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Normative standards for land use in Vermont: Implications for biodiversity

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ABSTRACT

The conversion of natural lands to developed uses poses a great threat to global terrestrial biodiversity. Natural resource managers, tasked with managing wildlife as a public trust, require techniques for predicting *how much* and *where* wildlife habitat is likely to be converted in the future. Here, we develop a methodology to estimate the "social carrying capacity for development" – SK_d – for 251 towns across the state of Vermont, USA. SK_d represents town residents' minimum acceptable human population size and level of development within town boundaries. To estimate SK_d across towns within the state of Vermont (USA), as well as the average state-wide SK_d, we administered a visual preference survey ($n = 1505$ responses) to Vermont residents, and asked respondents to rate alternative landuse scenarios in a fictional Vermont town on a scale of +4 (highly acceptable) to −4 (highly unacceptable). We additionally collected demographic data such as age and income, as well as ancillary information such as participation in town-planning meetings and location of residence. We used model selection and AIC to fit a cubic function to the response data, allowing us to estimate SK_d at a town scale based on town demographic characteristics. On average, Vermonters had a SK_d of 9.1% development on the landscape; this estimate is 68% higher than year 2000 levels for development (5.4%). Respondents indicated that management action to curb development was appropriate at 9.4% development (roughly the statewide SK_d average). Management by local, regional, and state levels were considered acceptable for curbing development while federal level management of development was considered unacceptable. Given a scenario where development levels were at SK_d, we predicted a 16,753 km^2 reduction in forested land (−11.16%) and a 1038 km^2 reduction in farmland (−60.45%). Such changes would dramatically alter biodiversity patterns state-wide. In a companion paper, we estimate how these changes would affect the distribution of wildlife species.

1. Introduction

Around the earth, human population growth leads to increased degradation and conversion of open lands. The conversion of natural lands to developed uses may pose the greatest threat to global terrestrial biodiversity (Vitousek, 1994). As human populations spread from urban centers, existing natural areas, working forests, and traditionally agricultural areas are converted, often permanently, to development. Conversion alters the amount and distribution of wildlife habitat and is the number one cause of decreasing biodiversity worldwide (Convention on Biological Diversity, 2010). With projections of global forest loss between 3 and 9 million km^2 by 2050 (UNEP, 2007), dramatic losses in terrestrial biodiversity can be expected.

Such landscape change affects wildlife in three major ways. First, habitat loss – the outright reduction in total habitat via land conversion – may be the single most important factor influencing wildlife biodiversity at the global scale (Ehrlich, 1995) and the population scale (Fahrig, 2003). Second, habitat fragmentation *per se* can have a large impact on wildlife: even if habitat amount is held constant across a landscape, the arrangement of natural habitat patches on that landscape can significantly affect wildlife population dynamics, particularly when the amount of habitat in the landscape is low (Fahrig, 2003). Finally, roads have been shown to alter wildlife movement patterns, increase mortality, increase

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population isolation, and serve as corridors for invasive species all of which can negatively affect native wildlife species (Forman et al., 2003).

Effectively predicting how and where development may occur in the future is of utmost importance in understanding how humans and wildlife will adapt to a more populated and developed landscape. In the United States, the human population has increased 9.7% between 2000 and 2010, adding 15,800,089 households. Between 1982 and 2003, 142,000 km^2 were converted to development, with 220,000 km^2 expected to be converted to development by 2030 (White et al., 2009). Unlike some areas of the western U.S., where large, publicly owned lands make possible top-down management decisions, landscapes in the eastern U.S. are primarily composed of small parcels owned by private landowners, whose individual decisions collectively determine the distribution and amount of natural habitat across the landscape. Natural resource managers, tasked with managing wildlife as a public trust, face the difficult challenge of being unable to direct management on privately owned lands.

Individual landowners, on the other hand, often have multiple objectives in terms of how to manage their lands. Farmers struggle with maintaining economic viability in their operations weighed against the pressures of development, and a wealth of environmental factors. Owners of forested parcels face trade-offs between managing for timber production, for game and non-game wildlife species, for water quality, and for meeting the economic and housing needs of a growing human population. In addition, the vast majority of landowners rely on services provided in the surrounding area, such as businesses, roads, and schools, and demand for these services can lead to conversion of natural lands to development. The collection of these thousands of decisions made every day by individual landowners and town planners ultimately shape the broader landscape. From the wildlife conservation perspective, there is great need to quantify what levels of development are acceptable to citizens, thus allowing wildlife managers to respond on behalf of wildlife.

Here, we used normative theory approaches to estimate what levels of forest, agriculture, and development on a landscape are "acceptable" to residents of Vermont, USA. In contrast to traditional land use change modeling, which often uses past trends in population growth and development to predict changes into the future (e.g. Theobald, 2005), we focused on identifying and mapping the acceptability of development (SK_d) by landowners across Vermont. In a companion analysis (Bettigole et al., 2013), we estimated how these levels will affect wildlife species in Vermont.

Estimation of social norms (i.e., what is "acceptable" or "normal" within a cultural context) has become increasingly used in setting management standards in recreation, parks and in broader natural resources settings (Vaske and Whittaker, 2004; Manning, 2007). For example, in a U.S. National Park, the visitor experience may be associated with how crowded the Park is: the quality of the experience declines as the crowd size increases, and at some point people may choose not to visit a park because it is too crowded. A normative standard identifies the size of the crowd that an average visitor finds "acceptable." Studies that estimate such normative standards are invaluable when the standards become incorporated into a management objective. For example, when crowds become too large, the Park may take management actions to reduce the number of people that occur in the same place and time.

A norm curve is estimated by surveying the opinions of people with respect to a given indicator, such as the percentage of development in a town, and recording their responses on a scale from highly acceptable (+4) to highly unacceptable (−4). For example, the hypothetical norm curve in Fig. 1. Fig. 1 indicates that

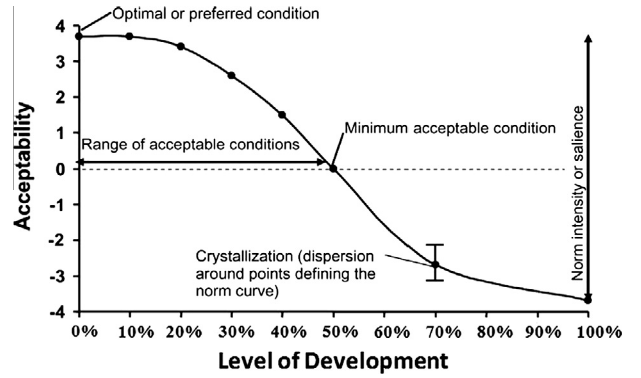

Fig. 1. Hypothetical acceptability curve (social norm curve). These curves are estimated by compiling results of responses to surveys, where respondents rate the acceptability of various conditions. In this example, each point on the curve represents the mean acceptability score for a given level of development on the *x*-axis. The Minimal Acceptable Condition occurs at the level of development where Acceptability = 0. Here, we define this point as the social carrying capacity for development, or SK_d.

acceptability of town-level development begins to drop sharply at a threshold (~30% developed) and begins to level out at an unacceptable level (~70% developed). Of particular interest is the minimum acceptable condition SK_d, the point at which an indicator level shifts from acceptable to unacceptable. Other characteristics of interest include the norm intensity (the range of reported acceptability ratings) and crystallization (the level of agreement among respondents for a given indicator level; Fig. 1). In addition to stated acceptability levels for various levels of town development, respondents can identify their preferred level of development (preference), the level of development where one would move away (displacement), the level of development where managers or town planners should take action (management), and the level of development most like person's town. These are collectively known as "alternative evaluative dimensions" of a norm curve (Manning, 2007). By assessing these standards, or social norms, with respect to different landcover types, we can begin to understand how these collected decisions and perceptions on acceptability may impact a suite of forest dwelling wildlife species in the future.

In this paper, we design a statewide visual preference survey to determine acceptable levels of development, forest and agriculture within Vermont towns. We asked respondents to evaluate a series of three-dimensional simulations of development in a fictional (but representative) Vermont town. Our goal was to measure and map the maximum amount of development that Vermont residents were willing to accept on their landscape, and by doing so understand how these social norms may affect forest dwelling wildlife species in the future. Thus, we evaluate the maximum potential for residential development as valued by current residents of Vermont and do not attempt to predict exactly how land use change will occur in the future. Prediction of future land use change is extremely complex, incorporating human population dynamics issues of immigration/emigration, births/deaths, technology, economics, transportation, and a wealth of other factors that we do not consider here.

Our objectives were to (1) Administer a statewide, mail-based visual preference survey, (2) Estimate acceptability curves for housing and associated development at a statewide level, (3) Measure alternative evaluative dimensions and preferences for scale of management, (4) Estimate the acceptability of development occurring on either forested or agricultural lands, (5) Explore the effects of covariates, such as age of respondents and household income on the shape and position of the acceptability curves within towns, and (6) Predict and map acceptable levels of development (SK_d) at the town scale across the entire state.

2. Materials and methods

2.1. Study area

The study area included the entire state of Vermont, encompassing 24,963 km^2 with a population of 625,741 and 322,539 households (U.S. Census Bureau, 2010). Vermont is largely rural, with the exception of Chittenden County – which contains 24% of the state population, 91 people per km^2, and 1.55 km roads/km^2. This sharply contrasts with Essex County in the northeast of the state, with 1% of the state population, 3.7 people per km^2, and road densities of 0.53 km/km^2.

Like other New England states, Vermont has been faced with issues of increasing populations, suburban and exurban development, and increased vehicular traffic on existing and new roads. Between 1970 and 2003, more than 405 km^2 of forested land in Vermont was converted to development (Austin et al., 2004). Over this time, the rate of development has been 2.5 times greater than that of population growth (Vermont Forum on Sprawl, 1999). Much of this development is not focused in existing population centers, but occurs haphazardly in rural and suburban areas. Because of this, large amounts of open and forested lands are lost every year to residential development, a form of conversion that is almost always permanent (Austin et al., 2004).

2.2. Survey development

To measure normative standards of land use in Vermont, we developed a statewide visual preference survey based on several studies of recreational crowding (Manning, 2004; Anderson et al., 2010). We presented respondents with a suite of simulated images, illustrating varying compositions of forested, developed, and agricultural lands (Fig. 2). The core of the survey was a set of six illustrations of a realistic three-dimensional model of a fictional Vermont town, displaying a gradient of housing development levels.

We used CommunityViz software (Placeways LLC, 2009), a companion program to ArcGIS (ESRI, 2009), to create a detailed three-dimensional model of a fictional Vermont town. We used the topography from an area just outside of Vermont's southern border, and then created a landscape identical to Vermont's average non-developed land use values from the most recent National Land Cover Database (NLCD). The fictional town began as 85% forested, 12% agricultural, and 3% water. We created a rule-based model for housing development that began with 1.7% developed (Fig. 2.1), the lowest levels found in Vermont, to 49.3% developed (Fig. 2.6), just above the urban threshold (as defined by Theobald, 2005; the U.S. Census Bureau, 2000).

Development build-out occurred exponentially between illustrations to allow respondents to more easily identify changes in density (Fig. 2). We prioritized building sites first in the town center, then in valleys, and then in uplands. We avoided building on the steepest slope per regulatory requirements for many town and regional plans in Vermont. Development followed past trends in Vermont, occurring 60% on forested lands, and 40% on agricultural lands (Vermont Forum on Sprawl, 1999). We ensured that the visible distance in the illustrations (from viewpoint of 3D model to horizon) was at least 5 km, which is the zone of impact for Vermont's largest ranging forest dwelling wildlife species (Long et al., 2010). The product of this visual modeling was a set of six three-dimensional color illustrations displaying a gradient of development scenarios in a fictional Vermont town (Objective 1, Fig. 2).

We asked respondents to rate the acceptability of each illustration from −4 (very unacceptable) to +4 (very acceptable) (Objective 2). In addition, for Objective 3, we asked respondents to identify: (a) the illustration they most preferred (preference), (b) the illustration that showed so much development that they would not want to live in the town (displacement), (c) the illustration that showed the maximum level of development a town should allow (management), and (d) the illustration that looked most like the town in which they live (looks like). The final piece of the questionnaire asked respondents to rate the acceptability (from −4 to +4) of four scales of land use planning as tools in controlling development (town, regional, state and federal).

While the analysis of the above questions allowed us to estimate norms for development, we also needed to understand what habitat (forest of agriculture) would be lost to accommodate new development (Objective 4). We asked respondents to imagine a scenario where 100 new homes were to be built on an undeveloped parcel composed of half forest, half agriculture. Providing a simple set of illustrations (Fig. 3), we asked them to rate the acceptability (from −4 to +4) of development occurring on (a) 100% forest and 0% agriculture, (b) 75% forest and 25% agriculture, (c) 50% forest and 50% agriculture, (d) 25% forest and 75% agriculture, and (e) 0% forest and 100% agriculture. Responses to these questions allowed us to estimate the proportion of forest and agriculture that would be lost under various development scenarios.

In addition to evaluating land conversion preferences, respondents also provided supplemental demographic information, which allowed us to evaluate if the shape of norm curves depended on these factors (Objective 5). Given variation in demographic characteristics among towns, a unique norm curve could be estimated for each town across Vermont. We asked nine questions: (a) Is Vermont your primary residence, (b) Were you born in Vermont, (c) Do you own the dwelling you live in, (d) Have you ever attended a planning or town meeting, (e) What town do you live in, (f) Do you live in the town/city center or outside of town, (g) What year were you born, (h) How many years have you lived in Vermont, and (i) What is your current annual household income? In addition, we estimated four additional covariates for each respondent based on their specified home town (e): population size, median income level, road density, and housing density.

To ensure high response rates, we followed standard survey design methodology to ensure that questionnaires were: (a) well written, attractive, and easy to read, (b) personalized as much as possible, and (c) mailings were repeated a number of times (Dillman et al., 2009). We included a single dollar bill along with half of our surveys to help boost response rates, a technique that sets up social exchange and encourages respondents to participate (James and Bolstein, 1990). Prior to mailing, we tested and modified our questionnaire with expert opinion and mock respondents following Dillman's (2009) methodology.

2.3. Sampling methodology

Based on expert opinion from the Center for Rural Studies at the University of Vermont, we expected a 15–20% response rate to our general population survey. In order to obtain a representative sample (target sample size of 384) with an estimated 15% response rate, we distributed questionnaires to a random sample of 4000 Vermont households between June 18th and July 2nd of 2011 (InfoUSA Inc., 2007). To boost response rates, questionnaires were printed in unfolded, full color booklets and included a prepaid return envelope for responses (Dillman et al., 2009). All questionnaires were preceded by a pre-notification postcard 3 days prior to mailing, and followed 1 week later by a reminder postcard. Full

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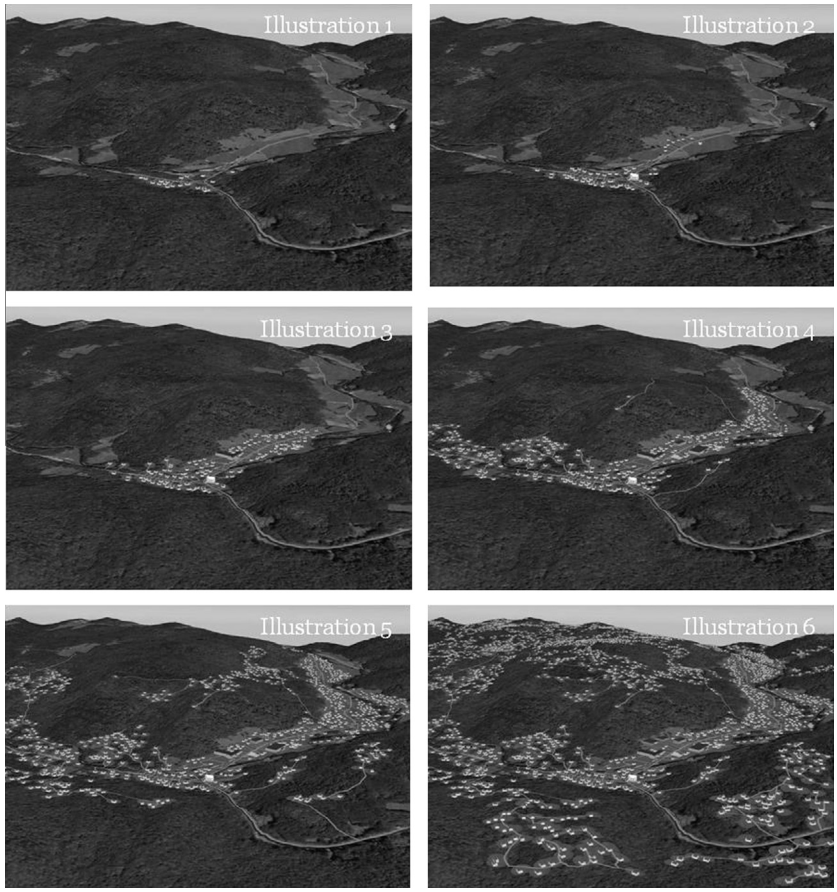

Fig. 2. These six illustrations were the core of our visual preference survey. The three dimensional model is fictional, yet representative of an average Vermont town. Illustration 1 is 1.7% developed (the lowest density found in Vermont), and Illustration 6 is 49.3% developed (the highest non-urban densities found in Vermont). Levels of development grow exponentially between illustrations.

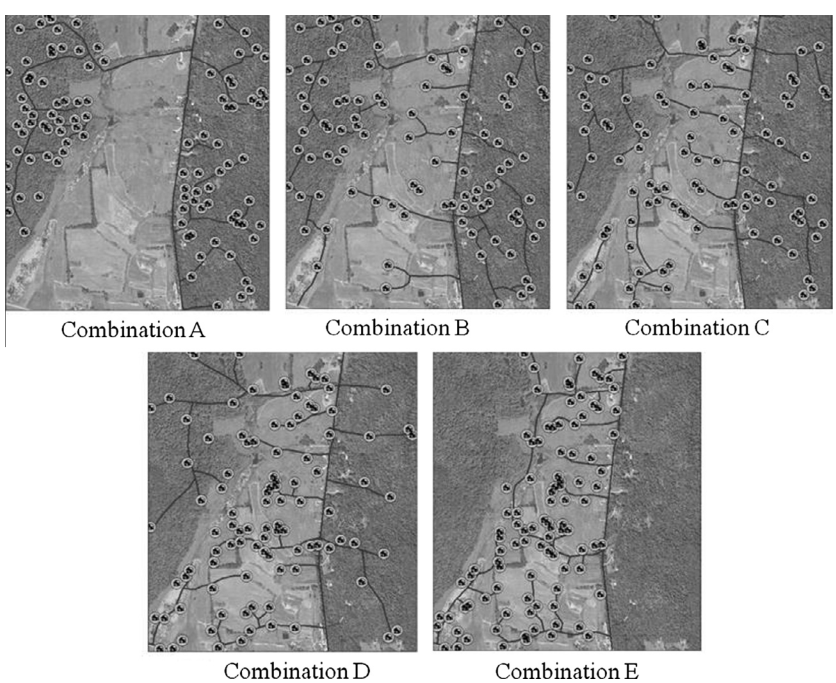

Fig. 3. We asked respondents to imagine a scenario where 100 new homes were built on a combination of forested and agricultural lands. We asked them to rate the acceptability of each of the above combinations: (A) 100% forest and 0% agriculture, (B) 75% forest and 25% agriculture, (C) 50% forest and 50% agriculture, (D) 25% forest and 75% agriculture, and (E) 0% forest and 100% agriculture.

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questionnaires and accompanying postcards were resent to a subsample of 500 non-respondents between August 18th and August 23rd of 2011 to enable evaluation of non-response bias.

2.4. Statistical analysis

We first assessed non-response bias by comparing mean responses to our six acceptability questions between initial respondents and respondents from our follow up survey. We used a *t*-test to test for significant differences in response from the two samples.

To estimate acceptability (norm) curves statewide (Objective 2), we plotted the mean acceptability rating for each of the six illustrations included in the questionnaire. We then calculated crystallization scores (or the level of agreement surrounding a point on the norm curve) for the ratings of each illustration. We used Van der Eijk's measure of agreement (*A*), which rates dispersion on a scale from −1 (least agreement with mean) to +1 (most agreement with mean), with 0 as a complete uniform distribution around the mean (Van Der Eijk, 2001). Compared with other measures of variance, *A* allows comparison among studies with ordered rating systems, regardless of the number of ratings. We also measured the minimum acceptable condition SK_d as the point at which average respondent acceptability ratings move from the positive range to the negative range. Finally, we estimated the norm intensity, or salience as the distance along the *y*-axis from the optimal to the minimal conditions; this measure reflects how strongly the respondents feel about the given issue.

To estimate the alternative evaluative dimensions to the norm curve (preference, displacement, management, looks like; Objective 3), we calculated and plotted mean responses, and compared these values to the minimum acceptable level of development SK_d. To evaluate the acceptability of various scales of land use planning, we plotted mean acceptability ratings and calculated Van der Eijk's *A*, to test for agreement on management at the town, regional, state, and federal levels.

Given increases in development, we estimated the proportion of forests vs. farmlands that respondents found most acceptable for development to occur on (Objective 4). We plotted the mean acceptability rating for each of the five scenarios outlined in the questionnaire (Fig. 3) and calculated crystallization scores using Van der Eijk's measure of agreement. Because the acceptability ratings produced in our survey were not independent (each respondent evaluated the acceptability of five distinct combinations), it was necessary to explicitly model the correlation among the five ratings from each respondent. A mixed effects model allowed us to deal with these correlated responses. We used the linear mixed-effects model (*lmer*) (Bates et al., 2011) from the statistical program R (R Development Core Team, 2011) to fit a quadratic model that included a random effect: $y_{ij} = intercept + b_1\,x + b_2\,x^2 + u_{ij} + e_{ij}$ (where y = acceptability for a given scenario displaying a ratio of forest to agriculture (i), for individual j, with the random effect variable u_{ij} and error term e_{ij}). This model allowed us to estimate the ratio of forest to agriculture which maximized acceptability.

We explored how a suite of socio-economic covariates, such as income and age affected the shape and position of the acceptability curves (Objective 5). Krymkowski et al. (2011) showed that a cubic function, developed using a similar mixed-effects model, closely fits acceptability curves ($y_{ij} = a + b_1\,x + b_2\,x^2 + b_3\,x^3 + \mu_{ij} + e_{ij}$ (where y = acceptability for a given illustration i, for individual j, with the random effect variable u_{ij} and error term e_{ij}). This modeling framework allowed the addition of covariate effects to be analyzed, thus providing a generalized equation that allowed the shape and position of a norm curve to be predicted for each town in Vermont, depending on the town's socio-economic status and other factors. This modeling framework also allowed us to explicitly model the inherent correlation among the six ratings from each respondent.

Twelve potential covariates were collected from the survey (see above). We sought to reduce this number for modeling purposes and eliminated covariates that were either highly correlated with another covariate or had low coefficients of variation (CV). This left five covariates to be added to the cubic modeling framework: (1) Was the respondent born in Vermont (born: born in Vermont = 1; outside Vermont = 0), (2) Has the respondent attended a town meeting (meeting: yes = 1, no = 0), (3) Does the respondent live in the center of town (inside: yes = 1, no = 0), (4) Annual household income of respondent (income), and (5) Population of the town of residence (pop; which was significantly and positively correlated with eliminated covariates town income, road density, and housing density).

Because this was an exploratory study, we evaluated all possible combinations of the five covariates, resulting in 63 alternative versions of our linear mixed effects cubic model. Model 1 was the baseline cubic function with no covariates, which reflected the generalized norm curve across the state of Vermont. Models 2–31 were additive models that included one or more covariates in an additive framework, which shifted the position of the norm curve but did not alter its overall shape. Models 32–63 were models that let covariates affect the squared and cubic terms, which affected the position and shape of the acceptability curve (as intercepts and slope effects). We used Akaike's Information Criterion (AIC) to choose the best model for our data from the 63 model set. AIC scores are commonly used as a measure of relative model strength, and AIC weights provide the probability that a given model is the best model in the model set (Burnham and Anderson, 2002). AIC and AIC weights were estimated for each of the 63 models. We calculated goodness of fit for the top models using methods from Nakagawa and Schielzeth (2013): we produced two statistics for the top selected model – R^2_{marginal} (variability explained by fixed effects) and $R^2_{\text{conditional}}$ (variability explained by random and fixed effects). As a general rule of thumb, Cohen (1992) suggests R^2 greater than 0.25 represent a large effect size.

We used the coefficients from our top model to predict and map the social carrying capacity for percent developed landcover (SK_d) for each of Vermont's 255 towns (Objective 6). This involved several steps. First, we used U.S. census data to estimate the variables *pop*, *income*, and *born* (U.S. Census Bureau, 2010), and developed land use classifications to estimate the variable *inside* (percentage of total housing units per town within NLCD developed land use types (Fry et al., 2011). We adapted equations from Bryan (2004), which use census data to predict attendance at town meetings to estimate the variable *meeting*. Given these town-specific covariate values, we estimated the norm curve separately for each town, and identified where curves crossed the neutral acceptability line SK_d. We used ArcGIS (ESRI, 2009) to map the minimum acceptable level of housing density statewide. This map reflected where the level of development moves from the acceptable realm to the unacceptable for the residents of each town.

The final step of our analysis was to compare these minimum acceptable values with the current landscape condition.

3. Results

3.1. Survey results (Objective 1)

We received 1505 responses from the 4000 questionnaires sent between June 18th and August 23rd, 2011 (38% response rate). We found no significant differences in acceptability ratings between respondents from the initial mailing ($n = 1400$) and respondents from the follow-up mailing ($n = 105$, $p < 0.0001$). As expected, we

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received 50% more responses from individuals who received questionnaires with the single dollar bill (n = 903 dollar, n = 602, no dollar). Respondent characteristics (age, income, gender, etc.) were representative of the greater Vermont population.

3.2. Acceptability curve (Objective 2)

Across all respondents, acceptability ratings decreased as the level of development in the illustrations increased (Fig. 4a). Acceptability ratings were highest for Illustration 2 (1.7% developed), and lowest for Illustration 6 (49.4% developed). Norm salience was strong, ranging from an acceptability rating of 2.42 to −3.21. Agreement (measured with Van der Eijk's A) was high, with the exception of Illustration 4, the point closest to the neutral acceptability line. The acceptability curve crossed the neutral acceptability line (moved from the acceptable realm to the unacceptable) just after Illustration 4, at a minimum acceptable housing density of 9.1% developed.

3.3. Norm evaluative dimensions (Objective 3)

Respondents preferred a scenario with 3.5% development (Fig. 4d). Residents identified that a scenario with 30.4% development would be unacceptable to the point that they would want to move away from the fictional town. Respondents indicated that management action was appropriate at 9.4% development (Fig. 4d), roughly equivalent to the minimum acceptable condition. In general, Vermonters were unable to judge levels of development in their home towns: respondents rated their home towns as 29% more developed than they actually were (U.S. Census Bureau, 2010; paired t-test, $p < 0.00001$).

Respondents displayed strong feelings about different scales of land use management. As the scale of management increased from town level to federal, acceptability decreased. Norm salience was strong, ranging from 2.65 to −1.70, indicating that this issue is of importance to Vermonters. Agreement was high (mean A = 0.45), with the least agreement surrounding state level land use planning (0.13). Federal level land use planning was the only scale of management with mean ratings in the negative range (−1.70).

3.4. Ratio of forest to agriculture (Objective 4)

Given a scenario where development was inevitable and 100 new homes needed to be added to a town, respondents generally preferred development to occur on an even mix of forested and agricultural lands (Fig. 4b). Respondents found development to be slightly more acceptable if it occurred in the combinations that were slightly dominated by forest than combinations dominated by agriculture. Van der Eijk's A was medium to high for the scenarios, ranging from 0.11 to 0.49 (mean = 0.26). The data fit a quadratic function very closely, allowing us to estimate the most acceptable ratio of forest/agriculture (57% forest, 43% Agriculture).

3.5. Effect of demographic covariates on the acceptability curve (Objective 5)

Of the 63 models evaluated, the best fit (lowest AIC score) was model *3.16.income.meeting.inside*, in which the shape and position of the norm curve depended on (a) the respondents income, (b) whether they had attended a town meeting, and (c) whether they lived in the center of town. This model has an AIC weight of 0.93, indicating that it had a 93% probability of being the best model

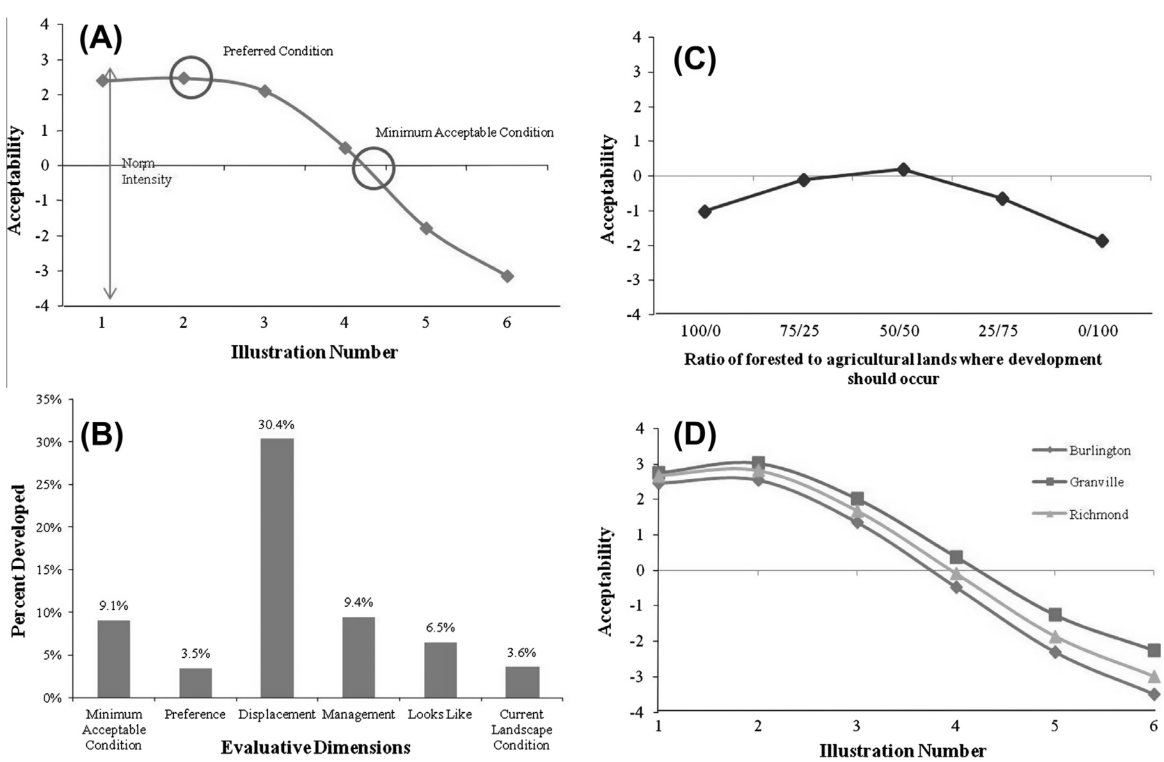

Fig. 4. (A) Vermont acceptability curve: statewide, as development in the illustrations increase, mean acceptability ratings decrease. Norm intensity is strong in this curve. Agreement (Van der Eijk's A) was also strong for all points except illustration 4 (Illustration 1: 0.64, Illustration 2: 0.63, Illustration 3: 0.53, Illustration 4: 0.18, Illustration 5: 0.46, and Illustration 6: 0.79). (B) Alternative evaluative dimensions. Although minimum acceptable condition is most commonly used in setting standards for management, preference, displacement, management, and looks like are also useful tools. (C) Respondents were asked, "If development is going to occur on the landscape, should it occur on forested or agricultural lands?" Respondents most preferred that development occur 57% on forests and 43% on agricultural lands. (D) Acceptability curves for three Vermont towns. Note the changing position of the minimum acceptable condition (SK_d).

Table 1
AIC scores for the top ten models of the 63 model set, where K = number of parameters, AIC = Akaike's Information Criterion, AICΔ = AIC − minimum AIC, $AIC_{Likelihood}$ = model likelihood, AIC_{Weight} = probability that given model has the best fit. Covariates = which covariates included in the 10 top models include: pop = population of town, born = born in Vermont, income = average household income, meeting = attended a town meeting, and inside = lives in town center.

Model name	K	AIC	AIC Delta	AIC likelihood	AIC weight
3.16.int.income.meeting.inside.	18	34158.24	0	1.000	0.935
2.31.pop.born.income.meeting.inside.	11	34164.4	6.16	0.046	0.043
2.27.pop.income.meeting.inside.	10	34165.82	7.58	0.023	0.021
3.27.int.pop.income.meeting.inside.	22	34171.87	13.63	0.001	0.001
3.26.int.born.income.meeting.inside.	22	34176.86	18.62	0.000	0.000
2.26.born.income.meeting.inside.	10	34185.83	27.59	0.000	0.000
2.16.income.meeting.inside.	9	34187.12	28.88	0.000	0.000
3.31.int.pop.born.income.meeting.inside.	26	34190.11	31.87	0.000	0.000
3.19.int.born.income.inside.	18	34282.56	124.32	0.000	0.000
2.29.pop.born.income.inside.	10	34288.33	130.09	0.000	0.000

in the model set (Table 1) ($R^2_{marginal} = 0.471$, $R^2_{\text{conditional}} = 0.578$). The second best model was the fully parameterized additive model (no slope effects), with an AIC weight of 0.043. The modeling equation that best predicts the town-specific norm curve (model 3.16) was:

$$y_{ij} = 0.715 - 0.005 * income - 0.523 * inside - 0.390 * meeting + 3.186 * x - 0.033 * income * x - 0.3205 * inside * x + 0.405 * meeting * x - 1.276 * x^2 + 0.029 * income * x^2 + 0.287 * inside * x^2 - 0.158 * meeting * x^2 + 0.106 * x^3 - 0.004 * income * x^3 - 0.035 * inside * x^3 + 0.015 * meeting * x^3 + \mu_{ij} + e_{ij}$$

The intercept parameter coefficient from the top model was 0.715; this represents the average acceptability score for an illustration with no homes, for respondents who live outside of town center and have not attended a town meeting. The parameter for income was negative (−0.005), indicating that for Vermonters as a whole, as income increased, SK_d decreased. The intercept value was lower for respondents who lived in town centers and who had attended a town meeting. In addition to affecting the intercept, the parameters for income, inside, and meeting affected the cubic function and the shape of the curve. Fig. 4c shows a subset of three town level norm curves for the towns of Burlington (45.6% developed year 2000), Richmond (7.5% developed year 2000), and Granville (2.2% developed year 2000). These towns were selected because the illustrated different norm curves. In general, rural towns with lower town center population densities were more likely to accept higher levels of development on the landscape than more developed towns.

3.6. Mapping at the town level (Objective 6)

Given town-specific norm curves, we mapped the predicted minimum acceptable level of development statewide (Fig. 5a). This map can be considered a potential land use scenario based on SK_d, and reflects where the level of development moved from the acceptable realm to the unacceptable for the residents of each town. For example, we predicted that residents in the town of Waterbury (circled on the map) would accept 8.9% development in their town.

Our final step was to map the difference between the minimum acceptable condition and the current condition on the landscape. Fig. 5b shows the difference per town between the number of housing units in the year 2000, and the minimum acceptable number of housing units from our modeling efforts. The town of Waterbury (circled on Fig. 5) was 5.8% developed in 2000, but we predicted that residents of Waterbury would find up to 8.9% development in their town to be acceptable: a 35% increase. In total, we predicted that residents in 226 out of 251 towns (90.0%) would be willing to accept higher levels of development than currently exist on the landscape.

4. Discussion

4.1. Social capacity for development

On average, Vermont residents were willing to accept a higher level of development than currently exists on the landscape. While there was some variation based on respondent and town characteristics, high levels of agreement and norm salience indicated strong interest in the issue of development in Vermont. If the minimum acceptable condition accurately reflected Vermonters' tolerance for future development, the land use scenario represents a 68% increase between the current condition of development (5.4% developed) and the social capacity of the landscape for future development, or SK_d (9.1% developed). Given a scenario where development levels were at SK_d, we could expect a 16,753.91 km^2 reduction in forested land (−11.16%) and a 1038.42 km^2 reduction in farmland (−60.45%), based on respondent preferences from the survey. There is no question that a near doubling of development across Vermont will decrease the amount of available wildlife habitat, fragment existing habitats, and alter the quality of what remains.

We discuss four considerations related to this social capacity for growth. First, Vermont remains a largely rural state, and residents may be willing to accept higher levels of development in their own town, with the knowledge that the next town over may have large patches of forested or agricultural land for wildlife habitat or recreation. This was common feedback from mock respondents and experts during the initial testing of the survey. In general, people are willing to accept living in more developed areas if there are nearby natural features (Dehring and Dunse, 2006), and are willing to pay more to do so (Correll et al., 1978). Additionally, we saw respondents in more rural areas were willing to accept higher levels of development than those in more urban/suburban settings. This is a common pattern, where residents in less populated towns are more accepting of the economic incentives that accompany increased development, while residents in towns closer to social carrying capacity are often skeptical of new development (Fischel, 2000).

Second, while Vermont's social capacity for increased conversion of lands to development is high, projections of population growth and housing development are relatively low, with some projections showing that the majority of towns in Vermont are likely to add less than 10 housing units by the year 2050 (Brown et al., 2012). Consequently, future growth in Vermont is

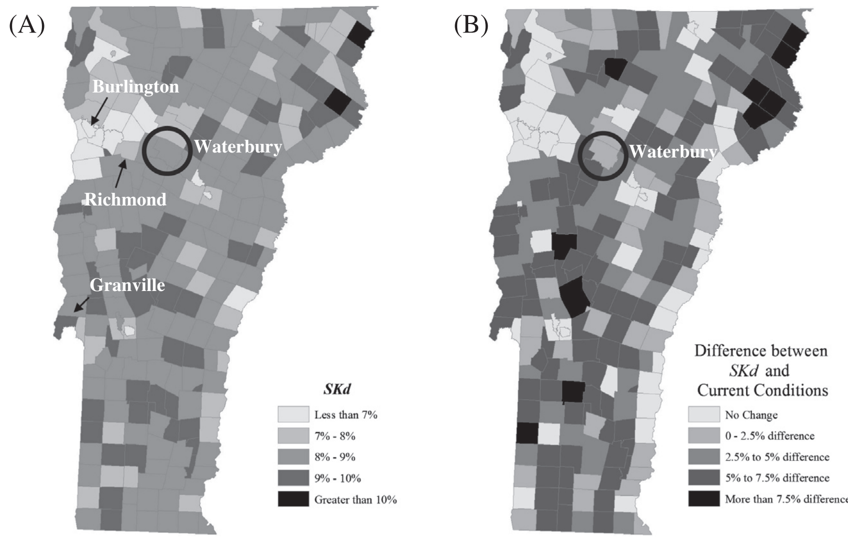

Fig. 5. (A) Minimum acceptable level of development. Darker towns indicate that the town finds higher percent development acceptable, lighter towns indicate that the town finds lower levels of development acceptable. (B) Difference between the minimum acceptable condition and the current condition (year 2000).

likely to fall within the range of acceptable conditions. However, if we were to apply our methodology to a similarly rural area with projections of dramatic future population growth (i.e. Boulder County, Colorado Theobald, 2005), situations may arise where projected population growth (and corresponding land conversion) falls into the unacceptable realm. In such cases, land use planning and regulation become an immediate priority to ensure that development and land conversion remain acceptable to the public.

Third, although results from this investigation indicated that the public is willing to accept a greater level of development than currently exists in Vermont, other public opinion survey results from 2000 to 2007 (Duda, 2000) make clear broad support for land use planning and regulation to protect open space and wildlife habitat. Survey results from the USFWS (2006) indicate that Vermont ranks 4th in the U.S. for public participation in wildlife-based activities. There is broad public interest in and support for wildlife and land conservation in Vermont that may be incongruous with the opinion data from this study. Respondents of our survey were not provided with the ecological consequences of each scenario; it is possible that the SK_d would be lower based on knowledge of these consequences.

Fourth, although we are confident in the validity of our survey methodology, the fact remains that respondents did not adequately understand what their own towns looked like. When asked to rate which illustration looked most like their own town, respondents overestimated the level of development of their own home towns by 29%. This may have led to an overestimation of the minimum acceptable condition; respondents may actually be willing to accept less development on the landscape than they reported. Conservation and land use planners commonly struggle with effectively conveying complex scientific, spatial, or numerical data to the general public. Photo-realistic, three dimensional visualizations excel at measuring variables which may be difficult to quantify using narrative methods, and for representing complex hypothetical scenarios (Manning, 2004). However, many people, including trained professionals, have difficulty estimating density from visual representations of land use; often overestimating density in rural settings, and underestimating density in urban settings (Campoli and Maclean, 2007). Our findings reinforce this point. Although visual methods may be the most effective means of understanding normative standards of land use, people still struggle with understanding their own landscapes. The propensity of individuals to over/underestimate density from visual cues is important to consider in making decisions using our results.

4.2. Survey validation and assumptions

The shape of the norm curve, the high levels of agreement and norm salience, and the relative values of preference (low) vs. management (medium) vs. displacement (high) (Fig. 4d) closely follow trends found in other visual preference surveys (Manning, 2007), supporting that this methodology can be used to estimate normative standards for land use in Vermont. However, it is important to note four assumptions made in the development and implementation of this survey.

First, these norms reflect the opinions of residents only at the time of survey administration. If change occurs slowly enough, as some projections indicate it may in Vermont (Brown et al., 2012), the perception of normality, or acceptability, may also change. Norm change, or "shifting baselines" have been shown in cases of crowding norms in wilderness and park settings (Kuentzel and Heberlein, 2003), in wildlife management (Zinn et al., 2008), and fisheries management (Pauly, 1995). New generations of residents, visitors, and managers have different interpretations of what is normal in a system as development increases, parks become more crowded, and fisheries or wildlife populations fluctuate. This suggests that as Vermont landscapes develop, understanding and monitoring acceptability becomes even more important.

Second, while we were primarily interested in measuring the *amount* of acceptable development, we explicitly avoided asking respondents about acceptable *patterns* of development. That is, the distribution of dwelling units across a landscape mixed with agriculture and forested lands can be configured in multiple ways, and this configuration can significantly alter wildlife distribution and viability (Fahrig, 2003). Although these issues are difficult to separate, we held constant the pattern of development across scenarios, while only measuring the acceptability of the amount of development. Future studies may target the separation of amount and arrangement of landcover patterns on acceptability.

Third, while land use planning decisions are made by town planning commissions, the home ranges of many wildlife species such as black bear (*Ursus americanus*), fisher (*Martes pennanti*), and bobcat (*Lynx rufus*) in Vermont are larger than the town scale. While our analysis unit is the town, wildlife management requires regional, state, and ecoregional scale consideration. In a companion

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paper, we compare wildlife occupancy for these three species in the current landscape conditions (year 2000) and a land use scenario in which the landscape is developed to reflect SK_d (Bettigole et al., 2013). This will allow wildlife managers and land use planners to understand how and where this suite of species may be affected by land use change, informing state, regional, and town scale planning and regulation.

Fourth, the results of our study allow us to understand *how much* development is acceptable to Vermonters, and *where* this acceptability is higher or lower throughout the state. However, the structure of our survey does not tell us *why* Vermont residents make these choices. Development carries with it a suite of complex social, economic, and ecological trade-offs, which we were unable to address in this study. Further analysis, using stated choice methodology, would be prudent to understand how landowners view the tradeoffs associated with land use change.

While Vermont remains a largely rural and forested state, the social norms of residents lead us to believe that there exists the social capacity for significant conversion of open lands to development in the future. The losses of forested land and farmland pose distinct threats to wildlife through habitat loss, fragmentation, and road building. However, the high degree of enthusiasm for town level planning, and the pervasiveness of town planning and conservation commissions throughout Vermont ensure that land conversion will not proceed completely unchecked in the 21st century. Government and private programs aimed at providing guidance and assistance to town planning and conservation commissions can benefit from this information by using it to illustrate the physical consequences of land use decisions. For instance, the Vermont Fish and Wildlife Department supports the Community Wildlife Program that provides assistance to these local planning organizations to understand and consider the effects of land use and development of land, habitat and wildlife. Results from this investigation can be used, in conjunction with occupancy modeling data for different species of wildlife, along with habitat and natural community data, to better illustrate the consequences of land use and planning decisions.

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