Urban Ecosyst (2013) 16:499–510
DOI 10.1007/s11252-013-0290-7

Using housing growth to estimate habitat change: detecting Ovenbird response in a rapidly growing New England State

Christopher A. Lepczyk · Aaron Wunnicke · Volker C. Radeloff · Curtis H. Flather · Anna M. Pidgeon · Roger B. Hammer

Published online: 20 January 2013

Abstract Numerous measures of human influence on the environment exist, but one that is of particular importance is houses as they can impact the environment from species through the landscape level. Furthermore, because the addition of houses represents an important component of landscape change, housing information could be used to assess ecological responses (e.g., decline in wildlife habitat) to that change. Recently developed housing density data represents a potential source of information to assess landscape and habitat change over long periods of time and at broad spatial extents, which is critically needed for conservation and management. Considering the potential value of housing data, our goal was to demonstrate how changes in the number of houses leads to changes in the amount of habitat across the landscape, and in-turn, how these habitat changes are likely to influence the distribution and abundance for a species of conservation concern, the Ovenbird (*Seiurus aurocapillus*). Using a relationship between Ovenbird abundance and housing density, we predict suitable habitat in the forests of Massachusetts (USA) from 1970 to 2030. Over this 60-year period, the number of houses was projected to increase from 1.84 to 3.32 million. This magnitude of housing growth translates into a 57 % decline in Ovenbird habitat (6,002 km^2 to 2,616 km^2), a minimum decline of ~850,000 (48 %) Ovenbirds, and an increase in the number of subpopulations across the landscape. Overall, housing data provide important information to robustly measure landscape and habitat change, and hence predict population change of a species. We suggest that time series of housing data linked to

C. A. Lepczyk (✉)
Department of Natural Resources and Environmental Management, University of Hawai‘i at Mānoa, 1910 East-West Road, Honolulu, HI 96822, USA
e-mail: lepczyk@hawaii.edu

A. Wunnicke · V. C. Radeloff · A. M. Pidgeon
Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, Madison, WI 53706, USA

C. H. Flather
USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO 80526, USA

R. B. Hammer
Department of Sociology, Oregon State University, Corvallis, OR 97331, USA

ecological responses (e.g., Ovenbird abundance) offers a novel and underutilized approach to estimating long-term and spatially broad predictions of ecosystem response to landscape change, which in turn can inform conservation and management.

Keywords Habitat change · Housing development · Landscape change · Ovenbird · Rural sprawl · *Seiurus aurocapillus* · Sprawl

Introduction

Historically, ecologists have typically used the human population as the main demographic factor relating people to the environment (e.g., Ehrlich 1968). However, houses and housing units (hereafter 'houses'), offer a different and perhaps more meaningful way to ascertain and investigate how demography specifically, and humans generally, influence the environment. One reason is that over the past century houses have been increasing at a faster rate than the human population in many locations in the United States and around the world (Liu et al. 2003; Lepczyk et al. 2007). Concurrent with this faster growth, is the fact that the physical dimensions of the average house have increased, while the average number of people occupying them have decreased. The net result is that over time there are fewer people per unit area, which translates into a less efficient allocation of land, demonstrating that housing may capture the ecological footprint better than population size (Theobald 2001; Liu et al. 2003).

Another consideration is that houses are not isolated items on the landscape, but rather are representative of a host of other attributes that also influence the environment, such as associated infrastructure like roads (Dwyer and Childs 2004; Forys and Allen 2005). For instance, as road density increases, the amount of habitat (e.g., forest) decreases, resulting in a more fragmented ecological system (Hawbaker and Radeloff 2004). Likewise, recreational infrastructure (e.g., hiking trails), can change ecological relationships such as between predator and prey (e.g., Miller et al. 1998).

Houses and housing growth have also been identified as one of the major threats to ecosystems, due to their effects on land use (Matlack 1997; Parks et al. 2000), water quality (Wear et al. 1996), forest management (Marcin 1993), wildlife populations (Soulé 1991; Cincotta et al. 2000), biodiversity (McKinney 2002; Hansen et al. 2005; Lepczyk et al. 2008), endangered species (Czech et al. 2000), habitat loss (Theobald 2000), and encroachment on protected areas and national parks (Radeloff et al. 2010; Wade and Theobald 2010). Notably, even an individual home impacts the environment as evidenced by the number of animals demonstrating a threshold effect with varying distances from a house (Odell and Knight 2001). Beyond simply the structure of the house, the environment surrounding a house is typically manipulated in ways that can be both beneficial and detrimental to species (Lepczyk et al. 2004). A case in point is the addition of backyard gardens, which can improve bird habitat for many species (Davies et al. 2009; Goddard et al. 2010). Even the ruins of ancient houses have a long ecological legacy, as demonstrated by markedly different patterns of species composition and richness where houses were located compared to adjacent locations without houses in the Aleutian Islands of Alaska (Warren et al. 2006). Thus, whether at the scale of a single home or an entire housing development, houses and housing growth result in marked ecological impact.

Besides impacting ecosystems, houses also provide a useful way to measure landscape change (i.e. the shift of one land use or land cover type to another over time). Specifically, all measures of the landscape, and hence landscape change, stem from two main types of data:

remotely sensed imagery (aerial photos, satellite imagery) and published data/censuses (Dunn et al. 1990). Housing units at the partial U.S. block level are a recently developed data set that falls in the latter category and offers a substantial advantage with regard to the limitations identified in traditional landscape change studies (Hammer et al. 2004). If we assume that the addition of new houses on the landscape results in the conversion of one land use into a residential land use then we can identify three advantages of these data. First, housing growth data at the partial block level (~80 ha) are a finer scale representation of landscape change relative to many human influence databases collected over time, allowing for more spatially detailed analyses of houses and housing growth (Lepczyk et al. 2007). Second, housing data have been collected over a longer period of time than remotely sensed information, thus allowing for more extensive temporal analysis. Finally, the spatially consistent nature of the partial block housing data allows for temporal analyses not previously possible with U.S. Census data, given the problem of shifting census boundaries each decade (Hammer et al. 2004).

Although spatiotemporally consistent housing data offers great promise to both basic and applied research questions in urban ecology, landscape ecology, and conservation (Hammer et al. 2004; Lepczyk et al. 2007), they have never been used to explore how housing growth can act as an agent of landscape change, and in-turn, how that may affect wildlife habitat, and consequently wildlife populations. Because landscape change leads to a corresponding change in habitat, the ability to use housing data for conservation and management could offer a great opportunity for broadening the scale at which we examine such questions. Considering the importance of landscape change on ecological systems, our overarching goal was to demonstrate how changes in the number of housing units leads to changes in the amount of habitat across the landscape, and in-turn, how these habitat changes are likely to influence species distribution and abundance. Given this goal, our objectives were to: 1) create a simple habitat suitability function based on housing information for a species of conservation concern; 2) link the habitat suitability function with a temporal series of housing data to estimate habitat change over time; and, 3) predict the resultant population response by the species.

Based upon previous work investigating the relationships between houses and breeding birds in the Midwestern United States (Lepczyk et al. 2008), we selected the Ovenbird (*Seiurus aurocapillus*) as our focal species. Ovenbirds are an ideal focal species for investigating the relationship between landscape change and habitat change, because their population dynamics are fairly well described (e.g., Larson et al. 2004), they have a strong association to housing density with abundances decreasing as housing numbers increase (Kluza et al. 2000; Lepczyk et al. 2008), and they are a forest species that can be used as an umbrella species for conservation (Hess and King 2002).

Methods

Study area and housing data

We selected the state of Massachusetts, USA (Fig. 1), to investigate the utility of measuring changes in housing density as a proxy for changes in habitat availability. Our selection was based on both the marked increase in the number of housing units from 1970 to 2000 as well as the presence of Ovenbirds, which have declined statewide at an average annual rate of nearly 2.4 % since 1990 (Sauer et al. 2008). Within Massachusetts, we used a dataset of fine resolution housing unit density in vector format. Specifically, the housing data are U.S.

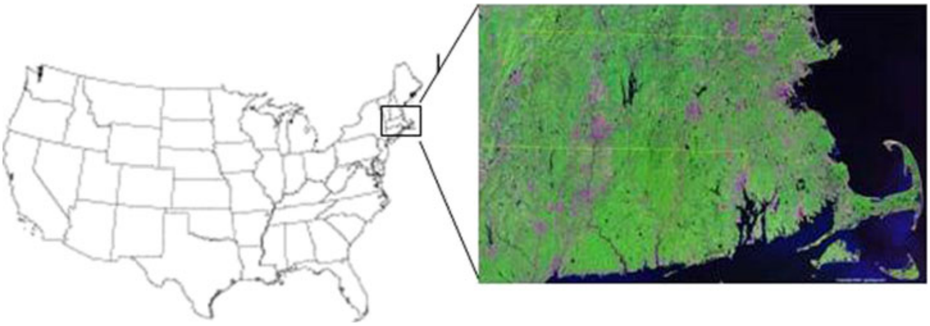


Fig. 1 Location of Massachusetts, USA, with forested locations identified from the 1992/93 NLCD data

decennial census data at the partial block group level (see Hammer et al. 2004 for details), along with projections of past and future growth trends, and are spatially consistent by decade from 1940 to 2030. Partial block groups fall between blocks and block groups in the hierarchy of U.S. Census Bureau geographies (see http://www.census.gov/geo/www/reference.html), and are roughly equivalent, in social terms, to subdivision sized neighborhoods. Housing units include both single detached homes and multi-unit complexes. A total of 24,511 partial block groups (excluding water polygons) occur in Massachusetts, with a mean area of 82.8 ha.

Breeding bird data

We used North American Breeding Bird Survey (BBS) data to quantify abundance of Ovenbirds. The BBS is an annual roadside monitoring program initiated in 1966 in the U.S. and Canada that surveys birds during the breeding season (Sauer et al. 2003). Each survey route is 39.4 km long and consists of 50 point counts, lasting 3 min each, spread at 0.8 km intervals. We estimated mean Ovenbird abundance on each BBS route in Massachusetts over the three closest years of BBS surveys within a 5-year window, centered on the decennial census years (i.e. 1970, 1980, 1990, and 2000). This selection procedure yielded 70 BBS surveys distributed among 25 routes and four different decadal time points (see Results).

Habitat suitability

For each of the 25 BBS routes we created a 400 m buffer around the survey route in a geographical information system (GIS), which corresponds to the detection range established by BBS protocol (Sauer et al. 2003). Within each buffer we determined the density of housing units. After an initial inspection, we $\log_{10}$ transformed the housing density data for analysis. Following transformation, mean Ovenbird abundance was regressed on the housing density using a general linear modeling framework. Because our primary goal was to measure the effect of housing growth on Ovenbird habitat, we chose to investigate a suite of simple linear and quadratic model specifications that related bird abundance to housing density for the decennial census years. These models were used to generate our estimates of habitat suitability.

In order to predict habitat suitability over time for the entire study area, we first converted the housing data from vector to grid format with 250×250 m cells (6.25 ha cells), which was the smallest cell size possible given the extent of the landscape. Second, because Ovenbirds are a woodland species, we restricted our area of analysis only to forested locations in the study area (Fig. 1). Specifically, we used the forest class (classes 41, 42, and 43) from the National Landcover Data (NLCD), which is a classification of 1992/1993 Landsat Thematic Mapper satellite imagery (Vogelmann et al. 2001) with 30 m cells and resampled it to 250 m cells using nearest neighbor resampling, in order to match the resolution of the housing grids. Subsequently, we overlaid forest cover with the housing data to create new decadal grids that masked out all non-forested locations in the study area for 1970, 1980, 1990, 2000, 2010, 2020, and 2030, and assigned housing density to each 250 m pixel. Thus, these seven grids only describe information for the forested regions of the study area and were the ones used for our habitat suitability modeling.

To investigate how changes in housing density are likely to influence Ovenbird habitat suitability, and thus the Ovenbird population over the 60-year period we used the metapopulation module of RAMAS GIS (Akçakaya 2002) to simulate statewide population estimates. The seven decadal grids were then loaded into RAMAS GIS and used to calculate suitable habitat for Ovenbirds in Massachusetts based upon the habitat suitability equation (see Results). Because our primary goal was to examine how housing growth leads to changes in the land, habitat, and hence, Ovenbird populations, we initialized our metapopulation model with the maximum demographic estimates that were ecologically realistic. Ovenbird territory size varies across the species range and among years, according to abundance of insect prey and the nesting stage, with an upper limit of approximately one female (or one pair) per hectare (Van Horn and Donovan 1994; Holmes and Sherry 2001). We used this upper limit as our carrying capacity for the landscape under pristine (i.e. forested land with no houses) conditions (which corresponds to 6.25 females per grid cell), which matches other modeling approaches (Larson et al. 2004). We then set RAMAS to determine the carrying capacity for each cell based upon the habitat suitability maps, and populated all grid cells. We considered our initial population to be that of the post-fledge period and thus comprising 36 % adults and 64 % juveniles. We used an intrinsic rate of growth (r_{max})=1.43, based upon the highest fecundity and annual survival rates reported in the best habitat (Larson et al. 2004). Using these initial parameters we then ran the model over the 60 year time period using 1 year time steps and three different levels of dispersal (0 %, 2 %, and 5 %; note that dispersal rates greater than 5 % resulted in species extinction). For each dispersal level the model was run twenty times. To determine if significant change occurred over time in the number of houses and amount of habitat we used linear regression (reported below as the F-statistic, degrees of freedom, adjusted r^2, and p-value), with a $p<0.05$ considered significant.

To verify the model results of the Ovenbird population in Massachusetts we investigated the BBS data in two ways. First, we inspected the trend results for the entire state of Massachusetts produced by Patuxent Wildlife Refuge based upon 26 BBS routes (Sauer et al. 2008). Because statewide trends produced by BBS use all available routes, the number of routes included differed from our use of raw BBS data in which we excluded routes that did not contain enough temporal resolution. This resulted in a difference of one route. BBS trends are broken out two different ways by Patuxent Wildlife Refuge. Under the first approach, change is analyzed over the entire period of surveys (i.e. 1966 to 2007), whereas under the second approach changes are analyzed over two smaller temporal periods of 1966 to 1979 and 1980 to 2007. Because the results of the BBS trend analyses are available online from Patuxent Wildlife Refuge, we report both the overall trend analysis and the partitioned trend analysis as rates of change and their significance level. Since the BBS statewide trend estimates include both forested and non-forested regions of the state, we used a second method of model verification whereby we inspected individual BBS routes that were in predominately forested landscapes (>50 % of route surrounded by forest according to Patuxent Wildlife Refuge route land cover data). Of the 28 BBS routes that have been surveyed in the state at least once, 23 were located in predominately forested locations, and of these 19 had been sampled for ≥10 years. We investigated each of these 19 routes for temporal trends in Ovenbird abundance.

Results

The best fit model relating housing density to Ovenbird abundance was: mean ovenbird abundance = constant + $\log_{10}$housing density + year ($F_{2,67}$=22.03; adjusted r^2=0.38; p< 0.0001). However, we selected the simpler linear model of mean ovenbird abundance= constant+$\log_{10}$ housing density, as the habitat suitability measure, over the previous model because it had nearly identical fit ($F_{1,68}$=38.22; adjusted r^2=0.38; p<0.0001; Fig. 2), the partial p-value for the effect of year was close to the cutoff level for significance (p=0.047), and the difference in y-intercept was marginal as the slopes were parallel. Thus, our habitat suitability equation was: ovenbird abundance =31.3–12.4*($\log_{10}$ housing density).

From 1970 to 2030, the total number of housing units in Massachusetts was projected to increase 38 % from 1,838,320 to 2,538,193. Concurrently, within the forested portion (i.e. forested cells) of the state, the total number of housing units was projected to increase from 360,293 to 974,013, representing a 170 % increase (Table 1). These housing increases were significant for both the entire state ($F_{1,5}$=890.73; r^2=0.99; p<0.0005) and the forested regions ($F_{1,5}$=455.42; r^2=0.99; p<0.0005).

In 1970, the state of Massachusetts contained slightly more than 6,000 km^2 of suitable habitat for Ovenbirds (Table 1). By 2030, suitable habitat is predicted to decrease by ~3,400 km^2 (56 %; $F_{1,5}$=27.86; r^2=0.99; p=0.003), as the number of housing units increase, especially throughout the forested portions of the state. Suitable habitat will have been reduced from ~30 % of the landscape in 1970 to ~13 % in 2030 (Table 1). Spatially, this loss of habitat is predicted to occur through the break-up of several large habitat patches in the western area of the state (Fig. 3). In 1970, this western area had one or two large, contiguous, blocks of habitat that are predicted to become greatly reduced and isolated by 2030 as housing numbers increase in this portion of the state.

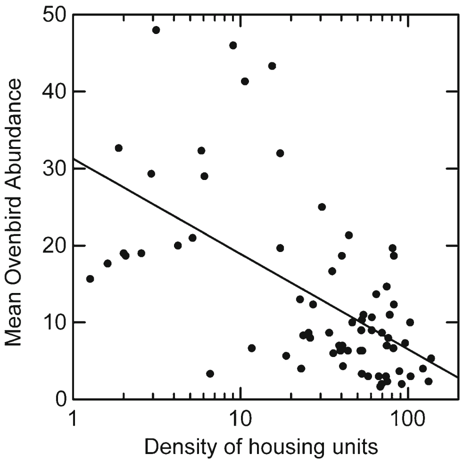


Fig. 2 Linear relationship between Ovenbird abundance and housing density (houses/km^2) used to create the habitat suitability function

Table 1 Housing and predicted forest habitat changes from 1970 to 2000, and projected for 2010–2030

Year	Total Housing Units	Forested Housing Units	Suitable Habitat (km^2)	Percent Suitable Habitat Remaining	Percent of State Containing Suitable Habitat
1970	1,838,320	360,293	6002	100	29.6
1980	2,143,554	462,860	4478	74.6	22.1
1990	2,396092	553,913	3636	60.6	17.9
2000	2,538,193	614,361	3414	56.9	16.8
2010	2,802,400	724,621	3062	51.0	15.1
2020	3,027,678	829,607	2760	46.0	13.6
2030	3,322,537	974,013	2616	43.6	12.9

In the model with no dispersal, the Massachusetts Ovenbird population was estimated to decline from 1,630,215 to 782,601 (48 %) individuals over the 60 year period (Fig. 3). Similarly, with dispersal rates of 2 % and 5 %, the Ovenbird numbers declined to 590,376 and 285,778 individuals, respectively, over the same period of

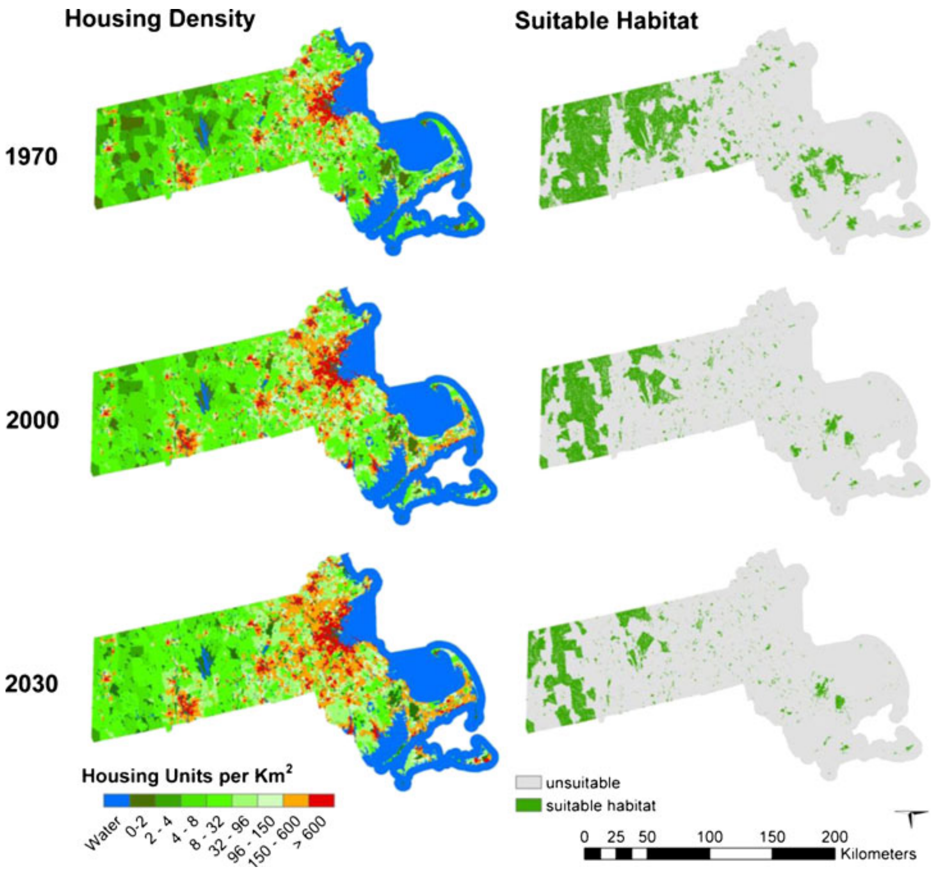
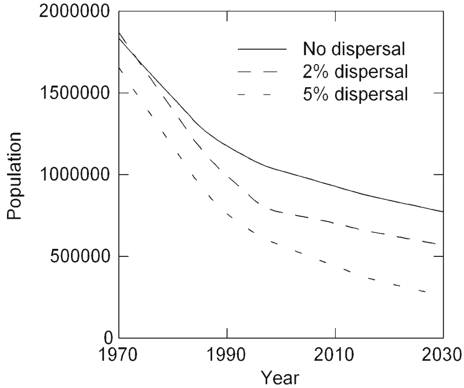


Fig. 3 Temporal dynamics of housing growth and suitable Ovenbird habitat loss from 1970 to 2030 in Massachusetts

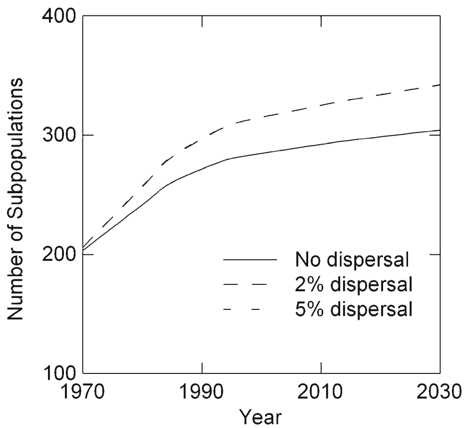
Fig. 4 Ovenbird population size under differing dispersal conditions. Data are presented as Lowess smoothed curves



time (Fig. 4). Concurrent with the decrease in population size was an increase in the number of subpopulations, from 200 to 303 (no dispersal) or 341 (2 % and 5 % dispersal; Fig. 5).

Our model results reflect the general trend of Ovenbirds within the state based upon our verification approaches. Specifically, from 1966 to 2007 BBS trend results for the entire state of Massachusetts indicate that Ovenbirds declined by 0.3 %/year, which while not statistically significant ($p=0.6$) (Sauer et al. 2008) does translate to a loss of 268,913 individuals from 1970 to 2030 based upon an initial model population of 1,630,215 in 1970. Furthermore, BBS trend estimates calculated separately for the time periods of 1966–1979 and 1980–2007, indicate that the Ovenbird population for Massachusetts has declined significantly at an annual rate of 2.4 % from 1966 to 1979 ($p=0.04$) and 1.8 % from 1980 to 2007 ($p<0.005$; Sauer et al. 2008). Based upon these two separate estimates (i.e. 2.4 % from 1966 to 1979 and 1.8 % from 1980 to 2007), the Ovenbird population would be predicted to decline from 1,630,215 in 1970 to 515,605 in 2030, which falls between our 2030 metapopulation model estimates based on 2 % dispersal (587,948 individuals) and 5 % dispersal (235,641 individuals; Fig. 4). Similarly, among the 19 forested BBS routes of Massachusetts, Ovenbird abundance was found to be significantly decreasing on four routes, with one route having a significant increase. Furthermore, the average annual rate of change among all 19 routes was −2.4 %.

Fig. 5 Number of Ovenbird subpopulations. Note that both forms of dispersal yield essentially the same outcome, resulting in overlapping lines. Data are presented as Lowess smoothed curves



Discussion

Overall, our findings demonstrate that changes in the number of houses on the landscape leads to changes in the amount of habitat available for Ovenbirds. Specifically, over the 60-year period ~56 % of the available habitat was or will be lost. This habitat loss translates to a minimum reduction in the Ovenbird breeding population of ~850,000 individuals. Hence, our results show that measuring changes in houses provides an important proxy for landscape change, thereby providing a robust approach for measuring landscape change and its affects on species at large spatial and temporal scales.

In recent years the use and importance of houses in ecology, conservation, and management, has gained widespread appeal. In part, this appeal has stemmed from the view that housing may capture the ecological footprint of human influence better than human population counts (Theobald 2001; Liu et al. 2003; Peterson et al. 2007). Concurrently, there has been a marked increase in concern over both rural and urban sprawl (Gillham 2002; Theobald 2001; Brown et al. 2005; Radeloff et al. 2005; Theobald 2005; Hansen et al. 2005). On the other hand, while research has suggested that changes in housing may serve as a surrogate for landscape change, to our knowledge this has not been demonstrated. Our findings indicate that housing density is an effective measure of anthropogenic landscape change, and provides a useful index of human influence on the landscape.

While our research demonstrates the utility in using housing data to measure landscape and habitat change, there are several caveats to bear in mind. First, our estimates of habitat prior to and following the 1990–2000 time period may be slightly biased because we used a static estimate of forest cover from 1992/93 based upon the NLCD. As forest cover clearly is not static, our estimates of forest cover and the abundance of Ovenbirds may be liberal where deforestation has occurred and may be conservative where afforestation has occurred. Because detailed time series forest cover maps at the resolution of the NLCD are unavailable, measuring the exact nature of forest change over the study period is not possible. However, estimates of forest cover from Forest Inventory Analysis as described by Hall et al. (2002) indicate that since the 1950s, there has been virtually no growth in forested areas across the different regions of the state. In fact, in the highlands of the state, which closely correspond in location to the suitable habitat of 1970 (Fig. 3), forested areas were virtually static from 1975 to 2000 (Hall et al. 2002). In contrast, in much of the coastal zone of the state, which closely corresponds with the unsuitable habitat of 1970 (Fig. 3), there has been a decrease in forested areas between 1975 and 2000. Thus, data from forest inventories support the trajectory and regions where forests have decreased between 1975 and 2000 in the suitable habitat of Massachusetts. Second, our primary assumption is that the addition of housing units translates to additional land being converted for houses. Because the U.S. Census definition of housing units includes multifamily housing (i.e. apartment and condominium complexes), it is possible that a home is razed and multi-unit development is built, thereby increasing the housing number and density, without necessarily changing the physical footprint on the landscape. While this may have occurred in some instances, it is not the predominant form of housing growth and is less likely to occur in forested portions of the landscape. Third, it is important to bear in mind that adding houses to the landscape does not in and of itself strictly make habitat unsuitable (Odell and Knight 2001). Rather, adding houses reduces the suitability and quality of the habitat such that a given area may support fewer individuals. Fourth, because Ovenbirds are Neotropical migrants, their survival also depends upon biotic and abiotic factors in their overwintering habitat, which affect habitat quality. However, when Ovenbird abundance was evaluated between overwintering habitat conditions vs. breeding habitat conditions in relation to weather (i.e. rainfall), they were found to be primarily dependent upon breeding habitat conditions (Dugger et al. 2004). Fifth, we deliberately chose a simplistic habitat suitability and metapopulation model to examine trends in the Ovenbird population as our goal was to demonstrate the validity of using housing data as a measure of landscape change, and hence habitat change, on wildlife populations for the benefit of managers, planners, and practitioners. If we were to alter the demographic parameters, we would certainly change the results. Notably, however, the importance and value of our approach is that it demonstrates that even under the maximum ecologically favorable conditions (e.g., using the maximum intrinsic rate of increase) the Ovenbird population in Massachusetts is predicted to decline markedly as the number of houses in forested areas increase. Thus, while one must bear in mind the context of this research, the outcome will likely remain qualitatively consistent regardless of how we might alter assumptions, parameter estimates, and specificity of the models used.

The findings of our research clearly demonstrate the utility of using time series of housing data as a measure of landscape change. Not only do the data provide spatially consistent measures of change over broad spatial and temporal scales, but they can be integrated with numerous ecological or natural resource data. For instance, housing data can be integrated with other birds and other wildlife species to run similar metapopulation models to the one presented here or more advanced models. Similarly, the housing data can be integrated with biodiversity measures to investigate their spatial concurrence over time, thereby aiding in conservation planning. As a result, the data offer a great potential for use by the natural resource, management, and conservation communities.

Acknowledgments We thank Shelley Schmidt for assistance with the housing data and Roarke Donnelly, Esteban Fernandez-Jurcic, David Turner and an anonymous reviewer for comments on the draft manuscript. This material is based upon work supported by the National Science Foundation under Grant No. 0306078 to CAL. We also acknowledge support by the U.S. Forest Service Northern Research Station for the development of the housing growth databases.

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