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Analysis

The effect of an aquatic invasive species (Eurasian watermilfoil) on lakefront property values

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ABSTRACT

Invasive species are one of the major threats to ecosystems. One of these "invaders", Eurasian watermilfoil, can crowd out important native aquatic plants, decrease habitat and diversity of native species in a lake, and interfere with water-based recreation. This study uses a hedonic property-value method to estimate the effect of Eurasian watermilfoil on lakefront property values at selected Vermont lakes. Results indicate that as the primary component of total aquatic macrophyte growth in a lake Eurasian watermilfoil significantly and substantially affects lakefront property values. As Eurasian watermilfoil infests a lake, adding to the total macrophyte growth, property values can diminish by <1% to 16% for incremental increases in the infestation level. Hence, policies that successfully prevent infestations have significant economic benefits to owners of lakefront properties and local communities.

1. Introduction

"Invasive species" are non-indigenous animals or plants that adversely affect the ecology of native habitats and can have adverse impacts on economic welfare (e.g., Halstead et al., 2003; Holmes et al., 2006; Horsch and Lewis, 2009; Kaiser and Burnett, 2006). Wilcove et al. (1998) argued the invasive species are second only to habitat loss as the greatest threats to biological diversity. Invasive species damage the lands and waters that native plants and animals need to survive. The estimated costs of invasive species worldwide total more than $1.4 trillion — 5% of the global economy (Pimentel et al., 2001). In the U.S. alone, estimated economic damages (welfare and production losses) and control costs associated with invasive species amount to approximately $120 billion annually (Pimentel et al., 2005).

The economic costs of invasive species estimated in Pimentel's work are best estimates based on available data and appear to focus on the direct costs through production losses in agriculture, forestry and other segments of the U.S. economy, and costs to manage invasive species. Welfare losses are more difficult to estimate due to their "non-market" nature (Lovell et al., 2006). If a full accounting of welfare losses were available the economic costs of invasive species would be much larger than the figure reported by Pimentel et al. (2005).

One species of aquatic invasive plant, Eurasian watermilfoil (*Myriophyllum Spicatum*), was introduced into North America in the mid 1940s and has spread to at least 45 states.[1] The primary means of transport between lakes is on boats, boat trailers, water skis, scuba gear and waterfowl.[2] Throughout Vermont, in particular, Eurasian watermilfoil infests about 60 lakes and several rivers, including the Connecticut River (Fig. 1). Eurasian watermilfoil is highly invasive and competes aggressively with native aquatic plant species, thereby reducing biodiversity. Dense milfoil infestations can severely impair human uses such as swimming, boating, and fishing. Water quality and fish abundance and distribution can also be affected when the plants grow into dense mats on the water surface.[3]

This study investigates if Eurasian watermilfoil (milfoil hereafter) affects property values on selected lakes in Vermont, and two measures of aquatic macrophyte (plant) growth are investigated.[4] First, we investigate if the infestation of milfoil reduces lakefront property sale prices. Second, we investigate if total aquatic macrophyte growth (including both milfoil and native plants) reduces lakefront property sale prices. There are several reasons to investigate two measures of aquatic plant growth in lakes. Milfoil looks like some of the native aquatic plant species.[5] This means that some people may

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[1] http://www.iisgcp.org/exoticsp/watermilfoil.htm, last accessed on May 31, 2010.

[2] http://www.miseagrant.umich.edu/downloads/ais/fs_EWM-milfoil.pdf, last accessed on May 31, 2010.

[3] http://www.vtfishandwildlife.com/library/factsheets/NonGame_and_Natural_Heritage/Invasive_Exotic_Plant_FactSheet.pdf, last accessed on April 20, 2010.

[4] "Macrophytes are aquatic plants, growing in or near water that are either emergent, submergent, or floating. Macrophytes are beneficial to lakes because they provide cover for fish and substrate for aquatic invertebrates. … However, an overabundance of macrophytes can result from high nutrient levels and may interfere with lake processing, recreational activities (e.g., swimming, fishing, and boating), and detract from the esthetic appeal of the system" (http://www.epa.gov/bioiweb1/html/macrophytes.html, last accessed on February 5, 2010).

[5] http://www.seagrant.umn.edu/exotics/eurasian.html, last accessed on May 31, 2010.

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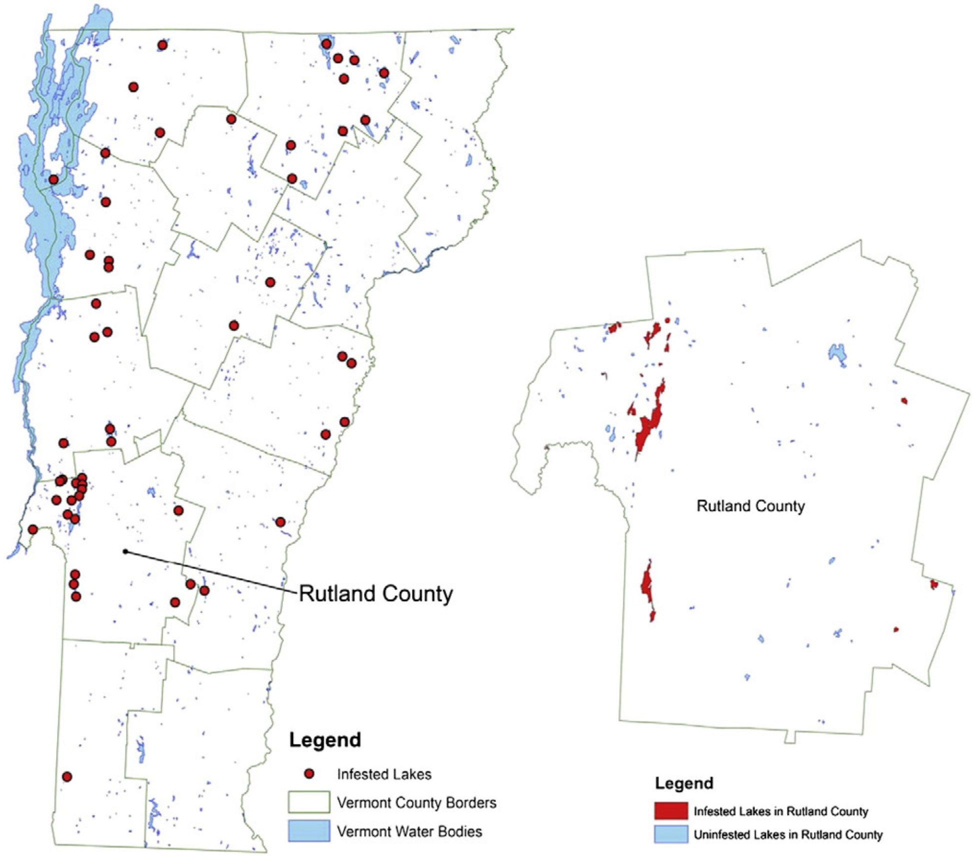

Fig. 1. Eurasian watermilfoil distribution in Vermont, 2004.

not be able to distinguish between milfoil and these native aquatic plants. In addition, total plant growth, including natives and invasives, can combine to potentially reduce the desirability of lakes for recreation activities and diminish the esthetic appeal of the waters.

2. Application

The presence of milfoil often brings changes in the natural lake environment (Madsen et al., 1991; Smith and Barko, 1990). Over time, milfoil may out compete or eliminate more beneficial native aquatic plants, reducing natural plant diversity within a lake. Commonly found in shallow bays and along the shoreline, milfoil can grow quickly from the lake bottom to the surface, forming very dense mats of vegetation on the surface of the water. These mats interfere with recreational activities such as swimming, fishing, water skiing, and boating (Eiswerth et al., 2000, 2005). The dense mats on the water surface may all reduce the esthetic qualities of lakes.

Smith and Barko (1990) state that eradication of milfoil is rarely ever successful because of the ability of this plant to reproduce from small fragments. Thus, from policy and management perspectives, a high priority should be placed on protecting lakes without milfoil from infestation and, if a lake is infested, continuous control efforts are required. The persistence of milfoil suggests that lakes that become infested may demonstrate reduced lakefront property values because of the perceived permanent reduction in the quality of lakes for recreation activities and the diminished esthetics of the lake surfaces.

2.1. Study Area

Milfoil currently infests a number of Vermont lakes, including the state's largest lakes, Champlain, Memphremagog, and Bomoseen (Fig. 1). Local populations of milfoil in Vermont were first documented in Lake Champlain in 1962 and it has since spread to about 60 lakes and several rivers throughout Vermont.[6]

The region for this study is four lakes and a pond in Rutland County, Vermont (Fig. 2). These waters were selected because they have established milfoil infestations and the Vermont Department of Environmental Conservation could provide data on the extent of milfoil coverage on the lake surface in front of each sold property.[7] The milfoil infestations in these waters, which occurred as early as 1982, are sufficient that each water has experienced multiple types of control actions (Table 1).

These unique, property-specific data on milfoil infestations provide the opportunity to estimate a hedonic, property-value model to better understand the economic costs of this invasive species. The model can be used to estimate the marginal benefits of preventing infestations or reducing the extent of infestations, which can be used to help justify the management costs of preventing milfoil infestations or reducing existing milfoil infestations.

2.2. Management Methods

The spread of milfoil is largely due to human uses (e.g., transporting recreational boats from one lake to another) that are difficult to monitor and efforts to control the spread of this invasive plant are largely dependent on public education efforts and voluntary

6 http://www.lcbp.org/nuissum.htm, last accessed on May 31, 2010.

7 The four lakes and the pond in Rutland County, Vermont are the only waters where the Vermont Department of Environmental Conservation was able to provide property-specific data on milfoil and total aquatic plant growth. As shown in Fig. 1, many other Vermont lakes and ponds also have identified infestation of milfoil, but property-specific infestation data are not available for these other waters.

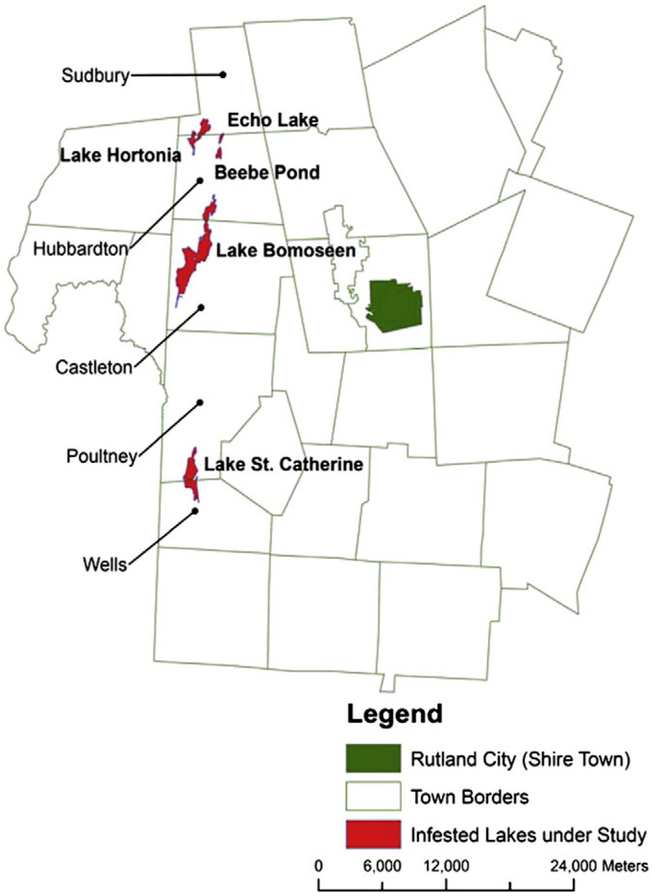

Fig. 2. Selected lakes with Eurasian watermilfoil infestation in Rutland County.

cooperation of lake users.[8] These efforts have included educational brochures distributed when people purchase fishing or boat licenses, signs at public access points to lakes, and greeters at public access points that educate people how to check their boats and trailers before and after they enter the lake. Because these voluntary compliance programs have met with limited success, milfoil has continued to spread to new lakes and states are left with attempts to control milfoil infestations. For example, the number of Vermont lakes infested with milfoil grew from a very small number in 1970 to about 65 in 2008 (Vermont Agency of Natural Resources, 2010).

Physical, mechanical, chemical and biological control methods (Table 2) are used in attempts to manage infestations of milfoil (e.g., Boylen et al., 1996; Unmuth et al., 1999; Wagner et al., 2007; Sheldon and Creed, 1995) and all four methods have been used on at least one of the five waters included in the present study (Table 1). Some methods are more appropriate for well-established populations, while others are better suited for those that are recent introductions. Pulling milfoil plants by hand, when done properly, can be somewhat effective for controlling newly introduced populations. However, this solution is tedious and it is virtually impossible to remove all of the plants in this manner. Machine cutting improves the lake for human uses, but does not remove milfoil colonies. Chemical control has been effective in temporary reductions in milfoil, but chemical applications are expensive and can be harmful to native aquatic plants. Natural predators, biological controls, of milfoil can also be introduced and the Vermont Department of Environmental Conservation has been working with the watermilfoil weevil (*Euhrychiopsis lecontei*) since 1989.

The effectiveness of each method depends on a suite of factors including the extent of the infestation, availability of funding, volunteer time and effort, follow-up efforts, and physical/environmental conditions in each lake. However, there is no way to completely eradicate milfoil from a lake once it has been introduced. Therefore, control efforts focus on controlling new infestations, preventing further spread of milfoil in established infestations, and reducing the nuisance level of well-established infestations.

3. Previous Research

A number of researchers have examined the relationship between water quality measures and housing prices using hedonic models of property values (e.g., Mendelsohn et al., 1992; Michael et al., 2000; Leggett and Bockstael, 2000; Poor et al., 2007). Only four hedonic studies have investigated an invasive species, but two investigated watermilfoil.

Holmes et al. (2006) examined the impact of the hemlock wooly adelgid (*Adelges tsuga*), an exotic forest pest, on the value of residential properties in Sparta, New Jersey. Land areas were classified according to four different categories of hemlock tree conditions: (1) lightly defoliated (<25%), (2) moderately defoliated (25–50%), (3) severely defoliated (50–75%), and (4) dead (>75%). The percentage land coverage in each of these four classes were included in the hedonic model as independent variables for buffers of 0.1, 0.5 and 1 km around sold properties. The lightly defoliated variable was significant and positive in all model specifications, indicating that the presence of hemlocks enhances property values. The moderately defoliated variable was significant and negative in all equations, indicating that defoliation of hemlocks by the invasive species diminishes property values. Moderate defoliation on subject properties reduced property values by 1%, and moderate defoliation in the 0.1, 0.5 and 1 km buffers reduced property values by 1.7%, 3.0% and 4.8%, respectively.

Kaiser and Burnett (2006) investigated reductions in property values due to the infestation by the coqui (*Eleutherodactylus coqui*), a species of small, noisy tree frogs in Hawaii. Two indicator variables were included to measure the presence of coqui; whether a property is within 500 m of a previous complaint and whether a property is between 500–800 m of a previous complaint. The results showed that a noise complaint within 500 m reduces property values 0.16% and a complaint between 500 m and 800 m reduces property values by an additional 0.12%.

Halstead et al. (2003) analyzed the effects of variable milfoil (*Myriophyllum heterophyllum*) on shoreline property values of selected New Hampshire lakes. Two milfoil variables were included in the hedonic Eq. (1) a dummy variable indicating whether milfoil was present in the lake at the time of house purchase and (2) an interaction term between the size of the lake and the presence of milfoil. The interaction term is included because the presence of milfoil concentrated somewhere in a large lake may have less of an effect on properties than in a smaller lake. The results indicate that the presence of milfoil in a water body has a substantial deleterious effect on shoreline property values, with reduction of 21% (linear dependent variable) to 43% (natural log of dependent variable). The authors note that a 40% reduction in property values is rather steep. There is every reason to question whether the 21% and 43% price diminutions are accurate. A binary variable (presence of milfoil) captures all differences between lakes that are not represented by the other explanatory variables in the model. These other effects could lead to over- or underestimation of the average effect on individual properties. If a property is not in a milfoil area, then the average effect overestimates the effect. Conversely, if a property has an extensive milfoil infestation in the lake immediately in front of the property, then underestimation may be present. In addition, if lakes with milfoil infestations are less

[8] http://www.seagrant.umn.edu/exotics/eurasian.html; http://www.anr.state.vt.us/dec/waterq/lakes/htm/ans/lp_ans-index.htm#help; http://dnr.wi.gov/invasives/publications/pdfs/EWMbrochure.pdf; last accessed on May 31, 2010.

Table 1
Rutland County, Vermont water bodies investigated[a].

Waters	Location	Year Eurasian watermilfoil found	Eurasian watermilfoil management actions[b]	Size (acres)
Beebe Pond	Hubbardton	1991	BB, HB, HP, SH	111
Lake Bomoseen	Castleton, Hubbardton	1982	BB, DD, H, HP, HR, W	2360
Echo Lake	Hubbardton, Sudbury	1989	BB, HP	54
Lake Hortonia	Hubbardton, Sudbury	1984	BB, DD, H, HB, HP	479
Lake St. Catherine	Wells, Poultney	1983	BB, H, HB, HP, HR, SH	904

[a] The information in this table is taken from VTDEC, Water Quality Division's website; it was last updated at September, 2009 (http://www.anr.state.vt.us/dec/waterq/lakes/docs/ans/lp_aismapmajorspecies2009.pdf, last accessed on June 30, 2010).
[b] Key to abbreviations: BB — bottom barrier, DD — drawdown, H — mechanical harvesting, HB — aquatic herbicide, HP — hand pulling, HR — hydro-raking, SH — diver operated suction harvesting, W — weevil introduction or augmentation.

Table 2
Eurasian watermilfoil control method comparison.
Source: All information is replicated from "Black Lake Eurasian Watermilfoil Management Plan" prepared by Quantitative Environmental Analysis, LLC, Liverpool, NY (http://www.weedinfo.blacklakeny.com/FINAL_Black_Lake_milfoil_plan_07_14_08-1.pdf, last accessed on June 15, 2010).

Class	Method	Advantages	Disadvantages	Costs
Physical	Bottom barriers	Effective at treating very dense beds; control growth in localized areas	Eliminates some non-target species; may interrupt spawning of some warm-water fish; may eliminate some benthic invertebrates	$10,000–$20,000 per acre for professional installation
	Suction harvesting	Removes only target plants; more effective in medium density beds	Labor intensive; added equipment costs; some difficulty with very dense beds	$20,000–$30,000 for equipment and $1000–$25,000 per acre for operations and disposal of harvested plants
	Hand harvesting	Removes only target plants; low equipment costs	Very labor intensive; harvesting dense beds is inefficient	$400–$1000 per acre
	Drawdown	Can be very effective for smaller water bodies with control structures	Negatively impact the ecosystem and recreational use of the lake	N/A
Mechanical	Rotovating	Both stem and roots are removed	Severe disturbance to sediments can lead to recolonization by invasive species; fragmentation of EWM can lead to colonization of new areas	$100,000–$200,000 for equipment and $200–$300 per acre for operations; or $1500 per acre to hire professional service
	Mechanical harvesting	Provide habitat for fish; leaves benthic community intact	May have to be repeated more than once a year; fragmentation of EWM can lead to colonization of new areas	$100,000–$200,000 for equipment and $200–$300 per acre for operations
Biological	Herbivorous insects	Milfoil weevil the aquatic moth target only EWM and are native species; slow reduction in plant biomass; minimizes chance of increased eutrophication	Slow method; results from introduction are inconsistent	Stocking costs approximately $1000 per acre
	Grass carp	Very little labor involved; very effective at removing vegetation given time	Removal of non-target species; grass carp prefer moving water and are very likely to migrate from the lake; highly regulated	Stocking costs $50–$100 per acre
Chemical	Aquatic herbicides	Effective on EWM; can provide short and long term control	Removal of non-target species; decomposing vegetation can reduce dissolved oxygen and cause algal blooms; use restrictions may be place on the lake after application	$200–$400 per acre

desirable than lakes without milfoil for reasons in addition to the presence of milfoil, then a binary variable indicating the presence of milfoil will overestimate the average price diminution due solely to milfoil. While Halstead et al. did not identify how many and which New Hampshire lakes had milfoil infestations during their study period (1990–95), available data indicate that only two of the 10 lakes in their data had variable milfoil infestations.[9] Thus, it is difficult to interpret the estimates presented in the Halstead et al. study.

Horsch and Lewis (2009) investigated the effect of Eurasian watermilfoil (*Myriophyllum Spicatum*) on property values over 170 lakes in Vilas County, Wisconsin where 20% of the lakes had milfoil infestations. These researchers use an identification strategy based on a spatial difference-in-differences specification, instead of a conventional cross-sectional hedonic model, to investigate how a milfoil infestation affects property values. The difference-in-differences method accounts for both bias and inefficiency problems associated with unobserved neighborhood effects that may be spatially correlated with milfoil infestations. The key milfoil variable is whether a property was or was not purchased before the occurrence of a milfoil infestation. Results indicate that a milfoil infestation reduces average property values by approximately 8% and reduces average land values, net of the value of any structures on the property, by approximately 13%. Horsch and Lewis avoid the Halstead et al. problem of simply observing whether milfoil is or is not present in a lake. They retain the Halstead et al. problem that their study says nothing about the effect of the level of milfoil on individual properties. Again, the average price diminution form purchasing property after an infestation likely overstates the price effect for a property with no milfoil in the water in front of the property and likely understates the effect on a property with a heavy infestation in the water immediately in front of the property. In addition, while the difference-in-differences approach controls for neighborhood effects, it does not capture other lake characteristics that might be changing concurrent with the infestation and the binary variable (sold before or after the infestation) could have an omitted variable bias that could lead to over- or underestimation.

These studies collectively indicate that invasive species reduce property values, and that the presence of milfoil in a lake can result in a substantial reduction in property values. However, neither the Halstead nor the Horsch studies had data on the coverage of milfoil

[9] http://des.nh.gov/organization/divisions/water/wmb/exoticspecies/documents/milfoil_map_list.pdf, last accessed on May 31, 2010.

infestations that are specific to individual properties. The unique contribution of the research reported here is that the Vermont Department of Environmental Conservation staff was able to provide data on a qualitative scale that indicates the percent the lake surface covered by milfoil immediately in front of each lakefront property for a small group of four lakes and one pond in Rutland County, Vermont. The scale ranges from 1 (less than 1% coverage) to 6 (80–100% coverage). Thus, the coverage of milfoil variable in the hedonic equation is unique to each individual property sale, and these data are better able to capture the effect of milfoil on individual property values than the crude presence or absence or before and after measures used in the Halstead and Horsch studies.

4. Hedonic Model

In a 1966 paper Lancaster developed what he called a "new theory of consumer demand" where consumers derive utility from characteristics of a good. One such characteristic of a lakefront property would be the extent of milfoil growth in lake water in front of the property. Rosen (1974) demonstrated that the hedonic-price function is simply an envelope of equilibrium of transactions between buyers and sellers of a good that is differentiated by its characteristics. Under the assumptions of this model, the marginal values (implicit prices) consumers place on individual characteristics can be recovered by regressing sale prices on the characteristics of the good.

The hedonic-price model is widely applied to study the housing market transactions because of the number and variation of housing characteristics. A house is seen as a bundle of characteristics and the sale price is a function of these characteristics. The value that a characteristic adds to the price of a house can be thought of as an implicit price for that characteristic. Such implicit price estimation is particularly helpful for characteristics that are not priced independently in markets, e.g., proximity to environmental amenities and disamenities.

4.1. Hedonic Model

To formalize the basic idea of the hedonic model, let the sale price of a lakefront property, *SP*, be expressed as a function of the property's attributes:

$$SP = f(S, P, L, Q) \tag{1}$$

where *SP* is a vector of property sale prices, *S* represents structural characteristics, *P* represents lot characteristics, *L* represents location characteristics, and *Q* represents environmental characteristics. In previous hedonic studies, examples of structural characteristics commonly included are square feet of living area, type of heating system, number of bedrooms and number of bathrooms. Lot characteristics of lake applications might include feet frontage on a lake and lot size. Location characteristics describe the area surrounding the property such as distance to the nearest large town or business district, property tax rates and neighborhood demographic characteristics. Environmental characteristics include environmental amenities (disamenities) that would contribute to (depreciate) the value of the property, e.g., water quality. Selection of independent variables, property characteristics, is based on knowledge from previous studies, intuition about the specific application, and data availability.

Hedonic theory does not guide the functional form for Eq. (1). The only restriction is that the first derivative for the environmental attribute of concern be positive if it is an amenity and negative if it is a disamenity (Freeman, 2003). Therefore, it is necessary that the functional form for the hedonic-price function be determined empirically (Cropper et al., 1988; Palmquist, 2003; Taylor, 2003). Following the majority of previous hedonic studies of water quality, and the two aquatic invasive species studies cited above, this study utilizes a nonlinear specification where the dependent variable is the natural log of sale prices. Thus, base specification of the hedonic model is:

$$\begin{aligned}\ln(SP) = {} & \beta_0 + \beta_1 UNIMP + \beta_2 \ln(LVAREA) + \beta_3 HEAT \\ & + \beta_4 FULLBATH + \beta_5 LAKEWATER + \beta_6 LOT + \beta_7 FF \\ & + \beta_8 DIST + \beta_9 INTWC + h(MC) + g(lakes) + u\end{aligned} \tag{2}$$

where the βs are parameters to be estimated and the independent variables are defined in Table 3. The independent variables in the hedonic model are additive with nonlinear specifications of living area (*LVAREA*), water clarity (*INTWC* — an indicator of eutrophication that is visually observable to property owners) and macrophyte coverage (*MC*). The natural log of the total square feet of living area is used because of a presumed nonlinear relationship between property price and house size. Marginal increases in living space will provide less utility to residents as initial total living area increases. Water clarity (*WATERCLARITY*), a component of *INTWC*, is logged because it is difficult for people to see changes in water clarity at deeper levels of clarity (Smeltzer and Heiskary, 1990). ln(*WATERCLARITY*) is then interacted with lake area based on the results of previous hedonic studies of water clarity (Gibbs et al., 2002; Michael et al., 2000).[10]

The function $h(MC)$ is modeled using two aquatic plant variables, either *EWM* (Eurasian watermilfoil coverage rating) or *TOTAL* (total aquatic macrophyte-coverage rating). Intuitively, one would expect that an increase in aquatic plant coverage would lead to a decrease in property prices. As aquatic plant coverage increases, each succeeding increment of increase may have a larger detrimental effect on property values. If the aquatic plant coverage increases from 10 to 30% of an area, this change may be noticeable to people, but they still have plenty of area for aquatic recreation activities. If the aquatic plant coverage increases from 70 to 90%, then it may be almost impossible for the lake area to support aquatic recreation. Thus, two nonlinear specifications of the aquatic plant coverage variable are considered in the hedonic-price function, a quadratic form and an exponential form, which both allow the marginal price to increase in absolute value as aquatic plant coverage increases. These specifications are:

$$h_{QUA}(MC) = \beta_{10} MC + \beta_{11} MC^2 \tag{3a}$$

and

$$h_{EXP}(MC) = \beta_{10} MC + \beta_{11} exp(MC) \tag{3b}$$

where *MC* is the percent coverage rating of macrophytes (either milfoil — *EWM* or total aquatic plant growth — *TOTAL*).

A common problem with estimated hedonic models is endogeneity. For example, milfoil infestation may be correlated with some unobserved characteristics not accounted for in the explanatory variables and, therefore, failure to include lake-specific effects could lead to bias in estimated coefficients (βs). Horsch and Lewis (2009) argued that milfoil is spread from lake to lake by the movement of boaters and anglers, who are more likely to visit popular lakes with desirable amenities that are usually unobservable to researchers. This potential concern is addressed in the current estimation by including lake fixed-effect variables [$g(lakes)$] that account for lake-specific characteristics that are not represented by the explanatory variables yet may be correlated with the level of milfoil infestations.[11] Lake Bomoseen is the omitted lake in the estimated equations.

[10] $INTWC = LAKEAREA \cdot \ln(WATERCLARITY)$. *LAKEAREA* and *WATERCLARITY* are defined in Table 3.

[11] Some hedonic studies corrected for identification problem caused by the endogeneity of environmental variable of interest (e.g., Poudyal et al., 2009; Irwin and Bockstael, 2001) by adopting IV regression.

Table 3
Names and descriptions of variables used in hedonic model ($N = 65$).

Variable Name	Description	Mean	S.E.	Min	Max
SP	Actual sale price of property (1995 dollars)	108,660.60	57,179.46	18,000	270,000
UNIMP	0,1 = unimproved land	0.11	0.31	0	1
LVAREA	Total living area (square feet)	886.42	480.79	0	1920
HEAT	0,1 = central heating system	0.78	0.41	0	1
FULLBATH	0,1 = presence of a full bathroom	0.88	0.33	0	1
LAKEWATER	0,1 = primary source of drinking water is from lake	0.48	0.50	0	1
LOT	Lot size (acres)	0.66	1.55	0.08	11.91
FF	Total lot frontage on lake (feet)	104.90	68.59	15	410
DIST	Distance to the nearest business district (mile)	18.93	4.04	15.80	28.90
INTWC	ln(*WATER CLARITY*) * surface area of lake (acres)	3012.31	1714.55	105.85	4723.49
LAKEAREA	Surface area of lake (acres)	1619.43	878.65	54	2360
WATERCLARITY	Water clarity (meters)	6.24	0.89	3.8	7.4
EWM	Eurasian watermilfoil percent cover rating	4.09	1.30	1	6
TOTAL	Total aquatic macrophyte percent cover rating	4.78	1.26	1	6
Beebe Pond	Fixed effect dummy for Beebe Pond	0.05	0.21	0	1
Lake Bomoseen	Fixed effect dummy for Lake Bomoseen (base group)	0.57	0.50	0	1
Echo Lake	Fixed effect dummy for Echo Lake	0.02	0.12	0	1
Lake Hortonia	Fixed effect dummy for Lake Hortonia	0.14	0.35	0	1
Lake St. Catherine	Fixed effect dummy for Lake St. Catherine	0.23	0.42	0	1

4.2. Selection of Functional Specification

Four base equations are estimated, quadratic and exponential specifications of milfoil (*EWM*) and total plant coverage (*TOTAL*) variables. This allows investigations of whether milfoil and total plant coverage have differential effects on sale prices. A J-test is used to investigate which functional specification, quadratic or exponential, fits the data best (Davidson and MacKinnon, 1981). This test is applied to choose between two non-nested models. Let:

$$\ln(SP) = f(X_{QUA}) + \alpha \ln\left(\widehat{SP}_{EXP}\right) + \mu \tag{4a}$$

$$\ln(SP) = f(X_{EXP}) + \delta \ln\left(\widehat{SP}_{QUA}\right) + \nu \tag{4b}$$

where $f(X_{QUA})$ and $f(X_{EXP})$ are the hedonic equations with the plant coverage variables specified as quadratic and exponential terms, respectively (e.g., Eqs. (3a) and(3b)). The second terms in each equation, $\ln\left(\widehat{SP}_{EXP}\right)$ and $\ln\left(\widehat{SP}_{QUA}\right)$, are predicted sale prices using the exponential and quadratic specifications, respectively. If α is significant and δ is insignificant, this is evidence that the exponential specification fits the data best. The converse pattern of results would suggest that the squared specification fits the data best. If both α and δ are insignificant, then the test is indeterminate.

4.3. One Real Estate Market

An important assumption of hedonic theory is that all the property sales used to estimate a hedonic regression must occur within the same housing market. This is because a hedonic-price function represents an equilibrium envelope of sale points that are arms-length transactions between willing buyers and sellers in a specific market. Markets are deemed as being separated, for example, if consumers in one market do not consider houses in the other market when making their purchase decisions.

There is no uniform theory to distinguish between housing markets and market segmentation usually rests on empirical observation and local market knowledge. Local data strongly supports the assumption that the four lakes and the pond are in the same market. As shown in Fig. 2, all waters are located within close proximity to each other in the same county and all lakefront properties are within 18 to 30 mile of the only major business district in the county and that region of Vermont, Rutland City. The waters are located in five adjacent towns and the longest distance between any two waters is about 22 mile (Lake Hortonia to Lake St. Catherine).

Another approach, borrowed from the industrial organization literature, uses the "price test" comparison for market segmentation (Stigler and Sherwin, 1985). If prices demonstrate closely parallel movements, then this suggest the loci of prices are in the same market. If significant nonparallel price movements are observed, then the loci of the prices are not in the same market unless the discordance in movements can be traced to differences such as commuting costs to work and shopping. Fig. 3 shows the trend of mean selling price of vacation houses located on less than 6 acres land from 1990 to 1995 in the five towns where the four lakes and the pond are located. The average prices of these properties increased and decreased together for Hubbardton, Poultney, Sudbury and Wells with one exception; the average price for Wells increased slightly from 1992 to 1993 while the other three averages decreased. This is evidence of a common price trend. The exception is Castleton whose average prices remained relatively stable and were bounded by the average prices from the other towns. Castleton is right in the middle of the five towns and has the most direct access to Rutland city so the price stability might be explained by reduced commuting costs to work and shopping.

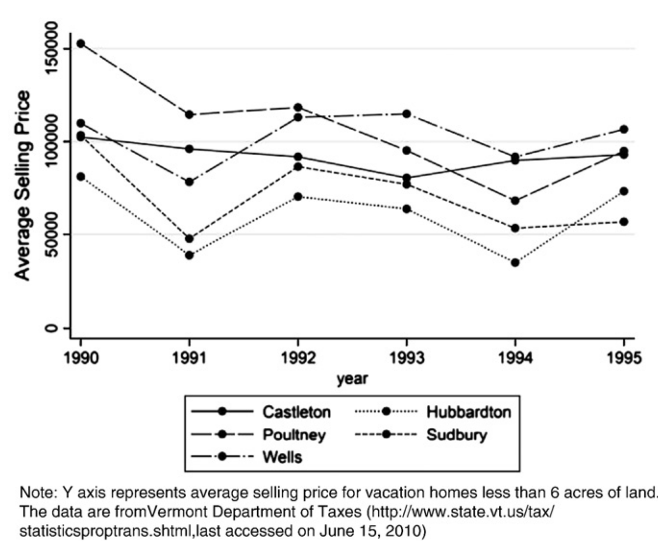

Fig. 3. Price test for one market assumption. Note: Y axis represents average selling price for vacation homes less than 6 acres of land.
The data are from Vermont Department of Taxes (http://www.state.vt.us/tax/statisticsproptrans.shtml, last accessed on June 15, 2010).

Table 4
Lake macrophyte percent cover rating and water clarity.

	N	Milfoil (percent cover rating)			Total aquatic plant (percent cover rating)			Water clarity (meters)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Beebe Pond	3	2.0	2	2	5.0	4	6	7.1	6.7	7.4
Lake Bomoseen	37	4.1	2	6	4.8	2	6	6.6	5.6	7.4
Echo Lake	1	3.0	3	3	6.0	6	6	7.1	7.1	7.1
Lake Hortonia	9	5.8	4	6	5.8	4	6	4.7	3.8	4.9
Lake St. Catherine	15	3.7	1	5	3.9	1	6	6.0	5.3	6.4
Total	65	4.1	1	6	4.8	1	6	6.2	3.8	7.4

Given the physical proximity of the five waters, their adjacency to the major business district in the area and the similarity of price trends we feel that it is reasonable to assume that transactions occurred within a common real estate market.

5. Data

This study uses lakefront property sales from four lakes and one pond in Rutland County, Vermont. These waters were selected because the Vermont Department of Environmental Conservation could provide data on aquatic plant coverage in front of each sold property.

Only single family residential or vacation homes and unimproved land were used in this study. Information on property sales and sale prices were collected from transfer tax records held in town offices (Table 3). Property sales data were collected for all lakefront properties on the selected lakes (pond) that sold during the period January 1, 1990 through December 31, 1995. The sale prices are converted to 1995 dollars. This resulted in 65 usable observations. Property tax records provided data on structural characteristics of any residences on the property and lot characteristics. Seven of the 65 observations were sales of undeveloped lots.

Data on water clarity, lake area, and aquatic macrophyte coverage were provided by the Vermont Department of Environmental Conservation. Water clarity is measured using a secchi disk that is 8 in. in diameter and is alternatively black and white in each quadrant. The disk is lowered into the lake water and the depth at which the disk disappears from sight is the measure of water clarity. The minimum water clarity during the summer months, the period of lowest water quality due to eutrophication, is used as the measure of water clarity.

Aquatic macrophyte growth is measured using a percent coverage rating. The percentage of the water surface covered by aquatic macrophytes is computed for the water surface area in front of each sold property. That is, for a fixed water surface area immediately in front of each shoreline property the percent coverage is computed as the surface area covered by the macrophyte growth divided by the total surface area under consideration. This was done for milfoil and for total plant growth. The Vermont Department of Environmental Conservation assigned categorical ratings to these percent coverages. Each number corresponds to the percent coverage of macrophytes ranging from 1 (less than 1% coverage) to 6 (81 to 100% coverage), e.g., 2→1–20%, 3→21–40%, 4→41–60%, and 5→61–80%. Table 4 summarizes the milfoil and total aquatic plant coverage data used to estimate the hedonic equations. These data indicate that milfoil as a percentage of total aquatic plant growth ranges from 14% (Beebe Pond) to 100% (Lake Hortonia), and the average across all five waters is 71%.[12] Among the 65 observations, 44 have milfoil ratings equal to the total aquatic plant ratings, indicating that for about two thirds of the properties milfoil is the primary aquatic plant growing in the water immediately in front of the property.

[12] Percentages are calculated using the midpoint of the percentages for each integer on the rating scale. For example, if the percentage coverage rating is 2, then we view the percent coverage as 10%, the midpoint of 1% to 20%.

5.1. Estimation Robustness

These data provide a unique opportunity to examine the effect of an aquatic invasive species on property values because the invasion data are specific to individual properties. This strength is tempered by the limitation of the small number of observations, $n=65$. To investigate the robustness of the estimation results two supplementary analyses are conducted.

Atkinson and Crocker (1987) found that including a large number of characteristics (explanatory variables) in hedonic-price equations can result in unreliable parameter estimates, which is more likely to be problematic for a study with a small sample size. A small sample size, such as 65, can easily result to a low degree of freedom and a high mean square error. Including correlated independent variables can increase the possibility of multicolinearity, leading to inflated standard errors. Some of the correlations reported in Table 5 are larger than 0.6. On the other hand, omitting relevant variables from a hedonic equation, especially those potentially correlated with the variables of interest, can lead to omitted variable biases.

In order to avoid omitted variable biases while reducing the number of explanatory variables, principal-component-analysis (Greene, 1994) and all-possible-regressions procedures (Neter et al., 1996) are used to investigate the effect of reducing the number of explanatory variables on the estimation results for the coefficient estimates on *EWM* and *TOTAL* variables.

5.1.1. Principal Component Analysis (PCA)

Principal component analysis uses a small number of indicator variables (L principal components) constructed from the K original independent variables ($L<K$) as new regressors. These L principal components are linear combinations of the K original variables, and they reduce the number of regressors (increasing degrees of freedom) and reduce colinearity between independent variables.

The problem with PCA is that it is unclear how to interpret the coefficient on the L principal-component variables. To avoid this problem, the PCA technique is applied to all property characteristic variables in the Eq. (2) except the *EWM* and *TOTAL* variables and the lake-specific variables. Four principal components, which are the linear combination of the 9 omitted characteristic variables, are retained and used in the new hedonic-price function:

$$\ln(SP) = \beta_0 + \beta_1 PC_1 + \ldots + \beta_4 PC_4 + h(MC) + g(lakes) + u \qquad (5)$$

where PC_i ($i=1,2,3,4$) denotes the ith principle component. L is set to four principle components because these are sufficient to account for nearly 90% of total variance in the original 9 independent variables (Fig. 4).

5.1.2. All-Possible-Regressions (APR) Procedure

The all-possible-regressions is a systematic procedure to reduce the number of independent variables to a parsimonious subset. Based on the assumption that the functional specification of Eq. (2) is correct, the all-possible-regressions considers all possible subsets of the pool of independent variables to identify “good” subsets according

Table 5
Correlation matrix.

	EWM	*TOTAL*	*UNIMP*	ln(*LVAREA*)	*HEAT*	*FULLBATH*	*R*	*LOT*	*FF*	*DIST*	*INTWC*
EWM	1										
TOTAL	0.63	1									
UNIMP	−0.33	−0.02	1								
ln(*LVAREA*)	0.32	−0.01	−0.99	1							
FULLBATH	0.28	0.01	−0.93	0.93	0.60	1					
LAKEWATER	0.20	0.04	−0.33	0.29	0.05	0.26	1				
LOT	0.21	0.14	−0.05	0.07	0.10	0.06	0.03	1			
FF	0.12	0.01	−0.03	0.01	−0.04	0.05	−0.03	0.43	1		
DIST	0.13	−0.01	−0.03	0.01	−0.37	0.07	0.24	0.27	0.43	1	
INTWC	−0.04	−0.03	−0.17	0.17	0.41	0.12	−0.23	−0.27	−0.37	−0.87	1

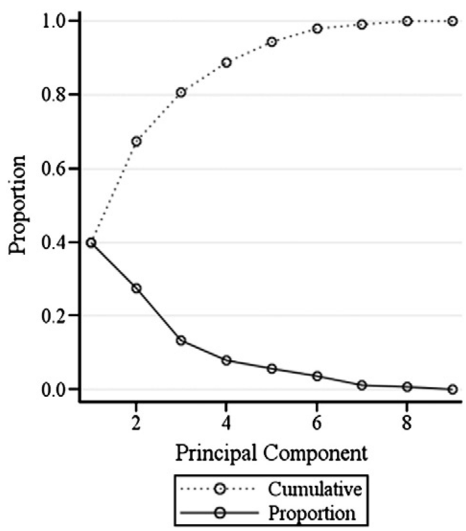

Fig. 4. Variance explained by the principal components.

to a selected criterion. Given a dependent variable Y and a set of potential independent variables, X (X_1, X_2,..., X_p), the problem is to find and fit the "best" model of the form $Y=\beta^*X^*+u^*$, where X^* is a subset of X. A variety of selection criteria are available to select among the 2^p possible submodels, including MSE, PRESS, and C (Neter et al., 1996). The MSE (mean square error) criterion seeks the subset of explanatory variables such that MSE is at the minimum or so close to minimum that adding more variables is not worthwhile. The PRESS (prediction sum of squares) criterion is a measure of how well the fitted subset model can predict the observed dependent variable, Y. Models with small PRESS values are considered "good" candidate models. The C criterion is computed based on MSE and SSE (sum of squared errors), and we seek to identify subsets of X variables for which C value is small. Specific to this study, we have $p=15$ potential independent variables that include the liner and quadratic or exponential plant coverage variables and lake binary variables. The all-possible-regressions procedure estimates 32,768 submodels (2^{15}).

6. Results

Estimation results for base models with all explanatory variables included (Eq. (2)) are presented in Table 6.[13] The second and third columns present the results for the milfoil coverage (*EWM*) equations (quadratic and exponential specifications) and the fourth and fifth columns present the respective results for the total aquatic plant coverage (*TOTAL*) equations.[14]

Living area [ln(*LVAREA*)], lot size (*LOT*), and distance to the nearest business district (*DIST*) are significant and positive in all four equations, and unimproved land dummy (*UNIMP*) is significant and positive in the two milfoil equations. None of the lake-specific binary variables are significant, which suggests that there are not unique aspects of the lakes, which are not controlled for by the variables in the equations.[15]

The results also show that the *EWM* does not significantly affect property values in the neither the quadratic nor the exponential specifications. In contrast, both *TOTAL* and $TOTAL^2$ are significant in the quadratic equation, and exp(*TOTAL*) is statistically significant in the exponential equation. Both of these results indicate that total aquatic plant coverage diminishes property values because the coefficients on $TOTAL^2$ and exp(*TOTAL*) are negative, but the quadratic result is surprising because the sign of the coefficient on *TOTAL* is positive. The quadratic specification suggests that plant coverage on the water surface up to a rating of 3 (21–40% coverage) increases property values and then decreases values for further increases in plant coverage. Given government documentation and media reporting there is no logical reason for this result; all conjectural evidence suggests that sale prices should decrease with an increase in plant coverage.

The PCA reduces the number of explanatory variables by 5 and results in the same pattern of results for the plant coverage variables (Table 7). *EWM* is not significant in the quadratic or the exponential specifications. Both *TOTAL* and $TOTAL^2$ have significant coefficients with *TOTAL* being positive and $TOTAL^2$ being negative. This pattern of results again indicates that property prices increase with plant coverage ratings up to 3 and then decline thereafter. The coefficient for the exponential term [exp(*TOTAL*)] is statistically significant and negative, which indicates that total aquatic plant coverage diminishes property values.

Table 8 presents the independent variables that the APR procedure indicated were the "best" models.[16] For the two milfoil models, *EWM* was not significant in the quadratic or exponential specifications and neither of these models is reported. The coefficients on *TOTAL* and

[13] Two kinds of spatial relationships were investigated, spatial dependence (or spatial autocorrelation) and spatial heterogeneity. These potential problems were investigated by using Lagrange multiplier (LM) tests (Anselin, 2005). The spatial weight matrix takes a dichotomous form where all "neighbors" (all properties abutting the same lake) are assigned a value of 1 and all "non-neighbors" are assigned a value of 0. For each of the four models in Table 6 neither LM-error nor LM-lag is significant, suggesting that neither spatial dependence nor spatial heterogeneity exist in the data.

[14] A variety of other specifications of the hedonic equation were estimated for both the milfoil and total aquatic plants, e.g., $[h(MC)=\beta_{10}MC]$ and $[h(MC)=\beta_{10}MC^2]$ separately. Other specifications of the macrophyte-coverage variables were generally not significant and when significant suggest that total aquatic plant coverage, not milfoil coverage, affects sale prices.

[15] The lack of significance suggests that there is not an endogeneity problem, that the lakes are not in separate markets and there are not other unique aspects of individual lakes that are not controlled by the independent variables.

[16] The APR procedure estimated $2^{15}=32{,}768$ submodels, they were then ranked according to MSE, PRESS and C criteria respectively. By "best", we mean that the submodel selected for each of the 4 specifications (2 for milfoil and 2 for total macrophyte) is top 10 for all the 3 criteria and has the highest total rank.

Table 6
Baseline hedonic models.

	Milfoil		Total macrophytes	
	Quadratic	Exponential	Quadratic	Exponential
UNIMP	2.3078**[a]	2.3143**	1.5990	1.5921
	(1.0463)[b]	(1.0469)	(1.0580)	(1.0452)
ln(*LVAREA*)	0.6112***	0.6182***	0.4703***	0.4553***
	(0.1538)	(0.1544)	(0.1608)	(0.1599)
HEAT	−0.2730	−0.2712	−0.1603	−0.1666
	(0.1986)	(0.1986)	(0.1940)	(0.1922)
FULLBATH	−0.3553	−0.3978	−0.2424	−0.1621
	(0.3956)	(0.3979)	(0.3894)	(0.3916)
LAKEWATER	−0.0773	−0.0822	−0.1248	−0.1151
	(0.1140)	(0.1136)	(0.1112)	(0.1098)
LOT	0.1007***	0.0992***	0.1011***	0.1023***
	(0.0354)	(0.0354)	(0.0345)	(0.0342)
FF	−0.0003	−0.0002	0.0003	0.0003
	(0.0008)	(0.0008)	(0.0009)	(0.0008)
DIST	−0.1181***	−0.1134***	−0.0981***	−0.1091***
	(0.0341)	(0.0334)	(0.0328)	(0.0319)
INTWC	−0.0004	−0.0004	−0.0002	−0.0002
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
EWM	**−0.2470**	**−0.0366**	NA	
	(0.2516)	**(0.0868)**		
EWM^2	**0.0378**		NA	
	(0.0315)			
exp(*EWM*)		**0.0010**	NA	
		(0.0009)		
TOTAL	NA[c]		**0.4475***	**0.1344**
			(0.2487)	**(0.0897)**
TOTAL^2	NA		**−0.0587***	
			(0.0293)	
exp(*TOTAL*)	NA			**−0.0016****
				(0.0007)
Beebe Pond	−1.0601	−1.0750	−0.3689	−0.2522
	(1.1365)	(1.1396)	(1.0999)	(1.0956)
Echo Lake	−1.4575	−1.5015	−0.4438	−0.2725
	(1.2207)	(1.2269)	(1.2293)	(1.2301)
Lake Hortonia	−0.8785	−0.9436	−0.0137	0.1798
	(1.0403)	(1.0512)	(1.0060)	(1.0115)
Lake St. Catherine	−0.3270	−0.3509	0.1062	0.2231
	(0.7890)	(0.7916)	(0.7749)	(0.7752)
Constant	12.0294***	11.6582***	10.4646***	10.9634***
	(1.8483)	(1.7515)	(1.8144)	(1.7196)
Adjusted R^2	0.6116	0.6115	0.6303	0.6373
N	65	65	6	565

[a] ***, **, * denotes significance at 0.01, 0.05 and 0.1 levels.
[b] Numbers in parentheses are standard errors.
[c] NA denotes not applicable.

Table 7
Estimated hedonic models with PCA.

	Milfoil		Total macrophytes	
	Quadratic	Exponential	Quadratic	Exponential
PC1	0.2484***[a]	0.2478***	0.2231***	0.2290***
	(0.0434)[b]	(0.0432)	(0.0394)	(0.0388)
PC2	0.2151*	0.2132*	0.1502*	0.1855*
	(0.1201)	(0.1180)	(0.1068)	(0.1036)
PC3	0.1840***	0.1837***	0.2088***	0.2130***
	(0.0611)	(0.0611)	(0.0537)	(0.0537)
PC4	−0.1221	−0.1208	−0.0846	−0.1073
	(0.0758)	(0.0744)	(0.0668)	(0.0654)
EWM	**−0.0659**	**−0.0120**	NA	
	(0.2918)	**(0.1011)**		
EWM^2	**0.0105**		NA	
	(0.0363)			
exp(*EWM*)		**0.0003**	NA	
		(0.0010)		
TOTAL	NA[c]		**0.6462****	**0.1449**
			(0.2559)	**(0.0935)**
TOTAL^2	NA		**−0.0882*****	
			(0.0298)	
exp(*TOTAL*)	NA			**−0.0022*****
				(0.0007)
Beebe Pond	0.7907*	0.7841*	0.5421	0.6176
	(0.4309)	(0.4320)	(0.4094)	(0.4016)
Echo Lake	0.8931	0.8832	1.0216**	1.1141**
	(0.5360)	(0.5327)	(0.4843)	(0.4835)
Lake Hortonia	0.7914	0.7711	0.8165*	0.9650**
	(0.5087)	(0.5112)	(0.4310)	(0.4231)
Lake St. Catherine	0.9447**	0.9424***	0.7092**	0.7839**
	(0.3572)	(0.3545)	(0.3187)	(0.3127)
Constant	11.1449***	11.0796***	10.1940***	10.8375***
	(0.5477)	(0.3314)	(0.5017)	(0.3278)
Adjusted R^2	0.4470	0.4474	0.5593	0.5599
N	65	65	6	565

[a] ***, **, * denotes significance at 0.01, 0.05 and 0.1 levels.
[b] Numbers in parentheses are standard errors.
[c] NA denotes not applicable.

TOTAL^2, as well as exp(*TOTAL*), were significant and parsimonious specifications of these models are reported. Again, the quadratic results indicate that property values increase with plant coverage ratings up to 3 and decline thereafter.

These results collectively indicate that the estimation results are robust to the inclusion and exclusion of explanatory variables despite the small sample size. Milfoil (*EWM*), by itself, does not after property values, but as the major component of total plant coverage (*TOTAL*) it does diminish property prices.

The theoretical question that remains is does the quadratic or the exponential specification of *TOTAL* fit the data best? The J-test[17] results indicate α (Eq. (4a) $-\alpha=0.826, se_\alpha=0.486, p_\alpha=0.095$) is significant, but δ (Eq. (4b) $-\delta=0.668, se_\delta=0.458, p_\delta=0.151$) is not, suggesting the exponential specification fits the data better.

Based on the coefficient estimates for the exponential specification, the total aquatic plant coverage variables in Table 8 are used to compute the marginal effect of aquatic plants on property values. Marginal values are computed for each of the 5 increments on the six-point, macrophyte-coverage scale (e.g., 1→2, 2→3, … , 5→6). This is done for increases (infestation) and decreases (remediation) of total plant coverage. If current aquatic plant coverage is "*k*" then the increment is "*k*+1" for an increase and "*k*−1" for a decrease. The marginal effects for increases and decreases in aquatic plant coverage, using the exponential specification, are computed as follows:

$$MP^{+}_{EXP} = \frac{(SP_{k+1}-SP_k)/SP_k}{(k+1)-k} = \frac{SP_{k+1}-SP_k}{SP_k} = e^{\beta_{10}\left(e^{k+1}-e^{k}\right)}-1, \quad \text{and} \tag{6a}$$

$$MP^{-}_{EXP} = \frac{(SP_{k-1}-SP_k)\,/\,SP_k}{k-(k-1)} = \frac{SP_{k-1}-SP_k}{SP_k} = e^{\beta_{10}\left(e^{k+1}-e^{k}\right)}-1. \tag{6b}$$

Marginal prices for increases in macrophyte coverage range from \$355 to \$17,764, which correspond to percentage reductions in property values ranging from 0.3% to 16.4% (Table 9). If a lake has heavy aquatic plant coverage, removing the milfoil such that the rating drops from 6 to 5 would increase property values by \$21,356 (19.65%). This, for example, would be the projected property average value improvement for Lake Hortonia that has an average coverage rating of 5.8 that is entirely composed of milfoil. The price diminutions for incremental increases in infestations according to the 6-point plant coverage scale are shown in Fig. 5.

[17] The J-test results reported here are for quadratic and exponential specifications in Table 8. The J-test is also applied to specifications in Table 6 (quadratic and exponential specification for total macrophyte coverage) and Table 7 (quadratic and exponential specification for total macrophyte coverage). The results show that both α and δ are insignificant, indicating the test is indeterminate.

Table 8
"Best" models from all-possible-regressions procedure.

	Quadratic	Exponential
UNIMP		2.0665**
		(0.9429)
ln(*LVAREA*)	0.1883***[a]	0.4789***
	(0.0280)[b]	(0.1357)
HEAT		
FULLBATH		
LAKEWATER	−0.1792*	
	(0.1003)	
LOT	0.1076***	0.1005***
	(0.0312)	(0.0310)
FF		
DIST	−0.0994***	−0.0985***
	(0.0304)	(0.0293)
INTWC	−0.0001	−0.0002
	(0.0002)	(0.0002)
TOTAL	**0.5118****	
	(0.2271)	
***TOTAL*²**	**−0.0692****	
	(0.0266)	
exp(*TOTAL*)		**−0.0007****
		(0.0003)
Beebe Pond	−0.0240	−0.2867
	(1.0530)	(1.0417)
Echo Lake	0.1018	−0.5146
	(1.1531)	(1.1450)
Lake Hortonia	0.3257	0.0220
	(0.9659)	(0.9565)
Lake St. Catherine	0.3637	0.1113
	(0.7433)	(0.7331)
Constant	11.7022***	10.8223***
	(1.3885)	(1.4806)
Adjusted R^2	0.6351	0.6442
N	65	65

[a] ***, **, * denotes significance at 0.01, 0.05 and 0.1 levels.
[b] Numbers in parentheses are standard errors.

7. Conclusions and Implications

This study shows that Eurasian watermilfoil significantly and substantially affects lakefront property values as the primary component of total aquatic macrophyte growth in a lake. As milfoil infests a lake, adding to total macrophyte growth, property values can diminish by <1% to 16% for incremental increases in the infestation. Four of the five percentages are 7% or less for increasing or decreasing milfoil invasions.

It is difficult to compare the marginal effects for different changes in aquatic macrophyte coverage to the all-or-nothing and before-or-after milfoil effects reported by Halstead et al. and Horsch and Lewis. To place these percentages in perspective, Boyle and Kiel (2001) reviewed seven hedonic studies of water quality and reported marginal price effects for three studies as percentages of sales prices. The marginal effects are 2% for a 100 U change in fecal coliform counts, 6% for a one-unit change in PH and 20% for location inside versus outside of a lake bay with eutrophication. The later study is another all-or-nothing application, like Halstead et al., which is not comparable to the current study. Boyle et al. (1998) report that a 1 m change in water clarity, from either an improvement or worsening of eutrophication, can have a 4 to 16% effect on property values. Our results, accompanied by the results from other hedonic studies of water quality issues, suggest the binary-modeling approaches of Halstead et al. and Horsch and Lewis may overestimate the property-price impacts of milfoil. The Halstead et al. study may be capturing other attributes that vary between lakes and the Horsch and Lewis study may be capturing other lake attributes that changed at the same time as the milfoil invasions.

Table 9
Marginal effect of changes in total macrophyte coverage[a].

Increasing aquatic plant coverage (invasion)		
k = 1 to k = 2	−0.33%	−$354.69
k = 2 to k = 3	−0.88%	−$961.45
k = 3 to k = 4	−2.39%	−$2593.66
k = 4 to k = 5	−6.36%	−$6906.54
k = 5 to k = 6	−16.35%	−$17,764.39
Decreasing aquatic plant coverage (remediation)		
k = 6 to k = 5	19.65%	$21,355.50
k = 5 to k = 4	6.82%	$7414.51
k = 4 to k = 3	2.46%	$2670.91
k = 3 to k = 2	0.90%	$975.04
k = 2 to k = 1	0.33%	$357.68

[a] Marginal effects of total macrophyte are calculated based on exponential form.

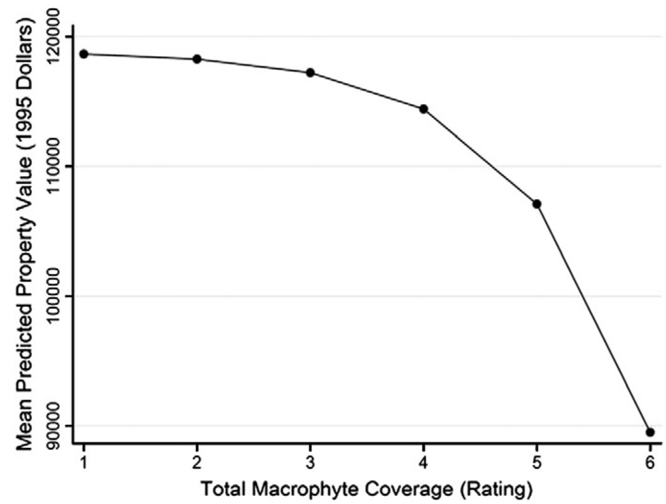

Fig. 5. Mean predicted lakefront property value (dollars). Predicted property values are calculated for each property at aquatic plant coverage level *k* (*k* = 1,2,3,4,5,6) based on exponential specification and the mean value is then computed over all *n* observations at each level.

The findings from the study reported here have important policy implications. First, milfoil is the primary component of total aquatic plant growth, which means that milfoil significantly reduces property prices even though the milfoil variable, by itself, was not significant. There are a number of reasons why the milfoil variable may not have been significant. Given that milfoil looks similar to some native aquatic plants property owners may not be able to distinguish between milfoil and these native plants. Property owners may find aquatic plant growth in total problematic, not just the milfoil. It is also possible that milfoil might be found to be significant if more data were available; a larger sample size and observations from more lakes. These interpretations are all observationally equivalent with the current data and we cannot comment on the relative credibility of these potential inferences.

Second, once milfoil is introduced into a lake it will grow rapidly and spread and is impossible to eradicate. Hence, management efforts have focused on protecting lakes from Eurasian watermilfoil. The results reported here indicate that policies that successfully prevent infestations have significant economic benefits to owners of lakefront properties and local communities. As shown in Table 4, the percentage of macrophyte growth attributable to milfoil ranges from 14% to 100%, and the average milfoil coverage rating across all five lakes is about 4. If milfoil infestation level increases from the average value, 4 (41%–60% coverage), to 5 (61%–80% coverage), the marginal change can have a 6.4% reduction in property values. Consider a simple example, if the average value of lakefront properties was $100,000 (close to the

$109 thousand reported in Table 3) and there were 1000 lakefront properties, then a 6.4% reduction in property values from further milfoil invasion would result in an aggregate property-value loss of about $6.4 million. If the property tax rate were 1.5%, then the $6.4 million lost in property value would result in an annual loss in property tax revenue of nearly $100,000. While this is an example for a stylized lake, the intuition applies to all lakes in Vermont. Even if a lake is free of milfoil currently, it is under threat from this invasive aquatic species.

This presents a dilemma for land owners, community leaders and resource managers as those that have the most to lose from milfoil infestation of lakes, property owners and local communities may not be the perpetrators of the spread of milfoil. Milfoil is spread from lake to lake by transient boaters, migratory waterfowl and other sources. Protection efforts rely substantially on programs to educate people to check and clean their aquatic gear of milfoil before and after entering a lake. While there are programs in place to educate boaters to check and clean their boats when they remove them from a lake, cooperation is voluntary and detection of milfoil on all parts of boats, motors and trailers is difficult.[18]

Thus, to enhance the voluntary control of milfoil, lake associations and local communities may want to pay trained professionals to education property owners, and monitor boat launches to educate and help boaters check their boats, motors and trailers for milfoil when launching and removing their boats from lakes. For lakes with milfoil infestations, the property value and property tax impacts can be used to justify efforts to control and reduce the extent of the invasions. Finally, the economic welfare losses estimated here are lower bounds of the total losses because they only count the losses to lakefront property owners and do not count the losses to people who use lakes to recreate but do not own lakefront property.

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