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Lakeshore zoning has heterogeneous ecological effects: An application of a coupled economic-ecological model

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Abstract

Housing growth has been widely shown to be negatively correlated with wildlife populations, avian richness, anadromous fish, and exotic invasion. Zoning is the most frequently used public policy to manage housing development and is often motivated by a desire to protect the environment. Zoning is also pervasive, taking place in all 50 states. One relevant question that has received little research concerns the effectiveness of zoning to meet ecological goals. In this paper, we examined whether minimum frontage zoning policies have made a positive impact on the lakes they were aimed to protect in Vilas County, Wisconsin. We used an economic model that estimated when a given lot will be subdivided and how many new lots will be created as a function of zoning. Using the economic model, we simulated the effects of multiple zoning scenarios on lakeshore development. The simulated development patterns were then input to ecological models that predicted the amount of coarse woody debris (CWD) and the growth rate of bluegills as a function of residential density. Comparison of the ecological outcomes under different simulated zoning scenarios quantified the effect of zoning policies on residential density, CWD, and bluegill growth rates. Our results showed that zoning significantly affected residential density, CWD counts and bluegill growth rates across our study area, although the effect was less clear at the scale of individual lake. Our results suggest that homogenous zoning (i.e., for a county) is likely to have mixed results when applied to a heterogeneous landscape. Further, our results suggest that zoning regimes with a higher minimum shoreline frontage are likely to have larger ecological effects when applied to lakes that are less developed.

Keywords: biological-economic models, housing growth, human-natural systems, lakeshore development, landscape simulation, land use, policy, sustainability, zoning.

INTRODUCTION

The use of private land has critical importance for conserving ecosystem functions and services (Bean and Wilcove 1997, Wilcove et al. 1998, Daily et al. 2001, Rosenzweig 2003). In the United States, over 70% of land is privately owned**,** and more than two-thirds of the nation's threatened and endangered species are partially or fully dependent on privately owned habitat (Doremus 2003, Sanford 2006). Private land also supports habitat for more common species and generates a variety of ecosystem services (Daily 1997). The conversion of natural habitat on private land to more developed uses has broad-scale ecological impacts (Leu et al. 2008). However, ecosystem service benefits generated from private land accrue to a broader population than just the individual landowners themselves. Economic theory suggests that land-use policy can improve the efficiency of allocating land to habitat and developed uses when benefits are accrued by a larger public (Lewis and Plantinga 2007).

Policy attempts to preserve environmental benefits generated from private land take many forms in the United States. Regulations such as the Endangered Species Act and zoning are examples of direct government intervention concerning the allowable use of land. Other approaches use economic incentives, such as the Conservation Reserve Program, or the outright transfer of land to protected status through the purchase of development rights or in fee title. All these policy tools can and have been used to preserve the public good benefits derived from ecosystems located on private land. A relevant question concerns the effectiveness of such policy tools in securing ecosystem services, ecosystem function, and biodiversity.

The purpose of this study was to empirically quantify the ecological effects of minimum frontage zoning on lake shorelines in Vilas County, Wisconsin, USA. Our application is implemented with a coupled economic-ecological model. An econometric model of private landowner decisions (Lewis et al. 2009) was input to a land use simulation model of shoreline development under varying zoning policies. The outcomes of the land use simulations were then input into ecological models (Christensen et al. 1996, Schindler et al. 2000). Integrating the land-use model directly with spatially-explicit landscape simulations and ecological models of lakeshore habitat and sport fish growth rates allowed us to quantify the effects of zoning on specific ecological metrics – thus, providing evidence concerning the efficacy of zoning to preserve ecosystem function. Past studies have hypothesized that initial landscape configurations have a large impact on the effectiveness of land conservation policies (Newburn et al. 2005, Lohse et al. 2008). Therefore, we used our results concerning the effect of zoning on ecological indicators to model how initial landscape conditions influence the impact of zoning. Our results provide policy relevant evidence as to the types of lake shorelines in which zoning is likely to be effective, and where it is likely to have little ecological effect.

Coupled economic-ecological models are often used to examine the effectiveness of conservation policies because these models can quantify the trade-offs between ecological indicators and economic returns. In forestry applications, coupled models have been used to analyze maximum timber yields given certain ecological benchmarks (Nalle et al. 2004, Hurme et al. 2007). At a broader scale, economic development has been weighed against the preservation of a large assemblage of species and carbon sequestration (Polasky et al. 2005, Nelson et al. 2008). In both the forestry and broad scale cases, the results have illustrated that, with appropriate policy, economic returns and species preservation *can* be compatible.

A particularly important land conservation challenge is suburban and rural development (Radeloff et al. 2005). While different types of development may have a variety of effects on species (Lenth et al. 2006, Niell et al. 2007, Merenlender et al. 2009), the general trend is widespread negative effects on wildlife habitat (Theobald et al. 1997), avian richness (Pidgeon et al. 2007), anadromous fish (Lohse et al. 2008), and the likelihood of species invasions (Hansen et al. 2005). The most widespread policy tool used to manage suburban and rural development is zoning. Throughout the United States zoning is pervasive – all fifty states have enabling acts that grant local governments the legal authority to implement zoning. Nearly all municipalities and many rural areas have enacted zoning ordinances, and many ordinances have explicit conservation goals. However, despite zoning's prevalence and underlying conservation ethos, little work thus far has focused on the basic question of whether zoning actually improves the provision of ecosystem services from private land (however, see Langpap and Wu 2008 and Lewis 2009 for two recent examples). In the last 12 years, only 11 articles have been published in six leading conservation journals (Biological Conservation, Conservation Biology, Ecological Applications, Ecological Monographs, Ecology, and Landscape Ecology) that match the topic search for "conservation and zoning" but not marine (Web of Knowledge as of June 23rd 2009, Appendix 1). None of these articles provide empirical estimation of the effects of zoning policies on particular species or ecosystems. While not an exhaustive search of the literature, it is emblematic of the lack of direct research on the conservation effects of zoning.

Zoning is a community effort to assign property rights concerning land-use (Mills 1990, Jacobs 1998). As the U.S. Supreme Court famously asserted, zoning attempts to prevent "[the] right thing from being in the wrong place, like a pig in the parlor instead of the barnyard (Babcock 1969)." While zoning can prevent some land uses in some locations, it is important to stress that zoning it is *not* a deterministic prescription for land use. Zoning deems some uses permitted and others prohibited, however, there is likely a large range of landscape outcomes possible within the realm of permitted uses. Zoning can influence many aspects of development, including the size of a structure (height limits), the use of a structure (residential, commercial, or industrial uses), and the placement of a structure (minimum set backs, clustering requirements) to name just a few.

In our study the relevant zoning restriction is minimum shoreline frontage. Within the minimum frontage requirement a land owner has a large range of development options. For example, a minimum shoreline zoning requirement of 100 ft. (30.5m) lots does not prohibit landowners from developing 200 ft. (61m) lots if they so choose. It is common in the recent conservation literature to assume that land development occurs at the maximum density allowed by zoning constraints that specify minimum lot size (e.g., Conway and Lathrop 2005, Pejchar et al. 2007). This assumption confuses the private property owner’s right to develop at a certain density with a duty to do so. There is evidence that actual development does not always occur at maximum density (although it may in some settings). For example, in exurban Maryland only 8% of newly created subdivisions develop to their full built-out state (McConnell et al. 2006). Similarly, only 15% of subdivisions on northern Wisconsin lakeshores take place at the maximum density allowed by zoning (Lewis et al. 2009). If subdivisions do not occur at their maximum density, the policy effects of zoning cannot be deduced by a simple comparison of deterministic landscapes.

Three effects of zoning on development are relevant in our setting. First, zoning may have little effect on land markets and land conversion (Wallace 1988). In this case, zoning is simply enacted in a way that reflects what would have taken place under a market scenario in the absence of zoning. Zoning can also have little effect in cases where zoning is not enforced or zoning laws change often (in our specific case, however, minimum frontage zoning is nearly always enforced, and the zoning laws changed at most once over the 24 years of our study). Second, zoning can act to constrain landowner's development decisions, and this is typically the intended outcome of zoning policies. Third, zoning can also *increase* the probability that a lot develops by increasing the open-space amenities in the neighborhood of the lot. There is evidence that development rents are higher on landscapes with stricter zoning (Spalatro and Provencher 2001), and any policy that increases the returns to residential development will reduce the time to land-use conversion in formal economic models of land-use change (e.g., Capozza and Helsley 1989).

Development on lakeshores – the development process studied here – differs from the commonly studied development of agricultural or forested land to residential uses (e.g., Bockstael 1996, Irwin and Bockstael 2004, Carrion-Flores and Irwin 2004). On lakeshores, the typical decision is to subdivide an *existing* residential lot to increase its density. Therefore, if a zoning policy that constrains lakeshore development generates open space amenities for shoreline residents, then its effect on the probability of development is ambiguous because zoning increases both the economic returns to the subdivision and the returns from keeping the lot in its current state (Lewis et al. 2009). Thus, zoning's ultimate effect on landscape pattern is an empirical question.

This study provides four main contributions. First, we quantified the ecological effects of zoning by developing a coupled economic-ecological model focused on two ecological indicators: coarse woody debris (CWD) in the littoral zone, and the growth rate of bluegills (*Lepomis macrochirus)*. Second, we analyzed the conditions under which zoning is likely to be an effective policy for limiting the effects of shoreline development, thus offering a targeting strategy for the application of zoning. Third, we applied a methodology developed by Lewis

(2009) that links econometric and ecological models to account for multiple sources of model variation. There is significant uncertainty in both economic and ecological models, and our methodology accounted for the estimated uncertainty in model parameters and sources of model variation. Finally, we conducted a rigorous examination of empirically estimated distributions of landscape change in response to policy scenarios.

METHODS

Study Area

We investigated the ecological effect of minimum shoreline zoning in Vilas County, WI. Vilas County offered a unique opportunity to answer both policy and methodological questions related to measuring and interpreting the effects of minimum shoreline zoning on littoral ecology because: 1) residential development has increased in the county, 2) the ecological effects of residential development have been well documented, 3) zoning is the main policy used to limit residential growth, and 4) the goals of shoreline zoning contain explicit conservation goals.

Vilas County is located in Northern Wisconsin (Fig. 1). The county harbors 1320 lakes, and water covers almost 15% of the surface area. The lakes of Vilas County are generally nutrient poor, and many are connected by groundwater (Kratz et al.1997; Riera et al. 2000). Most lakes are surrounded by second-growth forests (Curtis 1959). Old-growth of *Acer saccharum* (sugar maple) and *Tsuga canadensis* (eastern hemlock) is limited to a few scattered reserves (Mladenoff et al. 1993).

Abundant lakes make Vilas County a popular destination for vacations and second home ownership. Over the course of our study, from 1974 to 1998, shoreline residential density increased by 24% across the lakes in our sample, and over 50% of all homes in Vilas County are located within 100m of a lake (Schnaiberg et al. 2002). In general, the lakes of Northern

Wisconsin face increasing disturbance due to residential development (Radeloff et al. 2001, Scheuerell and Schindler 2004, Gonzalez-Abraham et al. 2007). Development has been linked to a host of lake ecosystem changes (Carpenter et al. 2007) including the clearing of sunken logs leading to decreased coarse woody debris (CWD) (Christensen et al. 1996, Marburg et al. 2006), reduced growth rates for bluegills (Schindler et al. 2000), reduced populations of green frogs (Woodford and Meyer 2003), and increased nutrient loading into lakes (Schindler 2006).

In order to reduce the effects of development on lakes, some townships in Vilas County have used zoning since the 1950s to limit rapid residential growth. In 1965, the State of Wisconsin passed a statute (Wisconsin Administrative Code Chapter NR 115) mandating at least 100 ft (30.5 m) of frontage for all residential shoreline lots. Between 1974 and 1998, seven of the 14 townships in Vilas County further strengthened zoning ordinances and required at least 200 ft (61 m) of frontage for new lakefront lots. Shoreline zoning is a particularly relevant example in which to examine the conservation effects of zoning. The legal statute which establishes statewide shoreline zoning specifies that shoreline zoning is needed to “prevent and control water pollution; protect spawning grounds, fish and aquatic life; control building sites, placement of structure and land uses and reserve shore cover and natural beauty (State of Wisconsin 2009).” Therefore, the motivation for shoreline zoning matches well with general goals of conservation as well as the specific ecological indicators used in this study.

The Economic and Ecological Models

The economic model

We used an existing economic model to predict the probability that subdivision will occur, and how many new lots are created by each subdivision (Lewis et al. 2009). A panel dataset representing subdividable lots on 140 lakes from 1974 to 1998 was used as input to the econometric model. Parameter values were estimated using a jointly estimated Probit-Poisson model, which accounted for unobserved spatial heterogeneity and sample selection bias. In particular, a suite of lot specific characteristics (e.g. lot size, soil restrictions for development), lake specific characteristics (e.g., lake size, water clarity, and development density), time specific dummy variables, interactions between characteristics, and random effects were used to estimate the Probit model based on observed lot subdivisions. The Probit portion of the model identified the factors that affected the probability that landowners subdivide. If a subdivision occurred, a Poisson count model was estimated using a similar set of variables to determine the expected number of new lots created.

In prior studies, we showed that the effects of zoning on development were variable (Lewis et al. 2009, Lewis 2009). Increased residential zoning did not significantly change the probability of lot subdivision. However, zoning did reduce the expected number of new lots created when a subdivision occurred. The overall effect of zoning, therefore, is to reduce development density over time in our study area relative to a counter-factual scenario with less restrictive zoning.

Coarse Woody Debris Model

CWD is an important link between lakes and forest ecosystems in Northern Wisconsin, promoting production of benthic invertebrates, and offering refuge to prey fishes, which in turn are consumed by piscivorous fishes (Roth et al. 2007). Christensen et al. (1996) modeled the amount of CWD located along a given shoreline as a function of residential density for 16 lakes located in Vilas County and the adjoining county to the north, Gogebic County, Michigan. The lakes were selected to represent a gradient of residential densities. CWD abundance was sampled on a total of 125 plots. When analyzing the mean CWD for each lake, the amount of CWD was significantly and negatively correlated with residential density (Christensen et al. 1996). The precision of the estimate was lowered somewhat due to the large variation in CWD on lakes with no development. Overall, 71% of the variation in CWD was explained by residential density. We directly integrate the estimates from this research; specifically we use the estimated equation: $CWD = 628 - 500 * \log_{10} RD + e$ (page 1146 in original text), where RD is equal to the residential density in cabins per kilometer, to estimate CWD in our land use simulation setting.

Bluegill Growth Rate Model

Schindler et al. (2000) modeled the growth rate of bluegills in northern forested lakes as a function of residential density. Their study included samples from 14 lakes in Vilas County, Wisconsin and Gogebic County, Michigan. Fish sampling was performed in June and July of 1996. Electroshocking took place 30 minutes after sunset along the 1 m depth contour. Collected fish were identified to species, and their lengths were measured to the nearest 1 mm. Weight measurements and scale samples were taken from most collected bluegills. Bluegill growth rates were determined with the Fraser-Lee method (Schindler et al. 2000). Statistical models showed that bluegill growth rates declined as housing density increased, but the relationship is non-linear. When density increases from 0 to 1 residence/km, bluegill growth rates drop by nearly 4mm/yr. However, as residential density increases further, the effect of an additional residence becomes less pronounced; the marginal change in bluegill growth is only 0.7 mm/yr when density increases from 5 to 6 residences/km, and by the time density reaches 10 residences/km the marginal change for an additional residence is only 0.36 mm/yr. The original estimates from Schindler et al. (2000) are directly applied to the land use simulation in this paper:

$\log_{10} Growthrate = 1.50 + -.11 * \log_{10}(RD+1) + e$ (page 234 in original text).

Using the econometric model to simulate residential development

The economic model provides an estimate of the probability that a parcel subdivides, along with probabilistic estimates of the number of new lots upon subdivision. These transition probabilities are functions of parcel-scale and lake-scale covariates, including the zoning status of each lake. Spatial data on each covariate in the economic model is used to link the estimated transition probabilities to specific parcels along each lakeshore. The transition probabilities are then used as a set of rules determining the development path of each parcel in a series of Monte Carlo simulations programmed with original Matlab code. The simulation model predicts the time-path of development decisions for each parcel on the landscape over the time period of our study – 1974 to1998. These simulations provided estimates of development density used as input to the ecological models. Since the economic model is a function of zoning, it provides the basis for simulating the effects of different zoning scenarios– 100 ft., 200 ft., 300 ft., and 400 ft. minimum frontage – on landscape and ecological change. This methodology allows us to compare the effects of zoning on residential density, CWD, and bluegill growth over the four zoning scenarios for the time period 1974-1998. Thus, the simulation model estimates *counter-factual* paths that lakes zoned 100 ft. could have taken from 1974 to1998, had they been zoned differently. A more detailed description of this methodology follows.

In order to include all sources of variation from the economic model, and thereby represent the stochastic nature of land use change, we followed Lewis (2009) and introduced three stochastic elements to the landscape simulations. First, we draw a set of parameter values for the economic model by implementing the Krinsky-Robb procedure (Krinsky and Robb 1986, Lewis 2009). Using this procedure, the parameters are random variables drawn from the asymptotic distribution of the parameter estimates of the econometric model. Second, following Lewis and Plantinga (2007) and similar to Markov models, we interpreted the fitted subdivision probabilities as a set of rules that govern land-use change. That is, if the subdivision probability for a particular lot is 0.1, the owner of the lot will subdivide 10% of the time, given that the choice is repeated enough times. Third, the number of new lots created was determined stochastically by an iterative process using the estimated Poisson probabilities. For a given lot, the Poisson probability that one new lot is created is compared to a random number on the unit interval. If the Poisson probability is greater than the random number, one new lot is created. If not, then the random number is compared to the Poisson probability that two new lots are created. This process continues until either the random number is smaller than the Poisson probability for a given number of lots – at which point that number of lots is assigned to the lot – or the maximum number of new lots given the zoning regime is reached. Fourth, all lot and lake level characteristics were updated in the model, and the simulation continued onto the next time period - the simulation was run in four year intervals over the time period 1974 to1998.

The four steps above generated a unique simulated landscape that reflected the estimated economic parameters and the stochastic nature of development. From this simulated landscape, we calculated the residential density under the assumption that each lot had one residence. To bolster our assumption, we used aerial photos from 1996 and 2001 to digitize all residence on our sample lakes. We found, on average, 1.1 buildings per lot. Given that some of these buildings are likely not residences, we assumed that the one residence per lot was reasonable. In order to obtain robust results, the simulation was run 1000 times, a process that generates 1000 landscape configurations consistent with the underlying economic model of landowner behavior.

A few important assumptions stemming from the economic model and landscape simulation deserve additional attention. First, the land use conversation model is a partial-equilibrium model; therefore as zoning regulations change, demand for shoreline lots remains the same. That is, in this model, increased regulation in Vilas County will not shift the demand curve for new shoreline lots. Second, the effect of zoning was econometrically estimated on lakes that were zoned either 100 ft. or 200 ft. minimum frontage - Lewis et al. (2009) estimate the model with a binary zoning indicator (1=200 ft.; 0=100 ft.). Simulations for 300 ft. and 400 ft. zoning provide a richer set of scenarios, but require us to use the model with minimum frontages beyond the range of the data used in estimation. We re-scale the zoning indicator as a function of the minimum frontage: (*Zone* - 100)/100, where *Zone* = 100, 200, 300, or 400ft; thereby allowing us to simulate zoning scenarios of 300 and 400 ft. minimum frontage. Due to the non-linear Poisson model, we find diminishing effects of stricter zoning on the expected number of new lots upon subdivision.

Estimating the effect of policy changes on residential development and lake ecology

We estimated the effect of changing zoning regulations on residential density, the amount of CWD, and bluegill growth rates across a set of 89 lakes that were zoned 100 ft. minimum frontage from 1974 to 1998. We examine three counter-factual zoning scenarios where the minimum frontage was increased to 200, 300 and 400 ft (61, 91, and 122 m) respectively. The effect of each zoning scenario is evaluated relative to a baseline simulation with 100 ft. minimum frontage. In each zoning scenario, lots which could no longer subdivide under the minimum frontage were dropped from the simulation – for example, a lot with 400 ft. frontage cannot subdivide under the 300 and 400 ft zoning regimes, but can subdivide under the 200 ft scheme. Also, the maximum number of new lots that could be created was updated for each lot under the alternative zoning scenarios.

After the three hypothetical scenarios depicting the new zoning rules were run 1000 times each, residential density, CWD counts and bluegill growth were estimated for each simulation. This was done by applying each simulated residential density pattern to the CWD and bluegill growth models. Rather than applying the estimated coefficients of the ecological models at the mean parameter values (which would ignore the unexplained variance in the ecological models), we modeled the stochastic nature of the parameters by drawing 1000 different parameter values from a normal distribution with the mean and variance given from the estimates (Fig 2).

The combination of land use simulations and drawn parameter values from the ecological models resulted in 1000 simulated values of residential density, CWD and bluegill growth for each lake, and for the landscape as a whole, at *each* of the four zoning scenarios (100, 200, 300, and 400 ft minimum frontage). We compared these distributions to quantify the effects of zoning. Each distribution (89 lakes + the landscape level = 90 observations x 4 zoning scenarios x 3 indicators = 1080 total distributions) was tested for normality using the Kolmogorov-Smirnoff test. All distributions failed this test. Therefore, non-parametric methods were used to analyze the changes in the distribution, median, variance, and skewness for varying policies and indicators.

Distributions were compared using a two sample Kolmogorov-Smirnoff test which indicated if the distributions of indicators on the same lakes differed among policies. In addition, a Wilcoxon rank-sum test was conducted on paired distributions to test for changes in the median. To test for changes in the distribution's variance and skewness, 10,000 variance and skewness estimates were bootstrapped for each distribution. These bootstrapped distributions of variance and skewness where then compared using a two sample Kolmogorov-Smirnoff test to test for changes in the distributions of the variance and skewness across distributions. Finally, Wilcoxon rank-sum tests were run to test for changes in the median of variance and skewness of each lake and of the landscape as a whole.

We hypothesized that initial lake conditions strongly influence the ability of zoning to decrease residential density, increase CWD, and increase bluegill growth rates on a given lake. If this is the case, a helpful policy exercise is to group lakes with similar initial conditions, and then compare the effects of zoning across lakes with different initial conditions. We use the following methodology to group lakes together. Each of the 1000 simulated residential densities, CWD counts, and bluegill growth rates for the 100 ft. zoning policy were randomly matched with a simulated outcome from the 400 ft. zoning simulation. Differences between matched pairs were taken to create a distribution of policy effects that arise due to a zoning increase from 100 to 400 ft. We use a stepwise weighted least squares procedure to estimate the effects of various initial lake conditions on the simulated policy effects. From 18 possible variables, the percent of shoreline that is subdividable, and the average size of subdividable lots, prove to be the most important variables in explaining the effect of initial conditions on the effect of zoning – regression results are available from the authors upon request. Lakes were than sorted into groups based on these variables and differences between outcomes were compared.

RESULTS

Comparing the simulated landscape change with the actual landscape over the period 1974 through 1998 provided an accuracy assessment of our model. Overall, the simulated landscapes were similar to the actual landscape at the end of the study period. On average, the model predicted the number of subdivisions across the study area within 3%, and the number of new lots created within 2%. At the lake scale, the average absolute deviation between the actual number of new lots created and the results of the simulation was approximately 6 lots. Using the 1000 simulations for each lake as the empirical distribution, the actual number of new lots created on each lake was within one standard deviation of the average number of predicted new lots on 86% of the 140 lakes in our sample. Further, our results shed light on the importance of modeling development *density* with the Poisson model, as opposed to simply assuming that all subdivided lots are developed at their maximum allowable density. Results indicate that a maximum density assumption overestimates the number of new lots created by 257% - see Lewis (2009) for further discussion.

At the landscape scale, our results suggest that zoning likely changed development density and CWD, but did not have much effect on bluegill growth rates according to the two-sided Kolmogorov-Smirnov tests. Looking at the medians, we found statistically significant changes in density and CWD for changes between 100 vs. 200 ft., 100 vs. 300 ft., 100 vs. 400 ft., and 200 vs. 400 ft. zoning, but not for the 200 vs. 300 ft. or 300 vs. 400 ft zoning (Table 1).

Median bluegill growth rates did not differ significantly between any policies. Looking at the bootstrapped variances and skewness values, at the landscape scale the two-sided Kolmogorov-Smirnoff test rejected the null hypothesis of equal distributions for density and CWD across all policy changes, but could not reject the null hypothesis that bluegill growth rate distributions remained the same (Fig. 3).

We found similar results when examining the effect of zoning on individual lakes (Table 2). In general, for density and CWD distributions, medians, variances, and skewness changed between policies for most lakes. However, significant changes in bluegill growth only occurred on a few lakes. The two-sided Kolmogorov-Smirnov test suggested different distributions among policies for every lake for density and CWD, but no significantly different distributions for any lakes for bluegill growth.

Following the stepwise regression results, lakes were divided by initial conditions according to two variables representing the development density of lakes: percent of shoreline that is subdividable (PPS), and average size of subdividable lots (ASP). Graphical analysis does not reveal any breaks in the data where the policy effect of zoning changes sharply. Hence, we use heuristic breaks to separate the lakes into three groups: High Development (PPS≤33% n=27; ASP≤500ft n=20), Medium Development (66%≤PPS>33% n=40; 1000ft≤ASP<500 n=40,), and Low Development (PPS>66% n=20; ASP>1000ft n=27). Statistically significant changes in the medians were found between each group for both variables (Figures 4 and 5), although the magnitude of the change for bluegill growth was quite small. Geographically, the lakes in different categories are dispersed rather randomly across the landscape (Figures 6 and 7).

DISSCUSSION

Our results showed that minimum frontage zoning policies on lake shorelines significantly reduced residential density and increased CWD counts. However, bluegill growth rates were, in general, not changed by zoning. Across the larger landscape, our results suggest that zoning policies have heterogeneous effects on different indicators of ecosystem function.

Results for individual lakes were similar to the results obtained for the entire landscape. Changes in the median, variance, and skewness occurred on a large number of lakes for development density and CWD, but not for bluegill growth. As the level of zoning increased, results indicated that more lakes exhibit lower density and higher CWD counts, although bluegill growth rates changed little. Furthermore, our results showed diminishing ecological “returns” to zoning. That is, zoning had the greatest effect when raising the minimum shoreline frontage from 100 to 200 ft. Additional zoning did further change the distributions of the ecological metrics, but by less than a change of 100 to 200 ft. These results are undoubtedly influenced by the non-linearity of the economic model of development density as a function of zoning, and the non-linearity of the ecological model as a function of development density.

The variation in the observed effects among different lakes also suggested that zoning is not uniformly effective. Initial development conditions on a lake were a good predictor of zoning’s effectiveness. In general, zoning worked best on relatively undeveloped lakes, where lots are relatively large, and where no one land owner’s decision has a disproportionate effect on shoreline density. Prudent policy may focus zoning on such lakes.

The coupled economic-biological model allowed the variance present in the econometric and ecological models to be fully propagated throughout the simulations. The Krinsky-Robb method (Krinsky and Rob 1986) was used to draw the parameters of the econometric model. The Markov type landscape simulation model captured the stochastic nature of landscape development and provided a distribution of possible landscape outcomes. Finally, the parameters of the biological models were modeled as random parameters drawn from a normal distribution with the mean and standard deviation of each parameter. Taken together, these techniques provided simulation outputs that accounted for model variation in the estimated parameters and in the error components.

Propagating errors caused, of course, confidence intervals to become larger. Reducing variance is rarely a major goal in ecological modeling and model selection focuses on model accuracy (i.e., a predicted mean without any bias) rather than model precision (i.e., smaller confidence limits). However, reducing the variance is essential if the ultimate goal is to build integrated models of coupled human-natural systems, and lower variance may even justify minor bias in the predicted means. Alternative model selection tools such as Lasso (Tibshirani 1996) that minimize variance may be particularly valuable for integrated economic-ecological models.

Our findings with regards to variance and skewness of the estimated distributions have important policy implications that have been mostly ignored in previous coupled landscape simulation models (Lewis and Plantinga 2007; Nelson et al. 2008). With our econometric estimates, stricter minimum frontage zoning decreased development. Therefore, variance necessarily decreased with increased zoning, and the distributions became generally more skewed to the left of the mean. From a policy perspective, this means that the likelihood of a bad ecological outcome decreased with an increase in zoning. Hence, even though zoning cannot assure an outcome on a lake, it can have the policy-relevant effect of reducing the likelihood of extreme outcomes that may be undesirable.

From a modeling perspective, our results highlighted the importance of the functional form of the underlying models. In this application, the non-linearity of the bluegill growth rate model meant that even large changes in residential density caused only small changes in the bluegill growth rate once residential density reached a threshold of approximately 5 residences per km. Since 83% of the lakes in our sample had a density higher than this threshold at the beginning of our study, it was not surprising that zoning had little effect on bluegill growth rates for most lakes. This finding is an empirical demonstration of the importance of ecological thresholds for conservation targeting (Wu and Boggess 1999), and the management implication is that efficient bluegill conservation efforts should be targeted towards lakes that are relatively undeveloped, as even small changes to density on these lakes can have large ecological effects. In addition, the ecological models we used suggested that CWD goes to zero at 18 residences per km, which is within the simulated range of densities we estimate. Hence, our model suggests that highly developed lakes with no CWD are possible.

We found that lakes could be classified into groups based on various measures of their initial development level. Relatively undeveloped lakes had a higher percentage of shoreline that is subdividable and larger subdivideable lots on average. Our results indicated that stricter minimum frontage zoning standards had a larger ecological effect on relatively undeveloped lakes. Classifying lakes into categories based on their initial development levels provides a simple measure that enables zoning to be targeted towards lakes where it can have the largest ecological effect.

One notable exception to these results takes place on lakes where nearly all of the shoreline is owned by one landowner; two such lakes exist in our dataset. On these lakes, the average effect of zoning is negligible even though most of the shoreline is subdividable and the size of the subdividable lot is large. In this case, the important question is not at what density the landowner will develop, but rather will the lot be developed at all? Indeed, the two lakes where one individual owns most of the shoreline face large potential changes in ecosystem indicators in the event of development (density increases from less then 1 lot per km to on average over 20), regardless of zoning regime. In such cases, alternative conservation methods, such as direct purchase of the large lot or its development rights, may be useful.

In general, our results suggest that zoning can be an effective conservation tool only under certain conditions. These findings are important in light of the various economic costs and benefits associated with zoning. A stricter minimum frontage zoning policy generates costs to landowners by constraining them from subdividing and selling off lots (Spalatro and Provencher 2001). Further, if strict zoning significantly reduces the supply of developable land, then lower-income individuals may become priced out of strictly zoned neighborhoods (Glaeser and Ward 2008). In contrast, stricter zoning can yield economic benefits by 1) increasing the market value of land due to a greater amount of open-space (Spalatro and Provencher 2001), and 2) producing a non-market public good in the form of enhanced ecosystem services. Importantly for the purpose of this paper, a zoning policy will yield *fewer* benefits to the public at large when zoning results in minimal effects on ecosystem services. The modern property rights movement (also know as the “wise-use” movement or anti-environmental movement) has gained momentum from cases where community appropriation of property rights disadvantages a landowner with little clear benefit to the public (Jacobs 1998). Strict zoning on lakes that are already nearly “built up” may be another case of this. An efficient application of zoning must carefully target zoning constraints towards landscapes where it will have significant environmental effects – relatively undeveloped lakes in our application – and avoid placing constraints on landscapes where it will yield minimal gains.

In extending our analysis to different landscapes where zoning is used, we suggest that future research investigate the following hypothesized generalizations: 1) the most common zoning controls (lot size minimums), are unlikely to provide certain ecological benefits at the individual lot scale, but may have strong landscape scale effects; 2) at the intermediate scale (such as lake level effects in our research), stricter zoning has larger ecological effects on relatively undeveloped landscapes; and 3) conservation at the lot scale can only be certain when all development rights are fully captured by the community; either through zoning or outright purchase.

Acknowledgments

We gratefully acknowledge support for this research by USDA McIntire-Stennis (# WIS01229), the National Science Foundation Collaborative Research Grant No. 0814424, the Long Term Ecological Research Network – North Temperate Lakes Site funded by the National Science Foundation, and the Northern Research Station of the U.S. Forest Service.

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Table 1. Changes in landscape scale medians. The diagonal of the matrix (bolded) is the landscape scale median. The upper right hand side of the matrix (italicized) is the absolute change between medians for varying policies. The lower left corner (underlined) is the percentage change in medians for varying policies. * denotes significance at p<0.05

		Change in median residential density (%)		
Zoning scenario	100 ft	200 ft	300 ft	400 ft
100 ft	**10.0772**	*-0.7672**	*-1.0472**	*-1.1972**
200 ft	-0.07613	**9.31**	*-0.28*	*-0.43**
300 ft	-0.10392	-0.03008	**9.03**	*-0.15*
400 ft	-0.1188	-0.04619	-0.01661	**8.88**
		Change in median CWD (%)		
Zoning scenario	100 ft	200 ft	300 ft	400 ft
100 ft	**180.6614**	*20.5834**	*29.7545**	*35.5277**
200 ft	0.113934	**201.2448**	*9.1711*	*14.9443**
300 ft	0.164698	0.045572	**210.4159**	*5.7732*
400 ft	0.196654	0.074259	0.027437	**216.1891**
		Change in median bluegill growth (%)		
Zoning scenario	100 ft	200 ft	300 ft	400 ft
100 ft	**32.199**5	*0.0032*	*0.0053*	*0.0073*
200 ft	9.94E-05	**32.2027**	*0.0021*	*0.0041*
300 ft	0.000165	6.52E-05	**32.2048**	*0.002*
400 ft	0.000227	0.000127	6.21E-05	**32.2068**

Table 2. Number of lakes (out of a total of 89) with a significant change ($p<0.05$) in median, variance, and skewness for residential density, CWD, and bluegill growth.

	Median Change					Variance Change					Skewness Change				
		100 ft	200 ft	300 ft	400 ft		100 ft	200 ft	300 ft	400 ft		100 ft	200 ft	300 ft	400 ft
Residential density	100 ft		83	87	89	100 ft		89	89	89	100 ft		88	89	88
	200 ft			67	78	200 ft			84	84	200 ft			84	84
	300 ft				57	300 ft				78	300 ft				78
	400 ft					400 ft					400 ft				
		100 ft	200 ft	300 ft	400 ft		100 ft	200 ft	300 ft	400 ft		100 ft	200 ft	300 ft	400 ft
CWD	100 ft		73	67	69	100 ft		87	87	89	100 ft		87	86	87
	200 ft			23	42	200 ft			83	83	200 ft			87	79
	300 ft				10	300 ft				73	300 ft				76
	400 ft					400 ft					400 ft				
		100 ft	200 ft	300 ft	400 ft		100 ft	200 ft	300 ft	400 ft		100 ft	200 ft	300 ft	400 ft
Bluegill growth	100 ft		0	0	0	100 ft		7	6	12	100 ft		5	9	13
	200 ft			0	0	200 ft			5	7	200 ft			7	13
	300 ft				0	300 ft				2	300 ft				9
	400 ft					400 ft					400 ft				

Figure Captions

Figure 1. The study area, Vilas County, Wisconsin, and the sample of lakes used in the simulations.

Figure 2. Schematic of the simulation methodology.

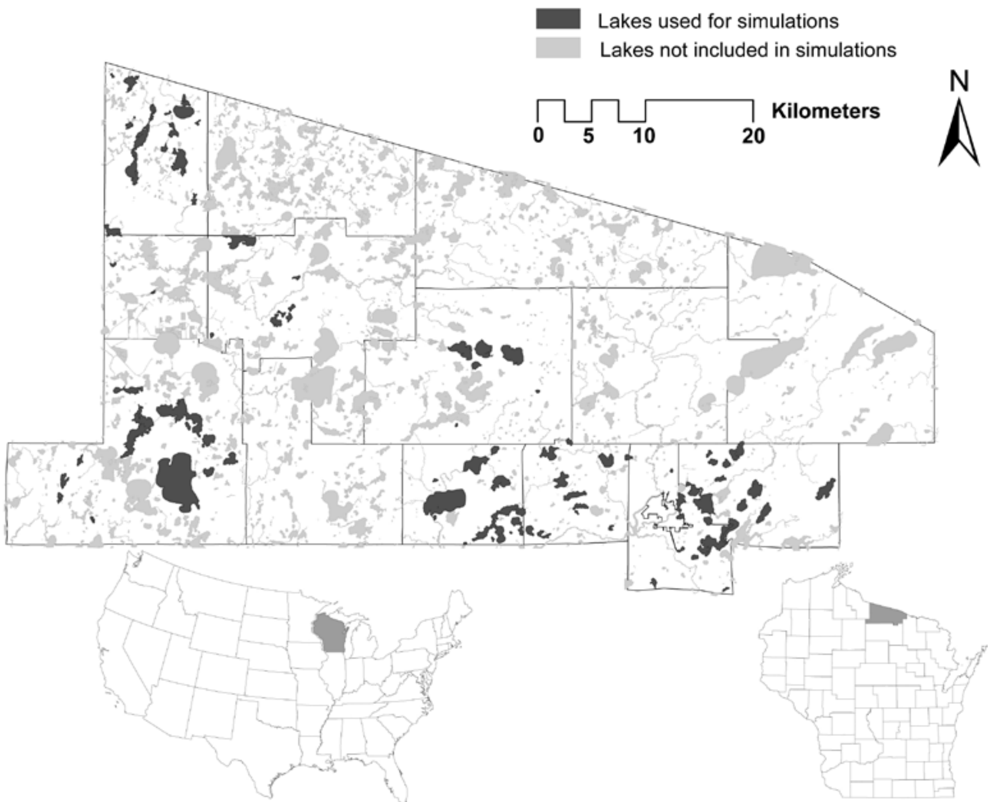
Figure 3. Landscape averages for 1000 simulations of residential density, CWD, and bluegill growth rates under different zoning scenarios. Densities are estimated using Epanechnikov kernel estimation. Bandwidths are: residential density =0.065, CWD = 0.18, and bluegill growth = 0.624.

Figure 4. Distributions of estimated policy change for lake types based on percent of shoreline that is subdividable. Lakes with ≤33% of shoreline subdividable are categorized as high development. Lakes with 34%-66% of shoreline subdividable are categorized as medium development. Lakes with >66% of shoreline subdividable are categorized as low development.

Figure 5. Distributions of estimated policy change for lake types based on the average size of subdividable lots. Lakes with ≤500ft average subdividable lot size are categorized as high development. Lakes with average subdividable lot sizes from 501ft to 1000ft are categorized as medium development lakes. Lakes with average subdividable lots sizes of >1000ft are categorized as low development lakes.

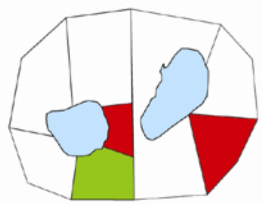
Figure 6. Geographic distribution of low, medium, and high development lakes as categorized by the percent of subdividable shoreline.

Figure 7. Geographic distribution of low, medium, and high development lakes as categorized by the average size of subdividable lots.

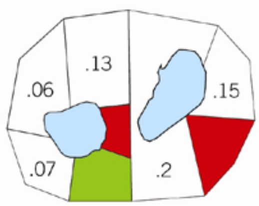

Lakes used for simulations
Lakes not included in simulations
N
0 5 10 20 Kilometers

LANDSCAPE SIMULATION AND THE EFFECT OF ZONING

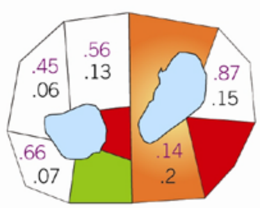
1. Initial landscape.



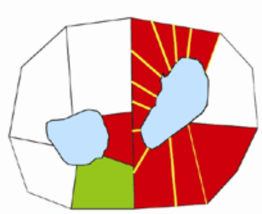
2. Each parcel is assigned a transition probability based on the estimated coeffcients and variance of the land conversion model



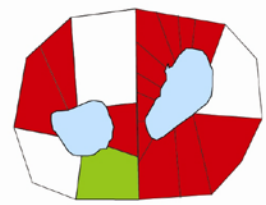
3. For each parcel a random number from the unit interval is drawn and compared to the transition probability. If the estimated transition probability is greater than the random draw the parcel subdivides.



4. The number of new lots created on the subdivided parcel is decided based on the estimated coeffcients and variance of Poisson count model, the zoning restrictions that govern minimum allowable frontage, and a stochastic process which compares the number of new lots created to a random draw.



5. The landscape simulation continues through end of study with more lots subdividing.



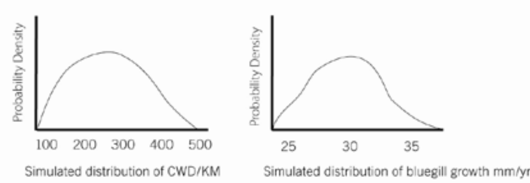
6. Residentail density (RD) is calculated for each lake using the assumption of one home per parcel. RD is then input into the biological models for CWD and bluegill growth (Christensen et al.1996, Schindler et al. 2000).

$$_{\log10}\text{Growthrate} = 1.50 - (.11 * {}_{\log10}(\text{RD}+1)) + e$$

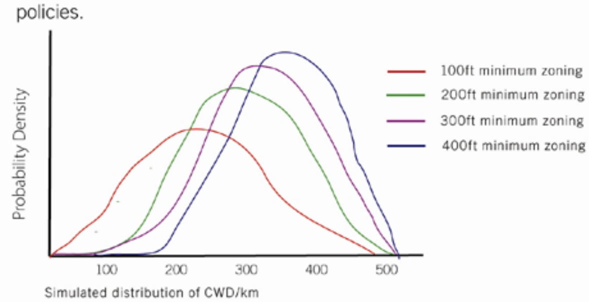
$$\text{CWD} = 628 - 500 *_{\log10}\text{RD} + e$$

Where *e* is approximated by drawing the model coeffcients from a normal distribution with the estimated mean and variance.

7. The landscape simulation is run 1000 times providing the input to 1000 estimates of CWD and blugill growth. These estimates form a simulated distribution of possible conservation outcomes for each lake and the landscape as a whole.



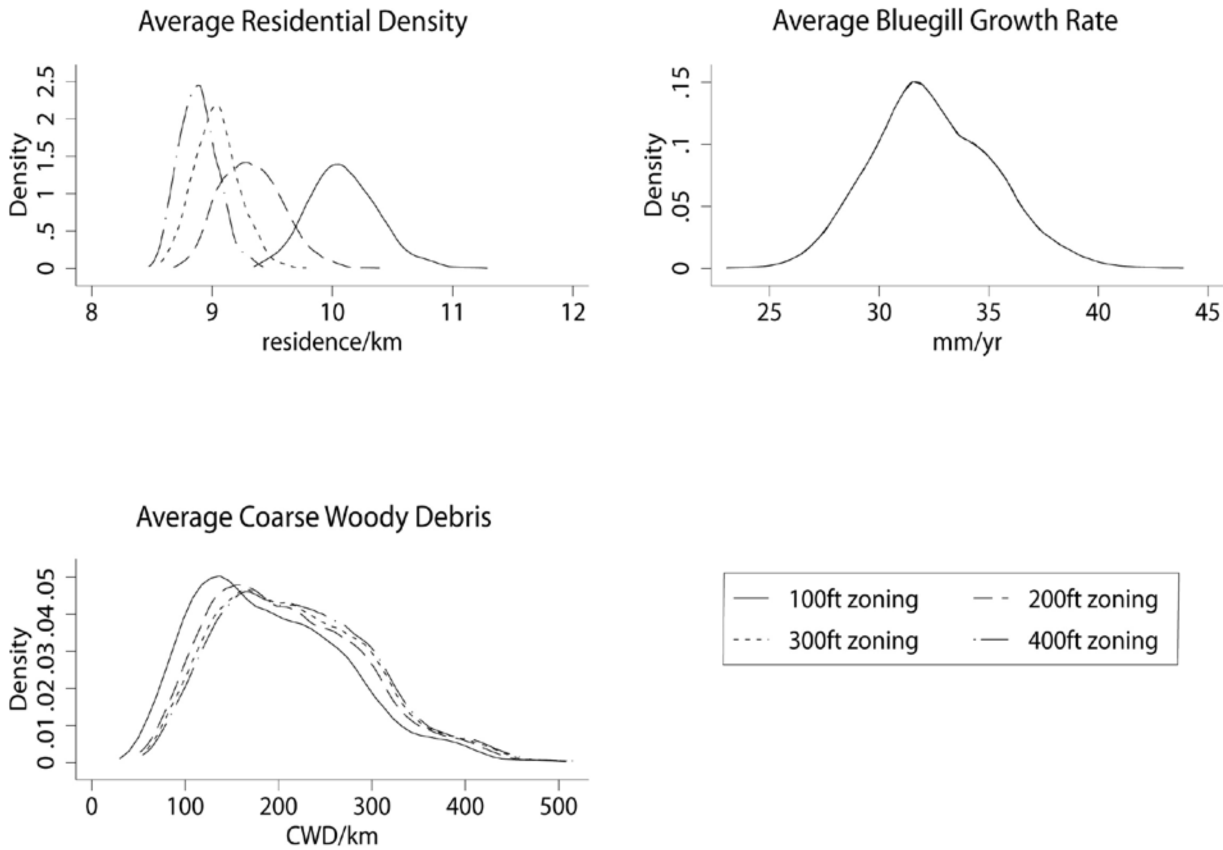
8. Changes in zoning were simulated by changing transition probabilities, the number of new lots created, and the number of new lots allowed. Distributions of ecological indicators were compared across zoning policies.

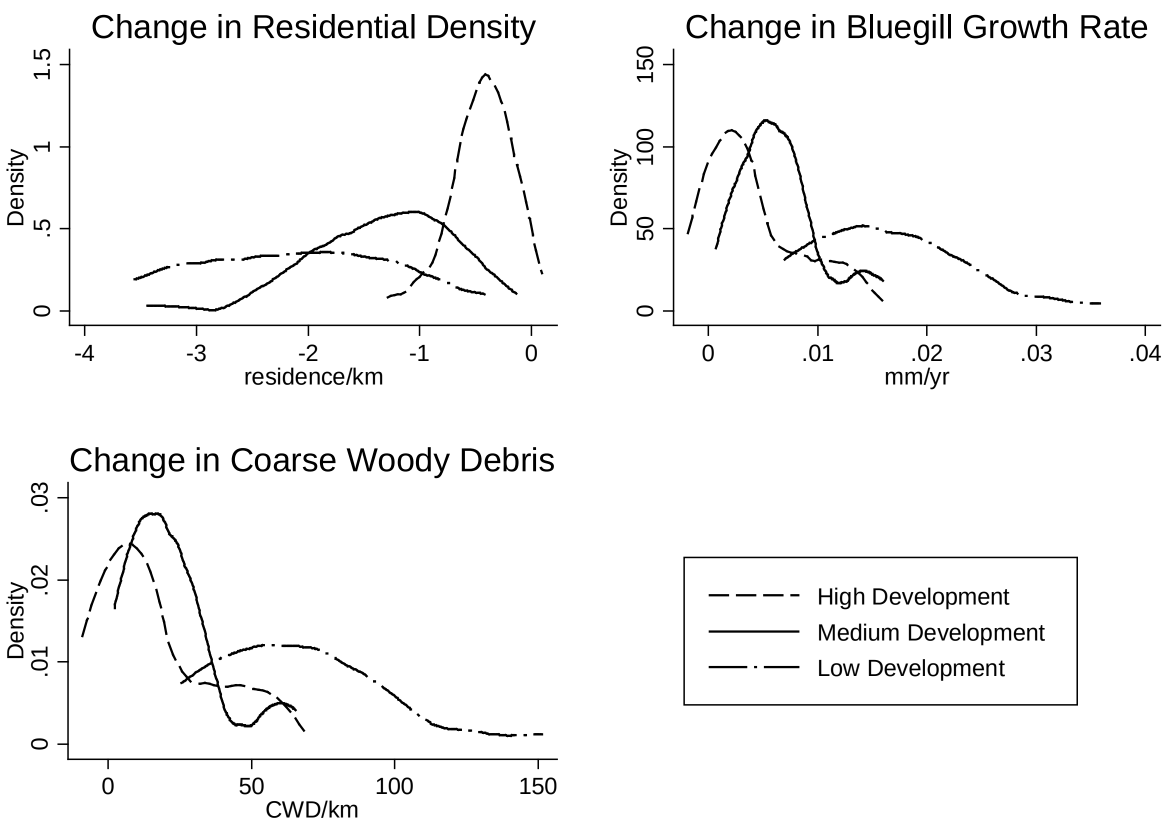


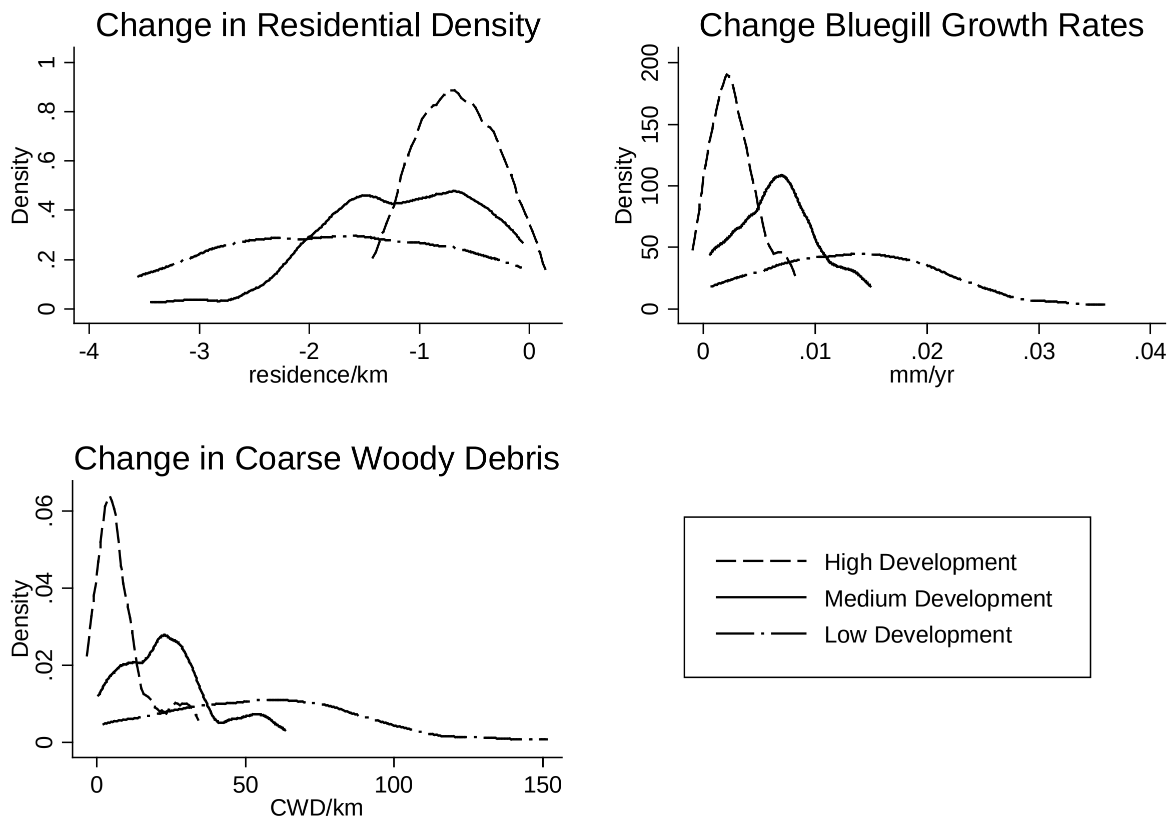
Legend

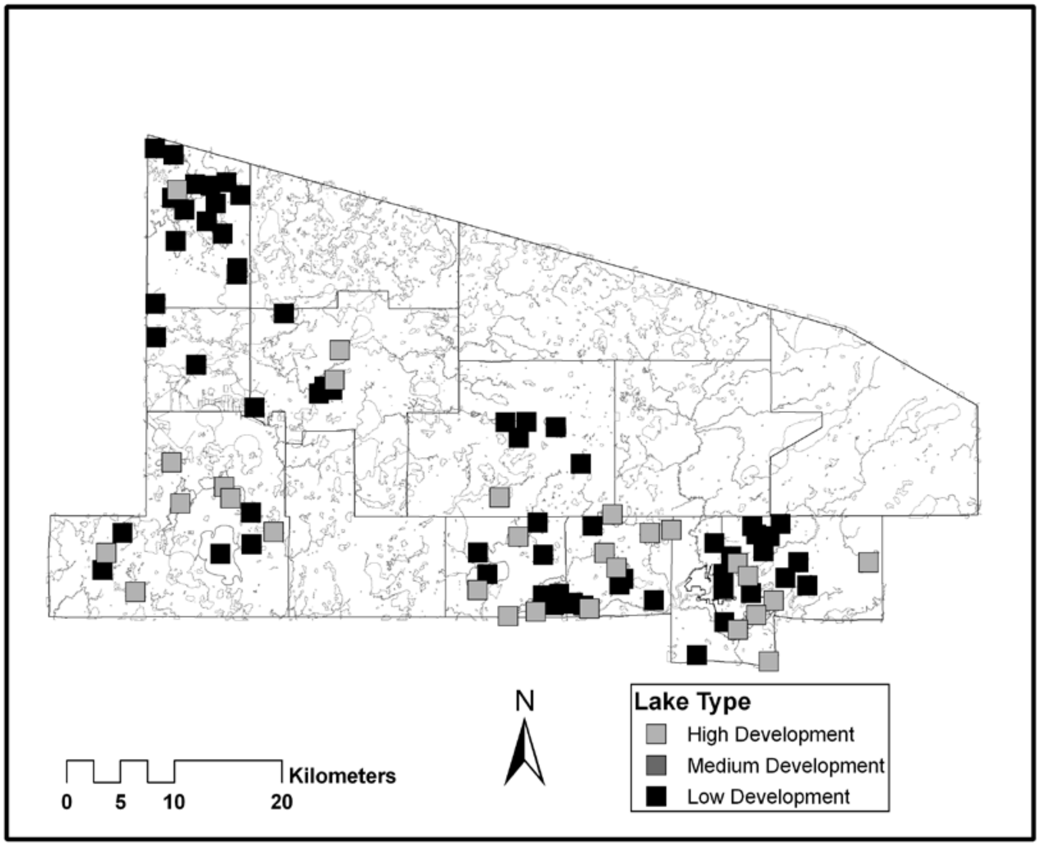
Developed Preserved Undeveloped Lake

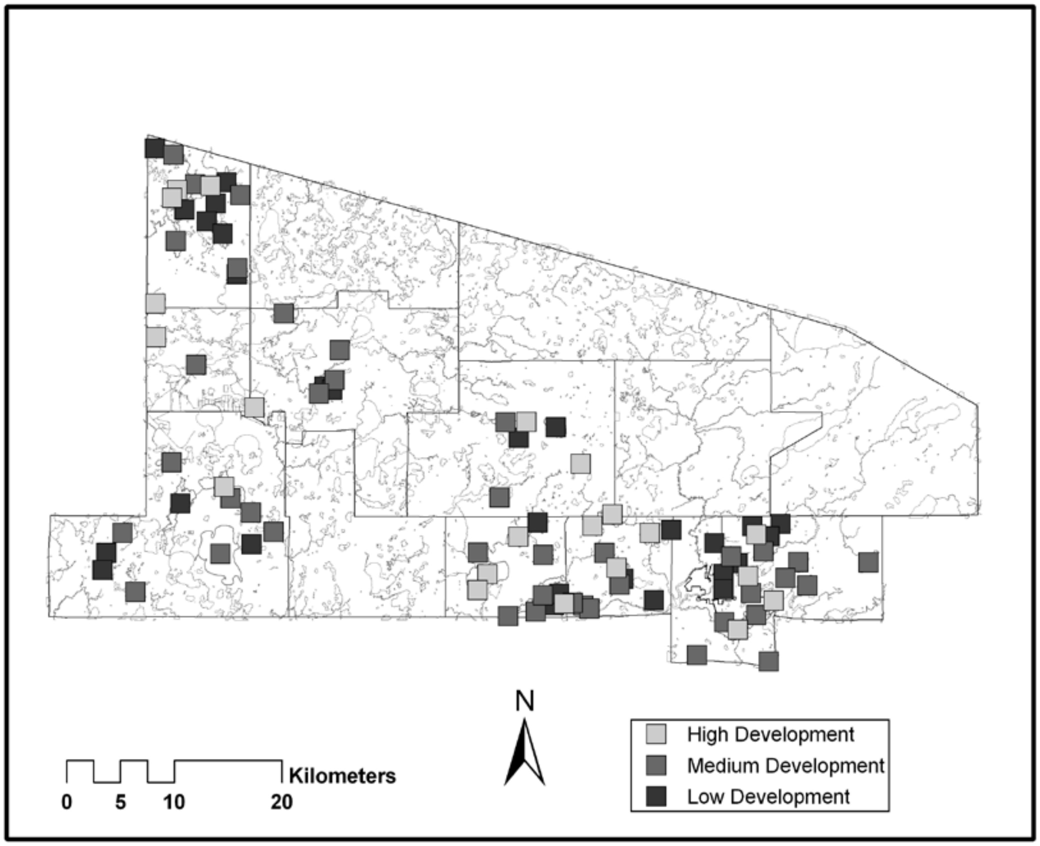
685


Average Residential Density
Density
residence/km
Average Bluegill Growth Rate
Density
mm/yr
Average Coarse Woody Debris
Density
CWD/km
100ft zoning
200ft zoning
300ft zoning
400ft zoning


Change in Residential Density
Density
0
.5
1
1.5
-4
-3
-2
-1
0
residence/km
Change in Bluegill Growth Rate
Density
0
50
100
150
0
.01
.02
.03
.04
mm/yr
Change in Coarse Woody Debris
Density
0
.01
.02
.03
0
50
100
150
CWD/km
High Development
Medium Development
Low Development


Change in Residential Density
Density
residence/km
-4
-3
-2
-1
0
1
.8
.6
.4
.2
Change Bluegill Growth Rates
Density
mm/yr
.01
.02
.03
.04
200
150
100
50
Change in Coarse Woody Debris
Density
CWD/km
.06
.04
.02
150
High Development
Medium Development
Low Development


N
Lake Type
High Development
Medium Development
Low Development
0
5
10
20
Kilometers


N
High Development
Medium Development
Low Development
0
5
10
20
Kilometers

699