Exotic Forest Insects and Residential Property Values

Thomas P. Holmes, Elizabeth A. Murphy, and Kathleen P. Bell

This paper presents a case study of the economic damages to homeowners in a northern New Jersey community due to an exotic forest insect—the hemlock woolly adelgid. Hedonic property value methods are used to estimate the effect of hemlock health on property values. A statistically significant relationship between hemlock health and residential property values is established. Moreover, there are some signs of spillover impacts from hemlock decline, as negative effects are realized on the parcels where the declining hemlock stands are located as well as on neighboring properties. These results give some indication of the benefits of potential control programs and strategies and also show support for community- or neighborhood-based programs in residential settings.

Key Words: invasive species, economic impacts, hedonic property values, general spatial model

Of the 70 major insect pests in U.S. forests, 19 are imported (Pimental 1986). Evolutionary adaptations between trees and pests are subverted by biological invasions, and exotic species pose an imminent threat to the maintenance of native forest ecosystems in North America (Liebhold et al. 1995). Accordingly, the need for information on the damages caused by such pests and the efficacy of different control strategies is great. However, forest managers are currently making difficult tradeoffs under great uncertainty.

This paper examines the impacts of the hemlock woolly adelgid (HWA, *Adelges tsuga*), an exotic forest pest, on the value of residential properties located in a forested landscape. The hedonic property value method is used to test various research hypotheses related to the nature of this relationship, notably the extent to which poor hemlock health results in a decline in residential property values (and high hemlock health results in an increase in residential property values) and whether or not impacts spill beyond parcel boundaries. The results of the study provide quantitative estimates of value that can be used in benefit-cost analyses of HWA control programs.

The HWA was accidentally introduced into Virginian forests from Japan in the early 1950s, and causes mortality to both eastern (*Tsuga canadensis*) and Carolina (*T. caroliniana*) hemlocks (Souto, Luther, and Chianese 1996). During the past half-century, it has spread to hemlock forests and ornamental trees in the Northeast, the Mid-Atlantic region, and the South. HWA attach to the underside of hemlock needles and feed on cellular material using a long stylet. This causes needle loss, and tree mortality typically occurs within four years (McClure 1991).

Eastern and Carolina hemlocks have shown no resistance to HWA, and once trees are moderately or severely infested, there is little chance for recovery. Dramatic losses of eastern hemlocks across broad geographic areas are likely unless successful control measures are found. In the early stages of infestation, individual trees in residential landscapes can be successfully treated using insecti-

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cidal methods. Greater challenges exist for controlling HWA in forested landscapes with pure stands of hemlocks and in remote settings where insecticidal methods are impractical because of high costs and limited access. In these settings, resource managers are experimenting with forms of biological control such as predator insects.

Eastern hemlocks are widely distributed throughout the Appalachian Mountains, the northern Midwest, the northeastern United States, and parts of Canada, and play a critical role in eastern forest ecosystems. Eastern hemlock is a very long-lived species and may approach 1,000 years of age. It is often found in cool, moist valleys and ravines, where it stabilizes soils and its shading helps maintain water temperatures favorable for trout species. It also favors cool habitats found on northerly slopes. Because these growing conditions are not evenly spread across landscapes, the distribution of hemlocks is spatially patchy. Where pure stands occur, they are typically cool and dark due to the dense foliage, and contain few understory species.

Eastern hemlock is a poor quality wood that is occasionally used in rough construction. Its principal economic value derives from the ecosystem services it provides and its high aesthetic quality. Brush (1979), in a study of the perceptions of forest landowners in Massachusetts for twenty different forest sites, found that old eastern hemlock stands were rated, on average, above all other sites for scenic beauty. Thus, eastern hemlocks may possess unique scenic attributes not shared by other species.

In the next section of the paper, an overview of the literature on the nonmarket valuation of trees in residential landscapes is provided. This is followed by a description of the setting and the data used for analysis. The empirical methods are described in the subsequent section, which is followed by a presentation of the results. In the final section, the implications of the findings for forest policy and management are discussed, along with recommendations for future research.

Existing Literature

The hypothesis that trees contribute to residential property value has been tested from three perspectives: (i) yard trees convey value, (ii) forest preserves near residential neighborhoods convey value, and (iii) trees in the general forest matrix surrounding a residential property convey value. Only a limited number of studies have been conducted to evaluate these hypotheses, and none of the studies have jointly tested two or more hypotheses. However, the following review suggests that the value of trees in residential landscapes depends upon both landscape context (urban, suburban, exurban, rural) and spatial configuration.

Concerning the value of yard trees, Morales, Boyce, and Favretti (1976) found that tree cover added about 6 percent to property values in Manchester, Connecticut. A similar result was reported by Anderson and Cordell (1988), who concluded that trees in the front yard of homes in Athens, Georgia, added about 3–5 percent to housing prices relative to houses without trees. Dombrow and Sirmans (2000) found that mature trees contributed about 2 percent to the value of single-family homes in Baton Rouge, Louisiana. These studies support the *a priori* hypothesis that yard trees enhance property values, although they do not explicitly consider the landscape characteristics surrounding the parcels studied.

Forest preserves near residential areas have been found to increase the value of residential properties. Using data on the sales of owner-occupied apartments in an urban region of Finland, Tyrväinen and Miettinen (2000) estimated that apartments with a view of hilltop forest preserves in the surrounding area commanded a price premium of about 5 percent, and that the value of the premium declined about 6 percent per kilometer distance from the nearest forest preserve. In contrast, Thorsnes (2002) reported that vacant subdivision building lots that are adjacent to a forest preserve in Grand Rapids, Michigan, received a significant price premium, although the price premium was highly localized and vanished or nearly vanished for lots not adjacent to the preserve. While these studies find evidence of capitalization of amenities generated by protected forest areas, they also call attention to the spatial extent of such amenities.

Understanding the impact of forested landscapes on property values is complicated by the additional dimensionality involved. While the economic valuation of yard trees has been essentially non-spatial (isolated points), and the estimation of the impact of forest preserves on property values has been one-dimensional (linear views and linear distances), the valuation of forest cover in a landscape matrix necessitates a two-dimensional spatial representation. In an early study of this type, Garrod and Willis (1992) conducted a hedonic study of property values in Great Britain for houses located in 1km squares that also contained Forestry Commission (FC) land. The data were limited by the fact that neither could the distance between houses and FC land be computed, nor could the size and composition of non-FC area be specified. Despite these data limitations, they found that nearby deciduous forest cover had a positive and significant influence on property prices, and that nearby coniferous forest plantations had the opposite effect.

A recent innovation in conducting hedonic property value studies that explicitly incorporates two-dimensional land use/cover data is the use of remote sensing data derived from satellite imagery. This technology allows researchers to test hypotheses about the influence of surrounding land uses and land cover types on property values. In an early study of this type, Geoghegan, Wainger, and Bockstael (1997) found that the degree to which landscape features are capitalized into residential property values depends on whether parcels are located in highly developed, suburban, or rural areas. More recently, Paterson and Boyle (2002) used GIS data to examine how property prices in a rural area of Connecticut (Simsbury and Avon) are affected by the extent of different land use/cover patterns within a 1 kilometer radius around each property. The model was specified to include both the proportion of land cover types located within the buffer and the proportion of each type within the buffer that could be viewed from the parcel.[1] The parameter estimate on forested area was positive and significant at the 11 percent level, while the parameter estimate on visible forest land was negative and significant at the 5 percent level. They suggested that, as the landscape viewed from an individual property becomes increasingly dominated by forests, the property may seem more closed-in, although people seem to prefer to live in areas close to forest amenities. Thus, the spatial distribution of forest cover may have a complex effect on property values.

If trees make a positive contribution to property values, then, presumably, factors that cause the demise of trees will reduce property values. We are unaware of any studies that have used the hedonic property value method to directly evaluate the economic impact of forest insect outbreaks. However, Jakus and Smith (1991) and Miller and Lindsey (1993) estimated homeowners' willingness to pay to protect trees from gypsy moth infestations using the contingent valuation method. Importantly, Jakus and Smith (1991) found that homeowners were willing to pay more for a public control program that would protect neighborhood values than for a private control program that would protect only the owner's individual parcel. This result suggests that residential landscape amenities have public good characteristics.

Description of the Data

Our empirical analysis is based on data from 3,379 residential property sales in the town of Sparta, New Jersey, between 1992 and 2002. Sparta is located in the Highlands region of northwestern New Jersey, an area characterized by farms, small villages and towns, lakes, forests, and wetlands (Lathrop 2000). This 39-square-mile township has a population of roughly 18,000 people, is located about 45 miles from New York City, hosts two golf courses, and has several lake communities. Lot sizes are relatively large in the township (the median lot size computed from the Sparta sales data was about one-half acre), the median house age was 29 years, and the median sales price was $342,260 (in 2002 dollars) (Table 1).[2]

Satellite data were used to construct land cover/use variables for each individual parcel and for 3 different spatial scales around each parcel centroid (0.1km, 0.5km, and 1km).[3] The land

[1] Data representing the landscape features that could be viewed from each parcel were created using topography and did not adjust for screening of further away objects by nearby objects. However, the use of topography introduces a third dimension into spatial hedonic property value models.

[2] The maximum lot size was set at 5 acres for analysis.

[3] A consensus has not been reached in the literature regarding the appropriate radial distance to specify spatial buffers in hedonic valuation studies (Acharya and Bennett 2001, Benson et al. 1998, Geoghegan, Wainger, and Bockstael 1997, Geoghegan 2002, Irwin 2002, Paterson and Boyle 2002, Powe, Garrod, and Willis 1995). Consequently, three radial distances were used in this research.

Table 1. Descriptive Statistics for Housing and Distance Variables

Variable	Mean	Median	Min.	Max.	Std. Dev.
Lot size (ac.)	0.98	0.55	0.05	5.00	0.94
Price ($2002)	382,180	342,260	50,000	1,435,987	193,023
Age (years)	31.64	29.00	0	100	23.61
Baths (#)	2.44	2	1	5	0.86
Small lot (dummy variable)	0.47	0.00	0	1	0.50
Floor space (ft^2)	2280.11	2120	750.00	5496.00	1,011.86
Finished attic (dummy variable)	0.02	0.00	0	1	13.10
Finished basement (dummy variable)	0.36	0.00	0	1	47.94
Distance to highway (m)	3,894.59	3,940.90	356.97	8,163.98	1,390.19
Distance to golf (m)	2,194.22	2,040.0	0	5,880.0	1,387.45

classifications used in the model specification were based on a 14-class scheme using 30m^2 pixels, although some of the classes were combined to simplify the analysis (Lathrop 2000).[4] Included for analysis in the empirical model were variables for high development (greater than 75 percent impervious soil) and low/medium development (25–50 percent impervious soil). Although *a priori* reasoning suggests that high development might be associated with negative amenities such as noise and traffic congestion, proximity to services such as shopping might enhance property values. Because the literature review showed that different forest types can have differing impacts on property values (Garrod and Willis 1992), three forest types were included for analysis (deciduous, coniferous, and mixed).

Surface water is an important landscape characteristic in this region, and three types of water features were included in the specification (streams, wetlands, lakes/ponds). The presence of streams on or near a property may confer scenic or recreational benefits. Conversely, their presence may increase the risk of floods. The anticipated sign on wetlands is also ambiguous, as the presence of wetlands on a property suggests poorly drained soil. However, nearby wetlands might convey a sense of naturalness as well as provide wildlife habitat. Lakes and ponds would presumably increase property values because of their aesthetic and recreational qualities, within some reasonable distance.

Because previous research indicates that public open space is an amenity that enhances nearby property values (e.g., Geoghegan, Wainger, and Bockstael 1997), a variable for public open space was included as well. Golf courses are an important land use in this township, so a variable was created describing the distance between parcel centroids and the closest golf course. *A priori* reasoning suggests that living close to a golf course would enhance property values, although it is not clear over what distance this enhancement would occur. Excepting distance to the nearest golf course, all land use/cover variables were created as percentages (similar to Geoghegan, Wainger, and Bockstael 1997, and Paterson and Boyle 2002).

Evaluating the impact of HWA on property values is complicated by a number of factors: (i) hemlock is a relatively scarce forest type, (ii) the distribution of hemlock stands is spatially patchy, (iii) the within-stand distribution of hemlock decline and mortality is also spatially patchy, (iv) it takes several years for infested trees to die, and (v) the spread of HWA across the landscape is relatively slow (approximately 30km per year). Because of the interest in protecting hemlock resources in New Jersey, special methods were developed to monitor hemlock health using a technique known as image differencing (Royle

[4] Two minor classes were omitted from the analysis: bare land and scrub.

and Lathrop 1997, Royle and Lathrop 2002). This methodology quantifies defoliation by subtracting spectral reflectance between satellite imagery for two points in time, and has been successfully used to map canopy defoliation by other defoliators such as gypsy moth and spruce budworm. By relating the spectral difference in reflectance to defoliation on the ground, different levels of defoliation can be quantified. Five hemlock classes were used to assign values to each pixel in the study area: (i) healthy and lightly defoliated (less than 25 percent defoliation), (ii) moderately defoliated (25–50 percent defoliation), (iii) severely defoliated (50–75 percent defoliation), (iv) dead (greater than 75 percent defoliation), and (v) no hemlocks present.[5] Leaf-off, winter scenes were obtained for November 1984, November 1992, December 1994, December 1996, December 1998, and December 2001. The 1984 image was used as the base scene for image processing and change-detection, as it was the pre-infestation data against which all vegetation changes were compared.[6]

Land use/cover characteristics on parcels sold demonstrate the relative scarcity of hemlock resources in Sparta (Table 2). Similar to hemlock forest cover, other coniferous and mixed stands were also scarce. The most dominant land use/cover types were low/medium development and deciduous forest cover. Wetlands, lakes/ponds, and agricultural land held minor, but potentially significant, positions in the distribution of land use/cover types. To control for potential differences in price between large and small parcels, sales price was specified as a quadratic function of parcel size. In addition, a dummy variable was created for parcels smaller than half an acre to test the hypothesis that a price premium existed for larger parcels independent of the quadratic specification. Finally, because hemlock stands were generally located on larger parcels, dummy variables were created for parcels containing hemlock, and for parcels containing hemlocks in the surrounding spatial buffers, to test the hypothesis that omitted variables associated with those parcels influenced sales price.

Empirical Methods

Our empirical analyses employ a hedonic property value model to examine the effects of hemlock quality on residential property values. Residential properties are viewed as differentiated goods, where the properties are differentiated by the amounts of various characteristics they have. Testing supported the treatment of Sparta as a single housing market and the pooling of sales data over time. In this paper, the marginal willingness to pay of consumers for hemlock health is inferred from the contribution of hemlock health to sales prices of residential properties. This is commonly referred to as a “first-stage” hedonic analysis (e.g., Freeman 1993).[7]

A variety of econometric issues arise when estimating hedonic property value models, notably multicollinearity, heteroskedasticity, omitted variables, functional form, and, most recently considered, spatial dependence (e.g., Anselin, Florax, and Rey 2004, Anselin 1988, Bell and Bockstael 2000). Spatial dependence is expected when the relative locations of sample observations matter. Given the importance of location and other spatial characteristics to residential property values, it is not surprising that hedonic property value models may exhibit such dependence.

Two potential sources of spatial dependence can cause econometric problems: structural spatial dependencies across observations on the dependent variable, and spatial dependence across error terms. In the context of hedonic property value modeling, structural dependence arises when, for example, the sales value of one property is systematically influenced by the sales value of nearby properties (perhaps due to the

[5] In the econometric model, the “no-hemlock” class was dropped. Parcels that did not contain hemlocks were coded as zeroes for each of the other four hemlock health classes.

[6] Ground-truth evaluations were conducted by evaluating hemlock canopy conditions for 142 field plots in northern New Jersey. Accuracy was 82 percent. Defoliated hemlocks were detected in the 1992 image, although it is uncertain precisely when the infestation began in this community.

[7] A second-stage hedonic analysis, which would have derived the demand functions of the characteristics or attributes included in the hedonic equation, was beyond the scope of this paper. We lacked sufficient data on property sales and socioeconomic characteristics to achieve identification using data from multiple markets. Future research will explore the availability of such data as well as the appropriateness of *a priori* restrictions on the hedonic equation and demand equations to achieve identification. We acknowledge the utility of such an analysis to support policy analysis and derive measures of willingness to pay.

Table 2. Descriptive Statistics for Land Use/Cover Variables for Sold Parcels and Spatial Buffers Surrounding Sold Parcels

Variable	Parcel	0.1 km buffer	0.5 km buffer	1 km buffer
Deciduous stands (%)				
mean	19.89	23.43	31.69	36.35
median	1.98	16.04	28.79	34.26
minimum	0	0	0	7.86
maximum	100	100	86.40	76.80
standard deviation	27.49	23.96	18.64	17.18
Other coniferous stands (%)				
mean	0.09	0.12	0.12	0.14
median	0	0	0	0.08
minimum	0	0	0	0
maximum	79.51	17.27	2.67	1.50
standard deviation	1.86	0.94	0.26	0.17
Mixed stands (%)				
mean	1.57	2.08	2.27	2.28
median	0	0	0	1.92
minimum	0	0	0	0.03
maximum	64.33	43.09	20.95	16.67
standard deviation	5.92	4.30	2.35	1.88
Hemlock: healthy-light (%)				
mean	0.10	0.10	0.13	0.16
median	0	0	0	0
minimum	0	0	0	0
maximum	68.98	50.03	17.86	10.65
standard deviation	2.21	1.57	0.97	0.80
Hemlock: moderate (%)				
mean	0.10	0.10	0.14	0.17
median	0	0	0	0
minimum	0	0	0	0
maximum	61.32	52.63	18.15	9.25
standard deviation	1.89	1.71	0.94	0.75
Hemlock: severe (%)				
mean	0.20	0.30	0.68	0.76
median	0	0	0	0
minimum	0	0	0	0
maximum	86.91	58.20	50.27	32.46
standard deviation	3.04	2.69	3.49	2.75
Hemlock: dead (%)				
mean	0.08	0.10	0.30	0.43
median	0	0	0	0
minimum	0	0	0	0
maximum	52.69	46.59	24.96	19.81
standard deviation	1.75	1.50	1.69	1.60
Agriculture (%)				
mean	2.13	2.82	3.86	4.74
median	0	0	0.64	2.59
minimum	0	0	0	0
maximum	100	100	73.62	50.39
standard deviation	10.22	9.67	7.59	6.74
Wetland (%)				
mean	1.81	2.82	6.51	7.88
median	0	0	4.47	7.79
minimum	0	0	0	0.59
maximum	85.20	86.05	0	38.60
standard deviation	7.37	7.89	56.84	5.23
Lakes/ponds (%)				
mean	0.92	2.58	9.21	10.98
median	0	0	1.27	3.54
minimum	0	0	0	0

cont'd.

Table 2. Descriptive Statistics for Land Use/Cover Variables for Sold Parcels and Spatial Buffers Surrounding Sold Parcels (cont'd.)

Variable	Parcel	0.1 km buffer	0.5 km buffer	1 km buffer
Lakes/ponds (%) (cont'd.)				
maximum	96.12	91.36	75.69	52.72
standard deviation	6.00	8.71	14.43	12.45
High development (%)				
mean	1.82	1.69	2.00	1.86
median	0	0	1.00	1.27
minimum	0	0	0	0
maximum	100	51.56	21.62	9.19
standard deviation	9.33	4.26	2.80	1.88
Low/medium development (%)				
mean	69.51	61.98	41.75	32.95
median	80.44	64.62	41.95	34.75
minimum	0	0	0.72	2.21
maximum	100	100	79.21	55.70
standard deviation	32.53	26.96	16.56	11.44
Public open space (%)				
mean	--	0.69	1.87	3.53
median	--	0	0	0
minimum	--	0	0	0
maximum	--	100	95.58	64.26
standard deviation	--	6.25	7.40	9.15

"comparable sales" in the assessment process). Spatial dependence among the errors is generally due to omitted variables, which are themselves spatially correlated, but could also be due to errors in measurement that are systematically related to location. Property characteristics omitted from the hedonic property value model that are spatially correlated would result in spatially autocorrelated or dependent residuals.

Diagnostic tests on an OLS regression model using the Sparta sales data indicated that the model needed to be corrected for both spatial lags in the dependent variable and spatial autocorrelation across the errors.[8] To address these econometric problems, a general spatial model was estimated:

$$(1) \qquad \mathbf{y} = \rho \mathbf{W}_1 \mathbf{y} + \mathbf{X}\beta + \mathbf{u}$$

$$\mathbf{u} = \lambda \mathbf{W}_2 \mathbf{u} + \varepsilon, \text{ where } \varepsilon \sim N(0, \sigma^2 I_n),$$

where **y** is (the logarithm of) property price, **W** is a spatial weights matrix, **X** is a vector of explanatory variables, ρ, β, and λ are parameter estimates, and **u** and **ε** are vectors of errors.[9] As shown in equation (1), ρ is the parameter estimate for the spatially lagged dependent variable and λ is the parameter estimate for a spatially correlated error structure.

Spatial dependence has implications for the validity of OLS parameter estimates and variance-covariance estimates and therefore for the validity of hypothesis tests based on such results. If spatial lag dependence is present and is ignored in the analysis, OLS will give biased and inconsistent parameter estimates. If spatial error dependence is present and ignored, OLS will produce unbiased parameter estimates but the standard errors associated with these estimates will be biased (inefficient).

Sales prices were adjusted using a housing price index to account for housing price inflation. Trends in housing prices vary by geographic re-

[8] For the analysis in this paper, all diagnostic tests and econometric estimates were generated using MATLAB code provided by LeSage (1999).

[9] A k-nearest neighbor model was used to define the spatial weights matrix. The k-nearest neighbor relationship considers whether or not two points neighbor each other in space. By using the x-y coordinates of the parcel centroid for each observation, the distance between each observation was calculated and the k-nearest observations were designated. The number of nearest neighbors in the spatial weights matrix for spatially lagged property prices was restricted to five and the spatial weights matrix for error components was restricted to 10 nearest neighbors. This specification is consistent with the analysis reported in Pace and Zou (2000).

gion, and the housing price index used in the analysis accounted for this with region-specific indicators.[10] With the introduction of spatially lagged terms, it was essential to account for inflation so that temporal trends in housing prices would not bias parameter estimates.

Results

As noted above, diagnostic tests indicated that both spatial lags and spatial error correlations were present in the data, so parameters of a general spatial model were estimated (Table 3). Although the parameter estimate on the spatial error term (λ) was highly significant, the t-statistics indicated that the parameter for spatial lag (ρ) was not significant at conventional levels. However, use of the general spatial model provides assurance that the parameter estimates are not biased by spatial factors and are more efficient than would be obtained using OLS.

Parameter estimates on several of the housing variables were highly significant across the various model specifications. For example, the results indicate that either an additional bedroom or bathroom adds about 3–4 percent to the value of a house in this market. The specification on lot size shows that additional acreage increases property value at a decreasing rate and, additionally, lots exceeding one-half acre receive a price premium. Although parameter estimates on distance of the parcel from the nearest highway were not significant in any of the models, they did have the anticipated negative sign indicating that proximity to major travel networks may be valued. However, the insignificance of the parameter estimates suggests that living too close to major travel corridors may create negative externalities resulting from noise and traffic congestion, thereby confounding parameter estimates.

Several of the parameter estimates on land use/cover variables were significant in the regression models. Proximity to a golf course appears to enhance property values, but only within a distance of about 0.5km. Parameter estimates on lakes and ponds on the parcel or in the surrounding landscape were positive and significant at the 1 percent level in all model specifications, indicating that these are important landscape amenities. However, streams had a negative impact on property values in the 0.1km buffer model. This result might reflect concern over potentially negative impacts such as flooding when streams are located nearby. Agriculture and wetlands did not have a statistically significant impact when located on the parcel, perhaps due to the scarcity of these observations in the data, but did have a positive and significant impact on property values when these land use/covers were located within 0.5km and 1km buffers. These land use/cover types may convey values associated with rural and/or natural landscapes. Living in a neighborhood surrounded by low/medium development conveyed value to properties, as evidenced by the positive and significant parameter estimates on this variable in the 0.5km and 1km spatial buffer models. Somewhat surprisingly, highly developed parcels received a significant price premium, although living very close by to such development significantly decreased property value, as shown in the 0.1km buffer model.

The effect of forested landscapes on property values in this market is somewhat complex. Deciduous forest cover had a significant impact on enhancing property values when located nearby, as shown in the 0.5km and 1km spatial buffer models. Although the parameter estimates on deciduous cover are negative in the parcel and 0.1km spatial buffer model, they are not statistically significant. Stands of coniferous trees were found to enhance property values in the 0.5km spatial buffer model, but were insignificant in the other model specifications.[11] Surprisingly, mixed forest stands had significant and negative parameter estimates in the 0.5km and 1km model specifications. It is unclear why this is so, unless

[10] The correlation coefficient between the housing price index and dummy variables representing the year the parcel sold, as estimated in an OLS model, exceeded 0.98.

[11] The coefficients in the parcel and spatial buffer specifications are relative to the percentages of land use/cover types in those areas. Thus, for example, the parameter estimate on coniferous forests in the 0.5km buffer specification (Table 3) is large (6.34), but the average amount of coniferous forest in the 0.5km buffer is only 0.12 percent (Table 2). Thus, an absolute increase of 1 percent in the area contained in this buffer that is classified as coniferous forest would increase housing prices by 6.4 percent. However, an absolute increase of 1 percent in the area of coniferous forest would be roughly 8.3 times as much of this forest type as currently exists ($1/0.12 = 8.3$). This is clearly not a marginal change. Consequently, any scenarios regarding the value of changes in cover type must be truly marginal relative to the levels of those cover types in the data used to estimate the models.

Table 3. Parameter Estimates for Semi-Log General Spatial Dependence Models

Variable	Parcel	0.1 km buffer	0.5 km buffer	1 km buffer
CONSTANT	**11.97**	**11.94**	**11.41**	**11.11**
	(151.04)	(130.97)	(80.41)	(59.64)
House age (10 years)	**-0.03**	**-0.04**	**-0.03**	**-0.03**
	(-8.80)	(-10.90)	(-9.47)	(-8.74)
Baths	**0.04**	**0.03**	**0.04**	**0.04**
	(4.98)	(4.16)	(4.87)	(4.53)
Bedrooms	**0.03**	**0.02**	**0.03**	**0.03**
	(3.24)	(2.89)	(3.44)	(3.45)
Lot acres	**0.15**	**0.15**	**0.14**	**0.13**
	(5.32)	(5.18)	(4.78)	(4.27)
Lot acres squared	**-0.02**	**-0.02**	**-0.02**	**-0.02**
	(-3.74)	(-3.63)	(-3.71)	(-3.23)
Small lot dummy	**-0.05**	**-0.06**	**-0.06**	**-0.06**
	(-2.42)	(-3.07)	(-2.94)	(-2.92)
Floor space (1000 ft^2)	**0.27**	**0.26**	**0.27**	**0.27**
	(26.69)	(26.72)	(23.21)	(23.00)
Finished attic	-0.02	-0.02	-0.04	-0.03
	(-0.62)	(-0.41)	(-1.13)	(-0.71)
Finished basement	**0.10**	**0.09**	**0.10**	**0.10**
	(9.07)	(8.57)	(8.98)	(9.38)
Distance to highway (10km)	-0.05	-0.07	-0.04	-0.04
	(-0.53)	(-0.02)	(-0.55)	(0.41)
Hemlock dummy	-0.05	-0.01	**0.06**	0.03
	(-0.67)	(-0.14)	(1.93)	(142)
Hemlock: healthy (%)	**0.66**	**1.03**	**3.94**	**8.08**
	(2.81)	(3.10)	(4.52)	(6.54)
Hemlock: moderate (%)	**-0.96**	**-1.66**	**-2.99**	**-4.76**
	(-3.02)	(-4.87)	(-2.91)	(-3.26)
Hemlock: severe (%)	-0.07	0.14	0.38	0.77
	(-0.35)	(0.56)	(1.30)	(1.54)
Hemlock: dead (%)	0.22	-0.15	0.30	**2.11**
	(0.71)	(-0.43)	(0.66)	(3.02)
Distance to golf (km)	**-0.05**	**-0.04**	**-0.02**	-0.01
	(-7.83)	(-6.17)	(-2.30)	(-1.00)
Stream (%)	-1.02	**-8.70**	-8.81	-8.56
	(-0.62)	(-2.58)	(-0.95)	(-0.46)
Lake/pond (%)	**1.06**	**1.40**	**1.20**	**1.45**
	(10.17)	(13.45)	(8.52)	(7.46)
Public open space (%)	0.08	0.02	0.01	0.08
	(0.98)	(0.27)	(0.13)	(0.74)
Development: high (%)	**0.22**	**-0.31**	-0.25	-0.18
	(2.73)	(-1.93)	(-0.68)	(-0.27)
Development: low (%)	0.06	0.11	**0.60**	**1.02**
	(0.99)	(1.49)	(4.90)	(5.83)
Deciduous forest (%)	-0.05	-0.02	**0.39**	**0.68**
	(-0.84)	(-0.23)	(3.49)	(4.92)
Coniferous forest (%)	-0.01	0.17	**6.34**	1.38
	(-0.02)	(0.29)	(2.07)	(0.22)
Mixed forest (%)	-0.14	0.06	**-1.71**	**-3.65**
	(-1.32)	(0.40)	(-3.39)	(-3.17)
Agriculture (%)	-0.02	-0.01	**0.43**	**0.97**
	(-0.31)	(-0.07)	(3.07)	(5.21)
Wetland (%)	-0.09	0.01	**0.54**	**0.77**
	(-0.92)	(0.06)	(3.16)	(2.99)
RHO	0.001	0.001	0.002	0.002
	(0.80)	(0.74)	(1.21)	(1.19)
LAMBDA	**0.41**	**0.31**	**0.34**	**0.39**
	(40.21)	(28.54)	(26.62)	(32.84)
Adjusted R^2	0.68	0.69	0.68	0.68

Note: t-statistics in parentheses. Bold indicates a statistically significant parameter estimate at the 0.10 level or higher.

mixed forest stands in this market are correlated with other, unobserved factors.

Parameter estimates on healthy hemlocks were positive and significant at the 1 percent level in all model specifications. The fact that the parameter estimate on healthy hemlocks is positive in the parcel model indicates that hemlocks have special aesthetic appeal and that people value living in and/or very nearby hemlock stands. Presumably, this is due to the special aesthetic appeal of this species that was highlighted by Brush (1979). Stands of hemlock in moderate decline were negative and significant at the 1 percent level in all of the models. These results indicate that declining hemlock health affects not only the property value where the hemlocks are located, but also spill over onto the value of neighboring properties. The impact of severe hemlock decline was not statistically significant in any of the models and, surprisingly, dead hemlock stands had a positive impact on property values in the 1km model. Although this result was not anticipated, it might be explained by the fact that an increase in the amount of light reaching the forest floor in severely declining and dead hemlock stands stimulates the establishment and growth of other, typically hardwood, tree species (Orwig and Foster 1998). Recalling that deciduous forest cover in this spatial buffer enhances property values, the positive parameter estimate may reflect this change in forest composition. Finally, parameter estimates on the hemlock dummy variable were statistically different than zero only in the 0.5km buffer model, where the estimate was positive. Although this model captures some unobserved effect related with hemlock stands, it is independent of, and does not influence, the effect of healthy and moderately declining hemlocks on property values. Thus, the impact of healthy and moderately declining stands of hemlocks on residential property values is robust.

Conclusions

The spatial and temporal characteristics of hemlock woolly adelgid induced mortality in hemlock stands, combined with the relative scarcity of hemlock forest types, presents substantial challenges in estimating economic impacts of this exotic pest on private property values. However, the empirical results of our case study clearly indicate that hemlock decline due to HWA is associated with reductions in private property values in a residential setting. Moreover, the relationship suggests that the decline of hemlock stands on both individual and neighboring properties matters, showing signs of spillover effects. Failure to incorporate these spillovers in the analysis would cause a large downward bias on estimates of the benefits of exotic insect control. However, the existence of contiguous stands of hemlock, or separate stands that are near each other, that are in different health states may interact to affect house prices. Although it is beyond the scope of the current research, future research will investigate the issue of how complex spatial and temporal configurations of healthy and declining stands of hemlocks affect housing prices.

The contribution of healthy hemlock stands to residential property values appears to be qualitatively different than other tree species in the housing market under investigation. This is presumably due to unique aesthetic attributes of hemlock stands. Factors influencing the aesthetic quality of hemlocks in a forested landscape likely include the following: (i) individual trees have a conical shape with drooping, fan-shaped branches that nearly reach the ground, creating a feeling of softness, (ii) the extreme longevity of the species permits individual trees to attain a large size, and (iii) pure stands of hemlocks create a cool, dark environment that is relatively depauperate of other species. Taken together, these attributes may convey a sense of relaxation or serenity that is valued in a residential setting.

While the costs and efficacy of biological control strategies for the HWA are not known with certainty, the presence of landscape-level externalities suggests that the formation of neighborhood or community groups to combat this insect may be a viable strategy to protect housing values. This sort of complementary group response would seem to work particularly well for the case of hemlock resource owners, because the resource is typically distributed in discrete patches. Further research should be conducted to determine the viability of invasive species control strategies that would take advantage of spatial patterns of resources at risk and that could capitalize on complementary group behavior at the neighborhood or community level.

Further research should also be conducted to extend the empirical work presented here. Notable limitations of this work include its focus on marginal willingness to pay values and its assumption of a stable hedonic equilibrium. We recognize the utility of future extensions, including second-stage hedonic analysis and analysis of the stability of preferences to marginal and nonmarginal changes in landscape attributes. Finally, we emphasize that these damage estimates are for a single housing market and it is not obvious how they can be directly applied to other areas. A more definitive assessment of how typical our study results are of damages in other regions would require replication of the procedures described here in other housing markets. However, if the results found in our study area are typical of other regions experiencing hemlock decline, then the total economic damages to property owners in the eastern United States from this exotic insect may be very large and justify aggressive control tactics.

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