Approaches to Watershed Management. The MIT Press, Cambridge, Massachusetts.

Lubell, M, PA Sabatier, A Vedlitz, W Focht, Z Trachtenberg, and M Matlock. 2005. Conclusions and recommendations. Pages 261-296 *in* PA Sabatier, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock, editors. Swimming Upstream: Collaborative Approaches to Watershed Management. The MIT Press, Cambridge, Massachusetts.

M.G.L. c.131§ 40. Massachusetts General Laws. Massachusetts Wetlands Protection Act.

MacCracken, JG, and JL Stebbings. 2012. Test of a body condition index with amphibians. Journal of Herpetology **46**: 346-350.

Madison, DM. 1997. The emigration of radio-implanted spotted salamanders, *Ambystoma maculatum*. Journal of Herpetology **31**: 542-551.

Mandarano, L. 2008. Evaluating collaborative environmental planning outputs and outcomes. Journal of Planning Education and Research **27**: 456-468.

Mangel, M, and SB Munch. 2005. A life-history perspective on short- and long-term consequences of compensatory growth. The American Naturalist **166**: E155-76.

Marczak, LB, T Sakamaki, SL Turvey, I Deguise, SLR Wood, and JS Richardson. 2010. Are forested buffers an effective conservation strategy for riparian fauna? An assessment using meta-analysis. Ecological Applications **20**: 126-134.

Marshall, WH, and MF Buell. 1955. A study of the occurrence of amphibians in relation to a bog succession, Itasca State Park, Minnesota. Ecology **36**: 381-387.

Mayer, PM, SK Reynolds, MD McCutchen, and TJ Canfield. 2007. Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality **36**: 1172-1180.

McCauley, SM, and JT Murphy. 2013. Smart growth and the scalar politics of land management in the Greater Boston region, USA. Environment and Planning A **45**: 2852-2867.

McMurry, ST, LM Smith, KD Dupler, and MB Gutierrez. 2009. Influence of land use on body size and splenic cellularity in wetland breeding *Spea* spp. Journal of Herpetology **43**: 421-430.

MEA. 2005. Ecosystems and Human Well-being: Wetlands and Water Synthesis. Millennium Ecosystem Assessment. World Resources Institute, Washington DC. Available from http://www.millenniumassessment.org/documents/document.358.aspx.pdf (accessed 11 Dec 2010).

Merenlender, AM, SE Reed, and KL Heise. 2009. Exurban development influences woodland bird composition. Landscape and Urban Planning **92**: 255-263.

Mermet, L. 1991. Participation, strategies and ethics: roles of people in wetland management. Landscape and Urban Planning **20**: 231-237.

Meyer, S, and D Konisky. 2007a. Adopting local environmental institutions - Environmental need and economic constraints. Political Research Quarterly **60**: 3-16.

Meyer, S, and D Konisky. 2007b. Local institutions and environmental outcomes: evidence from wetlands protection in Massachusetts. Policy Studies Journal **35**: 481-502.

Miller, A. 2001. Aquatic communities in northern forest wetlands: characteristics and influences of timber harvest. (Master's). North Dakota State University of Agriculture and Applied Science, Fargo, North Dakota, 121 pp.

Miller, JR, M Groom, GR Hess, T Steelman, DL Stokes, J Thompson, T Bowman, L Fricke, B King, and R Marquardt. 2008. Biodiversity conservation in local planning. Conservation Biology **23**: 53-63.

Mitsch, WJ, and JG Gosselink. 2007. Wetlands (4th ed.). Hoboken, New Jersey, John Wiley & Sons, 582 pp.

Moglen, GE, and S Kim. 2007. Limiting imperviousness - Are threshold-based policies a good idea? Journal of the American Planning Association **73**: 161-171.

Molotch, H. 1976. The city as a growth machine: toward a political economy of place. American Journal of Sociology **82**: 309-332.

Mora, C, DP Tittensor, S Adl, AGB Simpson, and B Worm. 2011. How many species are there on earth and in the ocean? PLoS Biol **9**: e1001127 EP.

Morey, S, and D Reznick. 2001. Effects of larval density on postmetamorphic spadefoot toads (*Spea hammondii*). Ecology **82**: 510-522.

Morris, KM, and TJ Maret. 2007. Effects of timber management on pond-breeding salamanders. Journal of Wildlife Management **71**: 1034-1041.

Morrison, C, and J-M Hero. 2003. Geographic variation in life-history characteristics of amphibians: a review. Journal of Animal Ecology **72**: 270-279.

Nagy, N. 2001. Life Free or Die as a linguistic principle. American Speech **76**: 30-41.

Neckel-Oliveira, S, and C Gascon. 2006. Abundance, body size and movement patterns of a tropical treefrog in continuous and fragmented forests in the Brazilian Amazon. Biological Conservation **128**: 308-315.

NEFA. 2013. The economic importance of the forest-based economies of Maine, New Hampshire, New York, and Vermont. Concord, NH, North East State Foresters Association, 4 pp.

Newman, RA, and AE Dunham. 1994. Size at metamorphosis and water loss in a desert anuran (*Scaphiopus couchii*). Copeia **1994**: 372-381.

Nolan, S, O Ferguson, and P Field. 2013. Land in Conflict: Managing and Resolving Land Use Disputes. Cambridge, MA, Lincoln Institute of Land Policy, xv + 188 pp.

Ogneva-Himmelberger, Y, H Pearsall, and R Rakshit. 2009. Concrete evidence & geographically weighted regression: a regional analysis of wealth and the land cover in Massachusetts. Applied Geography **29**: 478-487.

Olson, DH, and C Rugger. 2007. Preliminary study of the effects of headwater riparian reserves with upslope thinning on stream habitats and amphibians in western Oregon. Forest Science **53**: 331-342.

Owens, K, and C Zimmerman. 2013. Local governance versus centralization: Connecticut wetlands governance as a model. Review of Policy Research **30**: 629-656.

Pampel, FC. 2014. The Varied Influence of SES on Environmental Concern. Social Science Quarterly **95**: 57-75.

Parisi, D, M Taquino, SM Grice, and DA Gill. 2004. Civic responsibility and the environment: linking local conditions to community environmental activeness. Society & Natural Resources **17**: 97-112.

Patrick, DA, AJK Calhoun, and ML Hunter Jr. 2008a. The importance of understanding spatial population structure when evaluating the effects of silviculture on spotted salamanders (Ambystoma maculatum). Biological Conservation **141**: 807-814.

Patrick, DA, EB Harper, ML Hunter, and AJK Calhoun. 2008b. Terrestrial habitat selection and strong density-dependent mortality in recently metamorphosed amphibians. Ecology **89**: 2563-2574.

Patrick, DA, ML Hunter Jr., and AJK Calhoun. 2006. Effects of experimental forestry treatments on a Maine amphibian community. Forest Ecology and Management **234**: 323-332.

Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology and Evolution **10**: 430.

Payne, C. 1998. Local regulation of natural resources: efficiency, effectiveness, and fairness of wetlands permitting in Massachusetts. Environmental Law **28**: 519-568.

Pechmann, JHK, DE Scott, RD Semlitsch, JP Caldwell, LJ Vitt, and JW Gibbons. 1991. Declining amphibian populations: the problem of separating human impacts from natural fluctuations. Science **253**: 892-895.

Pechmann, JHK, DE Scott, J Whitfield Gibbons, and RD Semlitsch. 1989. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. Wetlands Ecology and Management **1**: 3-11.

Peig, J, and AJ Green. 2010. The paradigm of body condition: a critical reappraisal of current methods based on mass and length. Functional Ecology **24**: 1323-1332.

Penman, TD. 2008. Applied conservation management of a threatened forest dependent frog, *Heleioporus australiacus*. Endangered Species Research **5**: 45-53.

Perkins, DW, and ML Hunter, Jr. 2006. Effects of riparian timber management on amphibians in Maine. The Journal of Wildlife Management **70**: 657-670.

Peterson, CE, and PD Anderson. 2009. Large-scale interdisciplinary experiments inform current and future forestry management options in the US Pacific Northwest. Forest Ecology and Management **258**: 409-414.

Peterson, CE, and RA Monserud. 2002. Compatibility between wood production and other values and uses on forested lands: a problem analysis. General Technical Report PNW-GTR-564. Portland, OR, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 51 pp.

Petranka, JW, CK Smith, and AF Scott. 2004. Identifying the minimal demographic unit for monitoring pond-breeding amphibians. Ecological Applications **14**: 1065-1078.

Pimm, SL, CN Jenkins, R Abell, TM Brooks, JL Gittleman, LN Joppa, PH Raven, CM Roberts, and JO Sexton. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science **344**: DOI: 10.1126/science.1246752.

Pinheiro, JC, and DM Bates. 2000. Mixed-Effects Models in S and S-PLUS. New York, Springer, xvi + 528 pp.

Pocewicz, A, and M Nielsen-Pincus. 2013. Preferences of Wyoming residents for siting of energy and residential development. Applied Geography **43**: 45-55.

Pollett, KL, JG MacCracken, and JA MacMahon. 2010. Stream buffers ameliorate the effects of timber harvest on amphibians in the Cascade Range of Southern Washington, USA. Forest Ecology and Management **260**: 1083-1087.

Ponsero, A, and P Joly. 1998. Clutch size, egg survival and migration distance in the agile frog (*Rana dalmatina*) in a floodplain. Archiv fur Hydrobiologie **142**: 343-352.

Popescu, VD, and ML Hunter Jr. 2011. Clear-cutting affects habitat connectivity for a forest amphibian by decreasing permeability to juvenile movements. Ecological Applications **21**: 1283-1295.

Popescu, VD, DA Patrick, ML Hunter Jr., and AJK Calhoun. 2012. The role of forest harvesting and subsequent vegetative regrowth in determining patterns of amphibian habitat use. Forest Ecology and Management **270**: 163-174.

Pough, FH. 1980. The advantages of ectothermy for tetrapods. The American Naturalist **115**: 92-112.

R Core Team. 2011. R: A Language and Environment for Statistical Computing., R Foundation for Statistical Computing.

Ramsar. 2001. Wetland values and functions: reservoirs of biodiversity. Gland, Switzerland, The Ramsar Bureau, 2 pp.

Ramsar. 2013. The Ramsar Convention manual: a guide to the Convention on Wetlands (Ramsar, Iran, 1971) (6th ed.). Gland, Switzerland, Ramsar Convention Secretariat, 112 pp.

Randhir, T, and P Ekness. 2009. Urbanization effects on watershed habitat potential: a multivariate assessment of thresholds and interactions. Ecohydrology **2**: 88-101.

Raymond, L, and A Olive. 2008. Landowner beliefs regarding biodiversity protection on private property: an Indiana case study. Society & Natural Resources **21**: 483-497.

Reading, CJ. 2007. Linking global warming to amphibian declines through its effects on female body condition and survivorship. Oecologia **151**: 125-131.

Redmer, M, and SE Trauth. 2005. *Rana sylvatica* LeConte, 1825, Wood Frog. *in* MJ Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

Regester, KJ, KR Lips, and MR Whiles. 2006. Energy flow and subsidies associated with the complex life cycle of ambystomatid salamanders in ponds and adjacent forest in Southern Illinois. Oecologia **147**: 303-314.

Regester, KJ, and MR Whiles. 2006. Decomposition rates of salamander (*Ambystoma maculatum*) life stages and associated energy and nutrient fluxes in ponds and adjacent forest in Southern Illinois. Copeia **2006**: 640-649.

Regosin, JV, BS Windmiller, RN Homan, and JM Reed. 2005. Variation in terrestrial habitat use by four pool-breeding amphibian species. The Journal of Wildlife Management **69**: 1481-1493.

Regosin, JV, BS Windmiller, J Michael Reed, and ME Douglas. 2004. Effects of conspecifics on the burrow occupancy behavior of spotted salamanders (*Ambystoma maculatum*). Copeia **2004**: 152-158.

Regosin, JV, BS Windmiller, and JM Reed. 2003a. Influence of abundance of small-mammal burrows and conspecifics on the density and distribution of spotted salamanders (*Ambystoma maculatum*) in terrestrial habitats. Canadian Journal of Zoology **81**: 596-605.

Regosin, JV, BS Windmiller, and JM Reed. 2003b. Terrestrial habitat use and winter densities of the wood frog (*Rana sylvatica*). Journal of Herpetology **37**: 390-394.

Renken, RB, WK Gram, DK Fantz, SC Richter, TJ Miller, KB Ricke, B Russell, and X Wang. 2004. Effects of forest management on amphibians and reptiles in Missouri Ozark forests. Conservation Biology **18**: 174-188.

Reynolds, BJ. 2011. When the facts are just not enough: credibly communicating about risk is riskier when emotions run high and time is short. Toxicology and Applied Pharmacology **254**: 206-214.

RIDEM, Rhode Island Department of Environmental Management. 2010. Rules and regulations governing the administration and enforcement of the freshwater wetlands act. Providence, RI, Office of Water Resources, 89 pp.

Riffell, S, J Verschuyl, D Miller, and TB Wigley. 2011. Biofuel harvests, coarse woody debris, and biodiversity - A meta-analysis. Forest Ecology and Management **261**: 878-887.

Rittenhouse, TAG, EB Harper, LR Rehard, and RD Semlitsch. 2008. The role of microhabitats in the desiccation and survival of anurans in recently harvested oak-hickory forest. Copeia **2008**: 807-814.

Rittenhouse, TAG, and RD Semlitsch. 2006. Grasslands as movement barriers for a forest-associated salamander: Migration behavior of adult and juvenile salamanders at a distinct habitat edge. Biological Conservation **131**: 14-22.

Rittenhouse, TAG, and RD Semlitsch. 2007. Distribution of amphibians in terrestrial habitat surrounding wetlands. Wetlands **27**: 153-161.

Rittenhouse, TAG, RD Semlitsch, and FR Thompson. 2009. Survival costs associated with wood frog breeding migrations: effects of timber harvest and drought. Ecology **90**: 1620-1630.

Rodenhouse, NL, LM Christenson, D Parry, and LE Green. 2009. Climate change effects on native fauna of northeastern forests. Canadian Journal of Forest Research **39**: 249-263.

Rodriguez, JP, TD Beard Jr., JRB Agard, E Bennett, S Cork, G Cumming, D Deane, AP Dobson, DM Lodge, M Mutale, GC Nelson, GD Peterson, and T Ribeiro. 2005. Interactions among ecosystem services. Pages 431-448 *in* SR Carpenter, PL Pingali, EM Bennett, and MB Zurek, editors. Ecosystems and Human Well-being: Scenarios, Volume 2. Island Press, Washington.

Rojas, H, DV Shah, and LA Friedland. 2011. A Communicative Approach to Social Capital. Journal of Communication **61**: 689-712.

Rothermel, BB, and TM Luhring. 2005. Burrow availability and desiccation risk of mole salamanders (*Ambystoma talpoideum*) in harvested versus unharvested forest stands. Journal of Herpetology **39**: 619-626.

Rothermel, BB, and RD Semlitsch. 2002. An experimental investigation of landscape resistance of forest versus old-field habitats to emigrating juvenile amphibians. Conservation Biology **16**: 1324-1332.

Rothermel, BB, and RD Semlitsch. 2006. Consequences of forest fragmentation for juvenile survival in spotted (*Ambystoma maculatum*) and marbled (*Ambystoma opacum*) salamanders. Canadian Journal of Zoology **84**: 797-807.

Rowe, CL, and WA Dunson. 1995. Impacts of hydroperiod on growth and survival of larval amphibians in temporary ponds of central Pennsylvania, USA. Oecologia **102**: 397-403.

Rubin, BR. 2000. A Citizen's Guide to Politics in America (2nd ed.). New York, Armonk, M.E. Sharpe, xiii + 338 pp.

Rubin, HJ, and IS Rubin. 2005. Qualitative Interviewing (2nd ed.). California, Thousand Oaks, Sage Publications, ix + 291 pp.

Ruddock, K, PV August, C Damon, C LaBash, P Rubinoff, and D Robadue. 2013. Conservation in the context of climate change: practical guidelines for land protection at local scales. PLoS ONE **8**: 1-9.

Russell, KR, HG Hanlin, TB Wigley, and DC Guynn, Jr. 2002. Responses of isolated wetland herpetofauna to upland forest management. The Journal of Wildlife Management **66**: 603-617.

Ryan, RL. 2006. Comparing the attitudes of local residents, planners, and developers about preserving rural character in New England. Landscape and Urban Planning **75**: 5-22.

Ryan, RL, JG Fabos, and JJ Allan. 2006. Understanding opportunities and challenges for collaborative greenway planning in New England. Landscape and Urban Planning **76**: 172-191.

Sabatier, P, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock. 2005. Collaborative approaches to watershed management. Pages 3-22 *in* P Sabatier, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock, editors. Swimming Upstream: Collaborative Approaches to Watershed Management. The MIT Press, Cambridge, Massachusetts.

Sabel, C, A Fung, and B Karkkainen. 2000. Beyond Backyard Environmentalism. Pages 3-46 *in* J Cohen, and J Rogers, editors. Beyond Backyard Environmentalism. Beacon Press, Boston.

Savage, WK, and KR Zamudio. 2005. *Ambystoma maculatum* (Shaw, 1802), Spotted Salamander. Pages 621-627 *in* MJ Lannoo, editor. Amphibian declines: the conservation status of United States species. University of California Press, Berkeley, California.

Schiff, R, and G Benoit. 2007. Effects of impervious cover at multiple spatial scales on coastal watershed streams. Journal of the American Water Resources Association **43**: 712-730.

Schlossberg, S, DI King, and RB Chandler. 2011. Effects of low-density housing development on shrubland birds in western Massachusetts. Landscape and Urban Planning **103**: 64-73.

Schriever, TA, MW Cadotte, and DD Williams. 2014. How hydroperiod and species richness affect the balance of resource flows across aquatic-terrestrial habitats. Aquatic Sciences **76**: 131-143.

Schulte, LA, RJ Mitchell, ML Hunter, JR Franklin, RK McIntyre, and BJ Palik. 2006. Evaluating the conceptual tools for forest biodiversity conservation and their implementation in the US. Forest Ecology and Management **232**: 1-11.

Schulte-Hostedde, AI, B Zinner, JS Millar, and GJ Hickling. 2005. Restitution of mass-size residuals: validating body condition indices. Ecology **86**: 155-163.

Scott, DE. 1990. Effects of larval density in *Ambystoma opacum*: an experiment in large-scale field enclosures. Ecology **71**: 296-306.

Scott, DE. 1994. The effect of larval density on adult demographic traits in *Ambystoma opacum*. Ecology **75**: 1383-1396.

Scott, DE, ED Casey, MF Donovan, and TK Lynch. 2007. Amphibian lipid levels at metamorphosis correlate to post-metamorphic terrestrial survival. Oecologia **153**: 521-532.

Scott, DE, and MR Fore. 1995. The effect of food limitation on lipid levels, growth, and reproduction in the marbled salamander, *Ambystoma opacum*. Herpetologica **51**: 462-471.

Semlitsch, RD. 1985. Reproductive strategy of a facultatively paedomorphic salamander *Ambystoma talpoideum*. Oecologia **65**: 305-313.

Semlitsch, RD. 1987a. Paedomorphosis in *Ambystoma talpoideum*: effects of density, food, and pond drying. Ecology **68**: 994-1002.

Semlitsch, RD. 1987b. Relationship of pond drying to the reproductive success of the salamander *Ambystoma talpoideum*. Copeia **1987**: 61-69.

Semlitsch, RD. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology **12**: 1113-1119.

Semlitsch, RD. 2000. Principles for management of aquatic-breeding amphibians. The Journal of Wildlife Management **64**: 615-631.

Semlitsch, RD, and JR Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology **17**: 1219-1228.

Semlitsch, RD, CA Conner, DJ Hocking, TAG Rittenhouse, and EB Harper. 2009a. Effects of timber harvesting on pond-breeding amphibian persistence: Testing the evacuation hypothesis. Ecological Applications **18**: 283-289.

Semlitsch, RD, DE Scott, and JHK Pechmann. 1988. Time and size at metamorphosis related to adult fitness in *Ambystoma talpoideum*. Ecology **69**: 184-192.

Semlitsch, RD, BD Todd, SM Blomquist, AJK Calhoun, JW Gibbons, JP Gibbs, GJ Graeter, EB Harper, DJ Hocking, ML Hunter, DA Patrick, TAG Rittenhouse, and BB Rothermel. 2009b. Effects of timber harvest on amphibian populations: understanding mechanisms from forest experiments. BioScience **59**: 853-862.

Seymour, RS, J Guldin, D Marshall, and B Palik. 2006. Large-scale, long-term silvicultural experiments in the United States: historical overview and contemporary examples. Allgemeine Forst und Jagdzeitung **177**: 104-112.

Seymour, RS, AS White, and PG deMaynadier. 2002. Natural disturbance regimes in northeastern North America: evaluating silvicultural systems using natural scales and frequencies. Forest Ecology and Management **155**: 357-367.

Shelby, K. 2008. Taking public interests in private property seriously: how the Supreme court short-changes public property rights in regulatory takings cases. Journal of Land Use **24**: 45-78.

Shoop, CR. 1965. Orientation of Ambystoma maculatum: movements to and from breeding ponds. Science **149**: 558-559.

Shoop, CR. 1974. Yearly variation in larval survival of *Ambystoma maculatum*. Ecology **55**: 440-444.

Shvidenko, A, CV Barber, R Persson, P Gonzalez, R Hassan, P Lakyda, I McCallum, S Nilsson, J Pulhin, B van Rosenburg, and B Scholes. 2005. Forest and Woodland Systems. Pages 585-621 *in* R Hassan, R Scholes, and N Ash, editors. Ecosystems and Human Well-being: Current State and Trends, Volume 1. Island Press, Washington.

Sieg, AE. 2010. Physiological constraints on the ecology of activity-limited ectotherms. (Unpublished doctoral dissertation). Drexel University, Philadelphia, 245 pp.

Sims, KRE, and J Schuetz. 2009. Local regulation and land-use change: The effects of wetlands bylaws in Massachusetts. Regional Science and Urban Economics **39**: 409-421.

Skelly, DK, EE Werner, and SA Cortwright. 1999. Long-term distributional dynamics of a Michigan amphibian assemblage. Ecology **80**: 2326-2337.

Smith, MA, and DM Green. 2005. Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? Ecography **28**: 110-128.

Smyers, SD, MJ Rubbo, VR Townsend, and CC Swart. 2002. Intra- and interspecific characterizations of burrow use and defense by juvenile ambystomatid salamanders. Herpetologica **58**: 422-429.

Snodgrass, JW, AL Bryan, and J Burger. 2000. Development of expectations of larval amphibian assemblage structure in southeastern depression wetlands. Ecological Applications **10**: 1219-1229.

Spieles, DJ. 2005. Vegetation development in created, restored, and enhanced mitigation wetland banks of the United States. Wetlands **25**: 51-63.

Spotila, JR. 1972. Role of temperature and water in the ecology of lungless salamanders. Ecological Monographs **42**: 95-125.

Stedman, R, B Lee, K Brasier, JL Weigle, and F Higdon. 2009. Cleaning up water? Or building rural community? Community watershed organizations in Pennsylvania. Rural Sociology **74**: 178-200.

Stedman, RC. 2003. Is it really just a social construction?: The contribution of the physical environment to sense of place. Society & Natural Resources **16**: 671-685.

Stevenson, RD, and WA Woods. 2006. Condition indices for conservation: new uses for evolving tools. Integrative and Comparative Biology **46**: 1169-1190.

Stine, J. 2008. America's Forested Wetlands: From Wasteland to Valued Resource. Durham, North Carolina, Forest History Society, 86 pp.

Stoffyn-Egli, P, and JHM Willison. 2011. Including wildlife habitat in the definition of riparian areas: the beaver (*Castor canadensis*) as an umbrella species for riparian obligate animals. Environmental Reviews **19**: 479-493.

Suarez-Rubio, M, P Leimgruber, and SC Renner. 2011. Influence of exurban development on bird species richness and diversity. Journal of Ornithology **152**: 461-471.

Sundquist, D. 2010. New Hampshire's Changing Landscape 2010: Population Growth and Land Use Change in the Granite State. Concord, NH, Society for the Protection of New Hampshire Forests, 16 pp.

Sztatecsny, M, R Jehle, T Burke, and W Hodl. 2006. Female polyandry under male harassment: the case of the common toad (*Bufo bufo*). Journal of Zoology **270**: 517-522.

Taylor, B. 2009. "Place" as prepolitical grounds of democracy: an Appalachian case study in class conflict, forest politics, and civic networks. American Behavioral Scientist **52**: 826-845.

Taylor, BE, and DE Scott. 1997. Effects of larval density dependence on population dynamics of Ambystoma opacum. Herpetologica **53**: 132-145.

Taylor, BE, DE Scott, and JW Gibbons. 2006. Catastrophic reproductive failure, terrestrial survival, and persistence of the marbled salamander. Conservation Biology **20**: 792-801.

Taylor, M. 2011. Building social capital through rhetoric and public relations. Management Communication Quarterly **25**: 436-454.

Tennessen, J, and K Zamudio. 2003. Early male reproductive advantage, multiple paternity and sperm storage in an amphibian aggregate breeder. Molecular Ecology **12**: 1567-1576.

Thomas, R. 2008. State Wetland Protection: Status, Trends & Model Approaches: A 50-state study by the Environmental Law Institute. Washington DC, Environmental Law Institute, 67 pp.

Tilghman, JM, SW Ramee, and DM Marsh. 2012. Meta-analysis of the effects of canopy removal on terrestrial salamander populations in North America. Biological Conservation **152**: 1-9.

Timmer, DK, RC de Loe, and RD Kreutzwiser. 2007. Source water protection in the Annapolis Valley, Nova Scotia: Lessons for building local capacity. Land Use Policy **24**: 187-198.

Todd, B, B Rothermel, R Reed, T Luhring, K Schlatter, L Trenkamp, and JW Gibbons. 2008. Habitat alteration increases invasive fire ant abundance to the detriment of amphibians and reptiles. Biological Invasions **10**: 539-546.

Todd, BD, and BB Rothermel. 2006. Assessing quality of clearcut habitats for amphibians: Effects on abundances versus vital rates in the southern toad (*Bufo terrestris*). Biological Conservation **133**: 178-185.

Toikka, A. 2010. Exploring the Composition of Communication Networks of Governance - a Case Study on Local Environmental Policy in Helsinki, Finland. Environmental Policy and Governance **20**: 135-145.

Townsend, JM, and CT Driscoll. 2013. Red-backed salamander (*Plethodon cinereus*) as a bioindicator of mercury in terrestrial forests of the northeastern United States. Ecological Indicators **34**: 168-171.

Trachtenberg, Z, and W Focht. 2005. Legitimacy and Watershed Collaborations: The Role of Public Participation. Pages 53-82 *in* PA Sabatier, W Focht, M Lubell, Z Trachtenberg, A Vedlitz, and M Matlock, editors. Swimming Upstream: Collaborative Approaches to Watershed Management. MIT Press, Cambridge, MA.

Trapenberg Frick, K. 2013. The actions of discontent: Tea Party and property rights activists pushing back against regional planning. Journal of the American Planning Association **79**: 190-200.

Trenham, PC, and HB Shaffer. 2005. Amphibian upland habitat use and its consequences for population viability. Ecological Applications **15**: 1158-1168.

UN. 2013. World Population Prospects: The 2012 Revision, Volume 1: Comprehensive Tables ST/ESA/SER.A/336. New York, United Nations, Department of Economic and Social Affairs, Population Division, 463 pp.

Urban, MC. 2004. Disturbance heterogeneity determines freshwater metacommunity structure. Ecology **85**: 2971-2978.

USCB. 2014. *World Population Clock*. U.S. Department of Commerce, U.S. Census Bureau, Washington, D.C. Available from http://www.census.gov/popclock/ (accessed 28 Oct 2014).

van Ham, P. 2008. Place branding: the state of the art. Annals of the American Academy of Political and Social Science **616**: 126-149.

Verrell, PA, and JD Krenz. 1998. Competition for mates in the mole salamander, Ambystoma talpoideum: Tactics that may maximize male mating success. Behaviour **135**: 121-138.

Vesely, DG, and WC McComb. 2002. Salamander abundance and amphibian species richness in riparian buffer strips in the Oregon coast range. Forest Science **48**: 291-297.

Veysey, JS, KJ Babbitt, and A Cooper. 2009. An experimental assessment of buffer width: Implications for salamander migratory behavior. Biological Conservation **142**: 2227-2239.

Veysey, JS, SD Mattfeldt, and KJ Babbitt. 2011. Comparative influence of isolation, landscape, and wetland characteristics on egg-mass abundance of two pool-breeding amphibian species. Landscape Ecology **26**: 661-672.

Veysey Powell, JS, and KJ Babbitt. *in review*. An experimental test of buffer utility as a technique for managing pool-breeding amphibians.

Walker, AJ, and RL Ryan. 2008. Place attachment and landscape preservation in rural New England: A Maine case study. Landscape and Urban Planning **86**: 141-152.

Walls, SC. 1990. Interference competition in postmetamorphic salamanders: interspecific differences in aggression by coexisting species. Ecology **71**: 307-314.

Waltert, F, and F Schlapfer. 2010. Landscape amenities and local development: a review of migration, regional economic, and hedonic pricing studies. Ecological Economics **70**: 141-152.

Warren, PS, RL Ryan, SB Lerman, and KA Tooke. 2011. Social and institutional factors associated with land use and forest conservation along two urban gradients in Massachusetts. Landscape and Urban Planning **102**: 82-92.

Watson, R, A Mathis, and R Thompson. 2004. Influence of physical stress, distress cues, and predator kairomones on the. Behavioral Processes **65**: 201-209.

Webler, T, and S Tuler. 2002. Unlocking the puzzle of public participation. Bulletin of Science, Technology, & Society **22**: 179-189.

Webler, T, S Tuler, I Shockley, P Stern, and R Beattie. 2003. Participation by local government officials in watershed management planning. Society and Natural Resources **16**: 105-121.

Weitkamp, E, and J Longhurst. 2012. Mediating consultation: insights from private sector consultants involved in air quality consultations. Journal of Environmental Planning and Management **55**: 113-125.

Welsh, HH, Jr., and LMD- Ollivier. 1998. Stream Amphibians as Indicators of Ecosystem Stress: A Case Study from California's Redwoods. Ecological Applications **8**: 1118-1132.

Welsh, HH, Jr., KL Pope, and CA Wheeler. 2008. Using multiple metrics to assess the effects of forest succession on population status: A comparative study of two terrestrial salamanders in the US Pacific Northwest. Biological Conservation **141**: 1149-1160.

Werner, EE. 1986. Amphibian metamorphosis: growth rate, predation risk, and the optimal size at transformation. The American Naturalist **128**: 319-341.

Whitford, WG. 1973. The effects of temperature on respiration in the Amphibia. American Zoologist **13**: 505-512.

Whitford, WG, and VH Hutchison. 1967. Body size and metabolic rate in salamanders. Physiological Zoology **40**: 127-133.

Whiting, GJ, and JP Chanton. 2001. Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. Tellus B **53**: 521-528.

Willett, TR. 2001. Spiders and Other Arthropods as Indicators in Old-Growth Versus Logged Redwood Stands. Restoration Ecology **9**: 410-420.

Willson, JD, and JW Gibbons. 2010. Drift fences, coverboards, and other traps. Pages 229-245 *in* CK Dodd Jr., editor. Amphibian Ecology and Conservation: A Handbook of Techniques. Oxford University Press, New York.

Windmiller, B, RN Homan, JV Regosin, LA Willitts, DL Wells, and JM Reed. 2008. Breeding amphibian population declines following loss of upland forest habitat around vernal pools in Massachusetts, USA. Pages 41-51 *in* J Mitchell, R Jung Brown, and B Bartholomew, editors. Urban Herpetology. Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah.

Withers, PJ, P Jordan, L May, HP Jarvie, and NE Deal. 2013. Do septic tank systems pose a hidden threat to water quality? Frontiers in Ecology and the Environment **12**: 123-130.

Wondolleck, J, and S Yaffee. 2000. Making Collaboration Work: Lessons from Innovation in Natural Resource Management. Washington DC, Island Press, xviii + 278 pp.

Woodward, BD. 1982. Local intraspecific variation in clutch parameters in the spotted salamander (*Ambystoma maculatum*). Copeia **1982**: 157-160.

Yin, R. 2003. Case Study Research: Design and Methods (3rd ed.). California, Thousand Oaks, Sage Publications, xvi + 179 pp.

Yung, L, and JM Belsky. 2007. Private property rights and community goods: Negotiating landowner cooperation amid changing ownership on the rocky mountain front. Society & Natural Resources **20**: 689-703.

Zabik, MJ, and DL Prytherch. 2013. Challenges to planning for rural character: a case study from exurban southern New England. Cities **31**: 186-196.

Zedler, JB, and S Kercher. 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annual Review of Environment and Resources **30**: 39-74.