Effects of Aquatic Invasive Species on Home Prices: Evidence from Wisconsin

Marianne Johnson
Department of Economics
University of Wisconsin Oshkosh
Oshkosh, WI

Martin E. Meder
Department of Economics
University of Wisconsin Oshkosh
Oshkosh, WI

Corresponding author: Marianne Johnson
Corresponding author email: johnsonm@uwosh.edu

Abstract

While both the ecological and aesthetic impacts of some common invasive species such as water milfoil are universally negative, it less clear how property owners might view zebra mussel infestations. An invasive species, zebra mussels negatively affect the local ecology, crowd out some native species, and deposit sharp shells on beaches. However, zebra mussels are also associated with increased water clarity, a reduction in suspended pollutants, and increased numbers of popular game fish, making this an empirical question. We use a hedonic model to estimate the impact of zebra mussel and water milfoil infestations on lakefront property prices in 17 counties in North Central Wisconsin (n =1072). We find a statistically significant, negative association between sales price and milfoil infestations that is consistent with previous studies. In contrast, zebra mussel infestations are associated with higher property sales prices; this finding is robust to model specifications. The results suggest that generating compliance with containment and mitigation strategies may be difficult as lake users do not perceive a cost to zebra mussel infestation.

Key Words: Invasive Species, Zebra Mussels, Eurasian Watermilfoil, Property Values, Hedonic Models

JEL Codes: Q51, Q57

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1. Introduction

As our understanding of the ecological impact of invasive species improves, the small number of studies estimating the economic impact of invasions remains surprising. Pimental et al. (2001) estimated the global cost of invasive species at $1.4 trillion. In the United States, the estimated economic cost, including direct control costs as well as welfare and production losses, amounts to over $120 billion annually (Pimental et al., 2005). Most of these studies focus on measuring the direct cost of invasive species on agriculture, forestry, and aquatic production, as well as the costs of containment and prevention strategies; however, these strategies often require significant modifications in user behavior and hence additional welfare costs. Hedonic price models offer a logical strategy to assess these additional costs in cases of pollution or pollution abatement, sea level rise, beach quality and even airport noise. And while some studies have used hedonic models to examine the impact of invasive species such as watermilfoil (Horsch and Lewis, 2009; Zhang and Boyle, 2010), none have addressed *Dreissena polymorpha* (zebra mussels) despite significant national concern regarding their spread.

Native to Eastern and Central Europe, zebra mussels were first detected in 1988 in Lake St. Clair near Detroit, Michigan. It took barely twenty years for zebra mussels to spread to more than thirty states, engendering ecological concern for habitats as diverse as Lake Okeechobee in Florida (Adams, 2010) to the Great Lakes in the north central United States (Tímár, 2008). Zebra mussels are associated with significant environmental disturbances: they alter ecosystems by crowding out native species and by increasing water clarity, which in turn negatively affects some native fish species such as sturgeon and carp (Klerks, 2001; Strayer, 2004; McCabe, 2006).

Other species adversely affected by zebra mussels are those that either compete with zebra mussels for food directly, or whose food sources compete with zebra mussels in this manner. For example, declines have been observed in populations of American shad, a planktivorous species, in some regions invaded by zebra mussels (Strayer, 2004).

In addition to the ecological harm, zebra mussels are associated with millions of dollars in direct annual costs (Tímár and Phaneuf, 2009). Zebra mussels inhibit the functioning of intake pipes, cooling systems and other permanent submersed structures, although the cost estimates vary greatly. A 1993 report prepared for Congress by the Office of Technology Assessment estimated $3.1 billion over a ten year period, whereas Khalanski (1997) predicts a cost of $5 billion per year. Zebra mussels affect lakefront property owners, as they deposit sharp shells along beaches and increase maintenance and compliance costs for property owners and boaters. A survey of recreational boaters on Lake Erie cited average annual costs of $94 for protective paints and $171 in maintenance fees (Vilaplana, 1994), not including fines for failing to comply with containment rules.

Designing policies to slow or halt the spread of zebra mussels have become a priority for state-level departments of natural resources as well as lake managers. Studies of boater behavior suggest that behavioral adjustments, including the use of hot wash stations, can help contain the spread. However, most control mechanisms require substantial changes in behavior (Adams and Lee, 2012; Tímár and Phaneuf, 2009). To convince recreational boaters and lakefront home owners to modify their lake-use habits, it is therefore important to develop accurate estimates of the costs as perceived by lakefront property owners as a first step to designing response strategies. This study contributes to the literature through the use of a hedonic model to estimate the empirical impact zebra mussels have on lakefront property prices. Such estimates are also highly useful to policy makers constructing cost-benefit analyses of containment or mitigation strategies.

2. Literature Review

Previous research on zebra mussels has focused modeling human-induced spread (Tímár and Phaneuf, 2009), predicting contaminations (Tímár 2008), and optimal mitigation strategies (Adams and Lee 2012). However, containment and mitigation strategies for invasive species such as zebra mussels are costly and often require significant changes in behavior and practice (Eiswerth, Yen and van Kooten, 2011). Thus, such campaigns may be more effective if recreational lake users perceive direct costs to themselves.

In hedonic pricing models, the implicit values consumers place on the individual features of a property can be identified by regressions of sales price on the various characteristics of the product (Rosen, 1974). In housing models, these characteristics generally include the features of the house and of the land, as well as additional location and environmental characteristics. In an estimated model, the slope coefficient on a particular characteristic such as an aquatic species infestation, represents the marginal willingness to pay. Hedonic models are commonly used to assess legislated or other land-use policy changes, as the model allows researchers to isolate the effect of the policy variable on housing prices, and hence estimate the additional value or penalty as perceived by consumers. Only a handful of studies have attempted to use hedonic price models to estimate the impact of an invasive species (Halstead et al., 2003; Horsch and Lewis, 2009; Zhang and Boyle, 2010). While there are clearly a number of limits to hedonic pricing models in generating welfare estimates for environmental policy changes, these models can provide useful empirical evidence of whether consumers value a particular environmental amenity or disamenity (Leggett and Bockstael, 2000).

This may be especially the case for zebra mussels, where the ecological and scientific evidence does not convincingly tell us whether the invasive species should be perceived as a good or a bad by lakefront homeowners. One explanation for the absence of hedonic studies of zebra mussels has to do with the nature of the changes that zebra mussels engender in their environment. Aesthetically, while zebra mussels increase water clarity, they also encrust partially submerged structures such as piers in an unattractive layer of zebra mussels. For fishermen they disadvantage some unpopular species, such as carp, while encouraging more popular species such as smallmouth bass (Strayer, 2004). However, they also impede the feeding habits of lake sturgeon, around which an entire seasonal tourism industry has developed in some areas of Wisconsin (McCabe, 2006). For swimmers, they decrease the concentration of suspended pollutants in the water column through biosequestration yielding cleaner water. However, the sharp shells of zebra mussels can marr beaches. Hence, despite consistently negative publicity, it is not clear that lakefront homeowners would necessarily place an implicitly negative value on zebra mussel infestation.

A second explanation for the scarcity of estimates of the impact of zebra mussels on lakefront property values lies in the assumptions necessary for hedonic pricing models. These models rely on the assumption that all property sales occur in the same housing market and hence prices represent the market equilibrium price, conditional on house and land characteristics. Properties located on a single lake would constitute a single housing market, but would not evidence variation in infestation status. Infestation status varies across lakes, but these lakes may not exist in the same property market.[1] Hence, researchers face a difficult task appropriately identifying the market. And in fact, no agreed upon theoretical tests of market boundaries exists. Additional issues with hedonic pricing models have been extensively discussed (Leggett and Bockstael, 2000; Horsch and Lewis, 2009). These include the absence of a theoretical basis for the functional form of the model and difficulties with omitted variable bias (Palmquist, 1992).

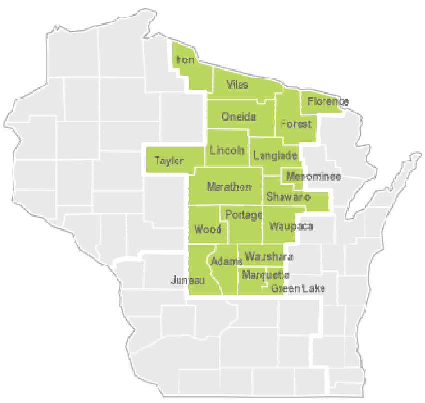
3. Methods and Data

3.1 Defining the Market

North Central Wisconsin's reputation as a vacation destination as well as its proximity to metropolitan areas Madison, Milwaukee, Chicago and Minneapolis help identify the region as a large but well-defined market, appropriate to use as a case study region (see Figure 1). Unlike previous hedonic studies of invasive species that have restricted their analysis to small areas (Horsch and Lewis, 2009; Zhang and Boyle, 2010), we argue that the housing market is neither county- nor lake-specific, but rather regionally focused and should be analyzed as such. Chi and Marcouiller (2012), in their study of recreational homes in north central Wisconsin, examine the same region. These counties represent a "contiguous remote rural region" with most counties nonadjacent to a significant urban center; these counties are classified as "recreational" and are likely to include substantial numbers of second homes (Chi and Marcouiller 2012, 49). For our purposes, by choosing to purchase lakefront property in this area, owners have self-selected for an interest in water recreational activities. Further, by indicating a premium on lake use, these buyers are likely sensitive to invasive species infestations; unlike disamenties such as water pollution, which can be difficult for property owners to discern, the infestation status of lakes are well known to owners and potential buyers.

In the absence of specific tests of market definition, we rely on an empirical examination of the North Central Wisconsin housing market. We examine three definitions of the region. The first is that defined by the Wisconsin Department of Transportation (hereafter, this region will be referred to as North Central DoT) and includes 17 counties, with a total of 1167 property sales between July 2009 and December 2011.[2] This area would be conventionally understood as a specific region with an emphasis on recreational lake usage. Palmquist (1992) suggests focusing on relatively smaller regions when possible, thus, we also consider a subset of these counties that self identify and market themselves as North Central Wisconsin under the North Central International Trade, Business and Economic Development Council (hereafter North Central ITBEC), including 10 counties and 969 property sales. As a counter control, we also consider a wider definition of North Central Wisconsin, which are the 17 counties identified by the Wisconsin Department of Transportation and all contiguous counties (a total of 32 counties), with 1435 sales of lakefront properties during our period of investigation (this region will be referred to as North Central Contiguous).

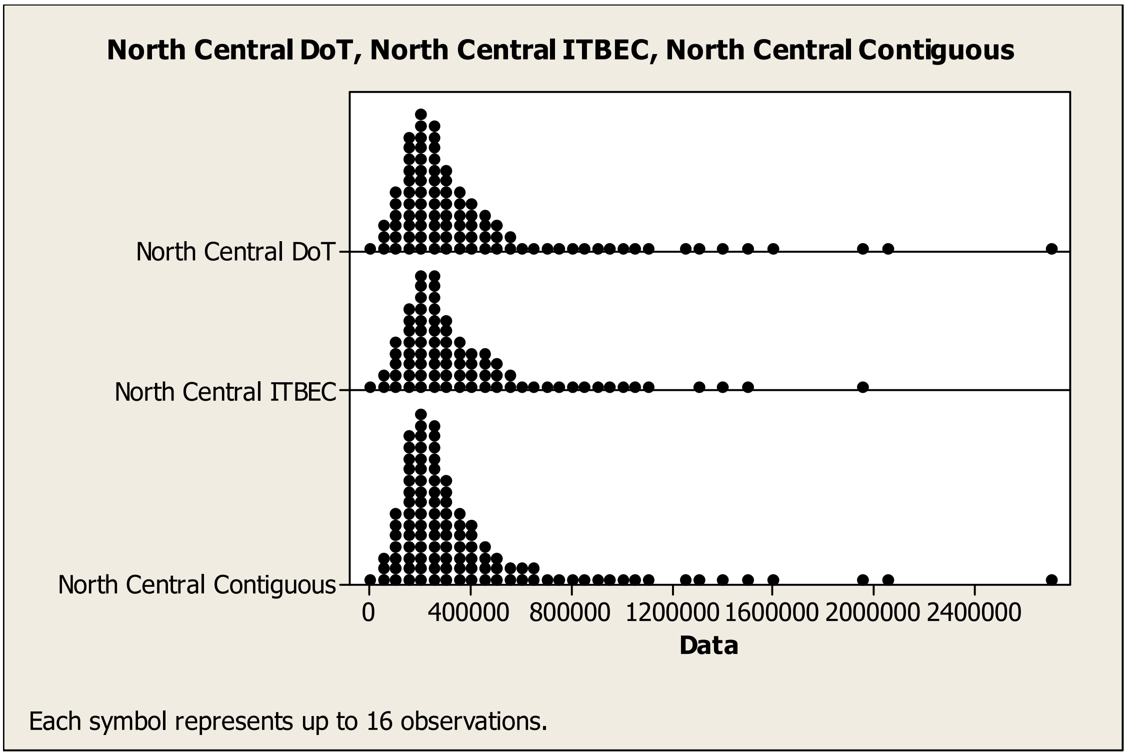
Figure 1. Map of North Central Wisconsin



UW Extension: http://www.uwex.edu/ces/dist/central/

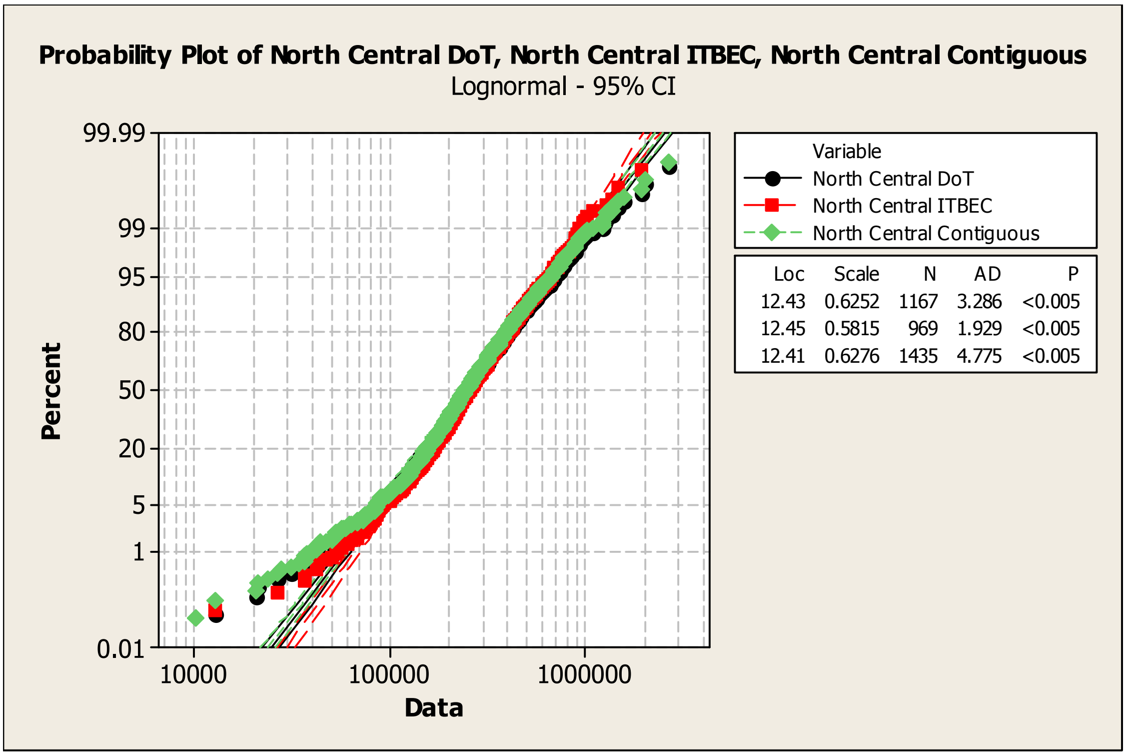
Zhang and Boyle (2010) attempt to define a property market by looking at the similarity of price movements on five different lakes. They find highly similar movements between three lakes, but that one behaves noticeably differently, but for geographic reasons they include it in their sample. We cannot take the same approach because of the time period captured in our data; any local differences in price variations across counties or lakes would be swamped by national macroeconomic trends driving housing prices following the housing bubble of 2008. Thus, instead, we look to define the region by examining the distributions of property values across different groupings of counties. Figure 2 provided a dot plot of property sales prices for the three regions defined. It is apparent that the distribution of property sales prices is highly similar for North Central DoT and North Central ITBEC and largely but not entirely consistent with the larger area, including contiguous counties to North Central DoT.

Figure 2. Dot Plot of Lakefront Property Sales Prices by Region Definition



Similarly, Figure 3 presents a probability plot of the distribution of property sales prices in the three regions. It is apparent that the distributions are highly similar, which is suggestive of a single property market.

Figure 3. Probability Plot of Lakefront Property Sales Prices by Region Definition



3.2 Measuring Invasive Species

While our primary interest lies in obtaining an estimate of the relationship between zebra mussel infestation and property sales price, reasonable coefficient estimates on the impact of another invasive species would lend credence to the validity of our estimates for zebra mussels. We choose to look at *Myriophyllum spicatum*, or Eurasian watermilfoil, which is a freshwater plant species nonnative to North America. Milfoil spreads rapidly and thrives in a range of temperatures and environmental conditions, allowing it to out-compete many native species, reducing biodiversity. Milfoil's presence can inhibit recreational lake usage, negatively affecting boating, swimming, and fishing. Additionally, milfoil presence can impose direct costs on lakefront property owners through higher lake association fees to keep boat channels open as well as to pay for herbicides and/or the harvesting of milfoil. Milfoil has the same transmission mechanism as zebra mussels, being primarily spread by transient recreational boating (Tímár and Phaneuf, 2009). Several studies have looked at the impact of a milfoil infestation on property values, giving us some guidance for constructing models to understand zebra mussel infestations. Halstead et al. (2003) report that a milfoil infestation is associated with a 20 to 40% decline in property values. Study design flaws and small sample size make these results suspect. Horsch and Lewis (2009) associate milfoil infestation with an 8 to 13% decrease in property values in Vilas County, Wisconsin. Zhang and Boyle (2010) argue that with the inclusion of a measure of the extent of a milfoil infestation, a more precise estimate of the impact on property values may be obtained. The construct a coverage scale based on data from the Vermont Department of Environmental Conservation. Their results indicate that while milfoil growth does not decrease house prices by itself, excessive aquatic plant growth, to which milfoil substantially contributes, decreases house prices by 0 to 16%.

While some previous hedonic studies of environmental disamenities have attempted to measure the extent of the "bad", measuring the extent of a zebra mussel infestation is highly problematic.[3] Although tests exist to detect the presence of veligers, the larval form of zebra mussels, in water samples, measuring their concentration may not provide an accurate representation of the number or concentration of adult mussels. Visual monitoring techniques are ineffective for a species which primarily inhabits the lake bed. These problems lead to inconsistencies in reporting and measurement by the Wisconsin Department of Natural Resources and mean that the data are too imprecise to be useful. Additionally we argue that uninformed buyers may be less sensitive to the extent of an infestation than whether the lake is infested or not.[4] This is additionally appropriate because the extent and visibility of milfoil or zebra mussels can vary significantly between lakes and across time periods, both being almost entirely unobservable over the winter months. Thus, we argue that the use of an indicator variable is most appropriate.

To assess the impact of aquatic invasions, we therefore choose to use a dummy variable to indicate the presence of the invasive species milfoil and zebra mussels. The prevalence of infestation varies depending upon the definition of market area. Of the lakes in our sample, between 5.8% and 14.5% are infested with zebra mussels, according to the Wisconsin Department of Natural Resources; an additional 32.9% to 44.7% are infested with milfoil.

3.3 The Model

One complicating factor of hedonic models is there is little theoretical basis to drive the functional form of the estimation equation. This has been extensively grappled with in the literature; the general consensus is that simpler forms perform as well or better as more complex variations, with the additional advantage of providing more intuitive relationships and explanations (Cropper, Deck, and McConnell, 1988; Leggett and Bockstael, 2000). Following the common strategy in literature, we adopt a specification where the dependent variable is the natural log of real sales price in 2011 dollars and independent variables are logged or untransformed depending on the type and measurement of the variable ($Price_i$); see Equation 1. While hedonic models are often interested in the isolating the effect of a policy change or environmental amenity or disamenity, a number of additional explanatory variables are generally included to capture the main factors that influence property values. Depending on the question of interest, previous studies have included relatively more or less information on the quality of the housing structure on the property. Because the focus of this paper is not on the values placed on specific structural attributes such as square footage or the number of bathrooms, we use the natural log of assessed improvements as a measure of the value of the structures on a property ($Improve_i$). In Wisconsin, the assessed value of improvements is obtained through on-site inspection, with the value of the improvements compared to those observed in similar structures. Leggett and Bockstael (2000) use the same approach in their hedonic study of the impact of water pollution on property values.

Property characteristics also have a significant influence on price. As is typical, we include the measures of acreage ($Acreage_i$), lake-frontage ($Frontage_i$) and the natural log of assessed land value ($Land_i$). The latter not only captures additional features that might be found attractive in a parcel of land, but in Wisconsin it is also meant to measure neighborhood quality. The Wisconsin Property Assessment Manual directs assessors to identify a neighborhood by discrete boundaries and then include physical, economic, governmental, and social factors in the valuation of properties within that neighborhood. Assessed land value therefore contributes a measure of neighborhood value which incorporates common hedonic measures such as proximity to the nearest town and neighborhood amenities (Wisconsin Property Assessment Manual, 2011, pp. 7-13).

Environmental and lake characteristics are measured by the following features: lake area ($Lake\ Acreage_i$), whether the lake has been endorsed for fishing ($Endorsed_i$), Secchi depth ($Secchi_i$), a measure of water clarity, and whether the lake has an improved boat launch

(*Improved*$_i$). Dummy variables indicating a lake infestation at the time of sale are included for zebra mussels (*Zebra*$_i$) and for milfoil (*Milfoil*$_i$). Also measured is the extent of neighboring infestations, calculated as the percentage of lakes infested in the same county *(%Zebra*$_i$ and *%Milfoil*$_i$). For buyers seeking to purchase a lakefront home, proximity to other infested lakes increases the likelihood of your lake becoming infested. These infestations may also diminish recreational options in the area. Conversely, as more of the alternatives become infested, this may reduce the perceived cost of an infested lake.

We include an indicator variable for the counties in our model (*County*$_i$), which subsumes county-level differences in property tax rates, zoning, and other land regulations. Other county-level variables such as median income, county population, and tax ratio for the property were collected, but not found to be statistically significantly related to lakefront property values. Hence, they were not included in the regressions reported here. Dummy variables indicating the year of property sales is our remaining explanatory variable (*Year*$_i$), while u_i represents the error term.

$$\ln(Price_{\mathrm{i}}) = \beta_0 + \beta_1 \ln Improve_i + \beta_2 \ln Land_i + \beta_3 Acreage_i + \beta_4 Front_i + \beta_5 LakeAcreage_i + \beta_6 Endorsed_i + \beta_7 Secchi_i + \beta_8 Improve_i + \beta_9 Zebra_i + \beta_{10} Milfoil_i + \beta_{11} \%Zebra_i + \beta_{12} \%Milfoil_i + \beta_{13} County_i + \beta_{14} Year_i + u_i. \quad [1]$$

Hedonic pricing models often suffer from the econometric problem of endogeneity. Zebra mussels are spread by contaminated boats or other recreational vehicles moving between bodies of water. Higher demand lakes – lakes with features that make it attractive for recreational use or lakes closer to population centers – are more likely to become infested. Simultaneously, these same lakes tend to evidence higher property values. Previous studies have grappled with endogeneity in different ways. Horsch and Lewis (2009) employ a difference-in-difference methodology, whereas Zhang and Boyle (2010) utilize lake fixed effects. We attempt to address the endogeneity inherent in invasive species models in three ways. First, we use milfoil infestation status as a control for zebra mussel infestation. Second, the presence of an improved ramp, indicates that the lake receives a high volume of boat traffic, which means that it is a popular destination, suggesting it may be more likely to become infested. Third, we attempt control for endogeneity by exploiting the method of assessing land value in Wisconsin as a way to get a measure of neighborhood characteristics.

3.3 The Data

Data used for this study were collected from the Wisconsin Integrated Property Assessment System, the Wisconsin Department of Natural Resources lake database, and county-level assessment and Geographic Information System data. Secchi depth estimates, a measure of water transparency, are from the University of Wisconsin lake survey project, available at Lakesat.org. Summary statistics for each of the three market definitions are reported in Figure 4.

Figure 4. Summary Statistics by Market Definition

Variables	**Mean or Frequency (Standard Deviation)**		
	North Central DoT	**North Central ITBEC**	**North Central Contiguous**
Sales Price**	303,489 (219,587)	300,182 (188,029)	296,049 (210,326)

Acreage	1.87 (7.24)	2.09 (8.00)	1.77 (6.77)
Lake Frontage in Feet	160.71 (157.28)	167.72 (157.25)	155.47 (151.84)
Assessed Land Value**	166,282 (151,273)	165,247 (119,234)	159,508 (143,063)
Assessed Improvements**	141,406 (116,216)	140,202 (112,556)	138,156 (112,389)
Secchi Depth	9.56 (5.09)	9.87 (4.95)	8.95 (5.23)
Lake Endorsed for Fishing[5]	57.14%	54.33%	57.98
Lake Acreage	1127.43 (2143.99)	849.70 (1305.06)	3697.08 (17437.16)[6]
Improved Lake Access	57.8%	54.6%	62.2%
Zebra Mussel Infestation	9.4%	5.8%	14.5%
Percentage of Lakes in County that are Infested with Zebra Mussels	4.6%	2.9%	3.7%
Milfoil Infestation	40.5%	32.9%	44.7%
Percentage of Lakes in County that are Infested with Milfoil	32.0%	23.6%	35.9%
Number of Observations	1167	969	1435
Number of Counties	17	10	32
Number of Lakes	413	364	490

* A variety of other data were collected, including length of milfoil infestation and property tax rates, but these were found to have no statistically significant relationship to property sales price.
** All monetary variables are measured in 2011 dollars.

4. Data Analysis

As discussed, the two primary methodological issues associated with using a hedonic model to study the impact of invasive species on house prices are the endogeneity problem and appropriately defining the housing market. While we have taken steps to address these issues at the model level, we also consider several different regression specifications in an attempt to tease out any unaccounted for effects. Note that county and year fixed effects are used to ensure that differences in sales prices across counties that are time-invariant and differences in sales prices across time that are common in all counties will not bias estimates. In addition, we cluster by municipality to correct for the non-independence of observations from the same municipality; this simultaneously generates heteroskedastic robust results. Our estimation results are presented in Figure 5 for North Central DoT.

While our primary interest lies in obtaining an estimate of the relationship between zebra mussel infestation and property sales price, the reasonableness of coefficient estimates on other explanatory variables support the validity of our estimates of the effects of invasive species. Hence we consider three specifications of our base OLS model: the first includes a dummy variable indicating whether a property is on a lake infested with zebra mussels as well as a variable indicating the proportion of lakes in the county infested with zebra mussels. The second specification includes a dummy variable indicating a milfoil infestation along with a variable indicating the extent of local milfoil infestation measured as the proportion of lakes in the county infested with milfoil; the third includes both measures for zebra mussels and milfoil. The advantage of this approach is that several reliable estimates of the impact of milfoil exist (Zhang and Boyle, 2010; Horsch and Lewis, 2009), allowing us to compare our model performance for milfoil against these results.

Figure 5. Estimation Results for North Central DoT, Dependent Variable is the ln(Sales Price)

	Zebra Mussels (1)	**Milfoil (2)**	**Zebra Mussels and Milfoil (3)**
ln(Assessed Land Value)	0.370 (0.027)***	0.381 (0.028)***	0.375 (0.027)***
ln(Assessed Improvements Value)	0.406 (0.021)***	0.407 (0.022)***	0.406 (0.022)***
Acreage	0.002 (0.0007)**	0.001 (0.0007)*	0.001 (0.0007)**
Frontage	-0.0001 (0.0001)	-0.0001 (0.0001)	-0.0001 (0.0001)
ln(Secchi Depth)	0.063 (0.023)***	0.065 (0.021)***	0.057 (0.022)***
Lake Endorsed for Fishing	0.076 (0.024)***	0.082 (0.024)***	0.082 (0.024)***
Lake Acreage in 1000s	0.007 (0.006)	0.010 (0.006)*	0.007 (0.006)
Improved Boat Access	0.021 (0.024)	0.023 (0.024)	0.022 (0.024)
Zebra Mussel Infestation	0.100 (0.050)**	--	0.103 (0.051)**
Proportion of Lakes in County Infested with Zebra Mussels	-0.013 (0.010)	--	-0.011 (0.009)
Milfoil Infestation	--	-0.045 (0.029)	-0.048 (0.029)*
Proportion of Lakes in County Infested with Milfoil	--	-0.011 (0.014)	-0.007 (0.010)
Year 2009	0.101 (0.037)***	0.095 (0.037)***	0.093 (0.038)**
Year 2010	0.082 (0.020)***	0.074 (0.021)***	0.077 (0.021)***
Constant	3.176 (0.275)***	3.195 (0.332)***	3.241 (0.331)***
N, R-squared	1072, 0.7531	1072, 0.7527	1072, 0.7540

Coefficients for county dummy variables are not included to save space. They are available upon request from the authors. Note that * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level. Standard errors are in parentheses.

As expected, in Regressions 1through 3, house and property characteristics such as assessed land value, assessed improvements value, acreage, and water clarity (measured as Secchi depth), all contribute positively and statistically significantly to sales price in all specifications.[7] Houses on lakes endorsed for fishing command an additional premium of 7.6% to 8.2% of sales price ($p < 0.01$). These results are highly robust to specification and estimation procedure and are consistent with previous estimates. We do not find a statistically significant relationship between property sales price and the size of the lake, measured in thousands of acres, nor whether a lake has an improved boat launch or access. We retain both variables as they contribute to the overall predictive power of the model and help us to control for endogeneity issues associated with the spread of invasive species.

The ecological literature suggests that zebra mussels generate both positive and negative effects on their environment, when viewed from the perspective of property owners. In fact, as reported in Regression 1 in Figure 5, we find that zebra mussel infestations are associated with a 10% increase in property values ($p = 0.048$). This runs counter to popular press reporting that claims infestations lower property values, though no empirical studies have actually documented this. The negative perception of zebra mussels might be better captured by our measure of the proportion of lakes in the same county that are infested with zebra mussels. Here we see that as the proportion of infested lakes in a county rises by 1%, other factors remaining constant, we expect property sales prices to decline by 1.1% ($p = 0.211$). One possible explanation may be that the visible effects of an infestation (clearer water, more high-value fishing) outweigh the negative perception of an infestation.

A second possible explanation is that we have failed to accurately control for the fact that higher demand lakes are more likely to become infested and simultaneously these lakes evidence higher property values. However, controlling for milfoil infestation status bring us some ways to addressing this issue. Milfoil has had a much longer residency in Wisconsin as an invasive species, with some infestations dating back to the 1960s. In contrast, zebra mussels were first documented in the late 1990s. Hence, we would expect that high demand lakes had been infested first by milfoil. In Regression 2, considering only the impact of a milfoil infestation, we estimate that such an infestation is associated with a 4.5% decline in property sales prices ($p = 0.124$), a value consistent with those estimated by Horsch and Lewis (2009) and Zhang and Boyle (2010), whose estimates range between 0 and 16%. Additionally, we note that as the proportion of infested lakes in the county increases, properties face an additional penalty, though the association is not statistically significant. These results suggest that we have appropriately captured the impact of milfoil infestations on property values.

In Regression 3, we see that zebra mussel infestation is associated with a 10.3% increase in property sales price ($p = 0.047$), even when milfoil infestation status is accounted for. Yet, milfoil continues to have a negative and statistically significant impact on price. People clearly view milfoil as a disamenity, but not zebra mussels. We note that regressions including various interactions between zebra mussels and milfoil, as well as interactions between infestation-status and the length of an infestation, fail to uncover any statistically significant relationships. These results are available upon request from the authors.

We investigate a third possible explanation for the positive and statistically significant coefficient on zebra mussels – that of a mis-specified property market. In Figure 6, we consider two additional definitions of the property market in North Central Wisconsin. In the first, we restrict our analysis to the subgroup of 10 counties that self-identify as North Central ITBEC. In the second, we consider the standard characterization of North Central DoT but include, in addition, all contiguous counties to this region. The third and fourth specifications limit our analysis to subgroups of contiguous counties that have higher concentrations of zebra mussels than the region as a whole. Note that these counties are not in the North Central DoT region proper, but are contiguous to the North Central DoT region. We speculate that counties with higher infestation rates may evidence greater sensitivity to an infestation than areas with lower infestation rates. On the other hand, because of their location, the lakefront properties in the third and fourth specifications are much more likely to be primary residences, and as a group, these property owners may value different features. Note that in the third and fourth specifications, we include dummy variables for county, but do not explicitly control for the proportion of lakes in the county infested due to the small sample of properties and few counties, leading to a lack of variation in the data.

Figure 6. Estimates for Different Market Definitions, Dependent Variable is ln(Sales Price)

	North Central ITBEC	North Central Contiguous	Adams, Columbia, Dodge, and Green Lake Counties	Shawano and Winnebago Counties
ln(Assessed Land Value)	0.338 (0.031)***	0.379 (0.024)***	0.356 (0.060)***	0.325 (0.092)***
ln(Assessed Improvements Value)	0.389 (0.023)***	0.400 (0.019)***	0.396 (0.058)***	0.419 (0.092)***
Acreage	0.001 (0.0006)**	0.001 (0.0007)**	0.020 (0.044)	-0.030 (0.046)
Frontage	-0.00004 (0.00009)	-0.0001 (0.001)	-0.0007 (0.0001)***	0.0006 (0.0003)*
ln(Secchi Depth)	0.066 (0.027)**	0.077 (0.021)***	0.049 (0.053)	0.193 (0.062)***
Lake Endorsed for Fishing	0.092 (0.025)***	0.088 (0.023)***	-0.107 (0.162)	0.088 (0.057)
Lake Acreage in 1000s	0.026 (0.001)**	0.00027 (0.0005)	0.021 (0.0006)***	0.00007 (0.00007)
Improved Boat Access	0.042 (0.023)*	0.028 (0.023)	0.199 (0.091)**	-0.103 (0.086)
Zebra Mussel Infestation	-0.054 (0.046)	0.115 (0.041)***	0.002 (0.072)	0.041 (0.053)
Proportion of Lakes in County Infested with Zebra Mussels	0.016 (0.015)	-0.012 (0.010)	--	--
Milfoil Infestation	-0.047 (0.030)	-0.024 (0.027)	0.127 (0.162)	-0.085 (0.086)
Proportion of Lakes in County Infested with Milfoil	-0.004 (0.012)	0.0009 (0.001)	--	--
Year 2009	0.112 (0.047)**	0.107 0.034)***	0.093 (0.077)	0.035 (0.116)
Year 2010	0.104 (0.022)***	0.08(0.020)***	0.054 (0.054)	0.122 (0.073)
Constant	3.736 (0.391)***	3.018 (0.255)***	3.284 (0.609)***	3.511 (1.032)***
N, R-squared	894, 0.7055	1307, 0.7282	105, 0.8932	98, 0.7007

Coefficients for county dummy variables are not included to save space. They are available upon request from the authors. Note that * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level. Standard errors are in parentheses.

Compared to the regressions reported in Figure 5, we see that restricting our analysis to the North Central ITBEC or expanding our region to include counties contiguous to the North Central DoT has little impact on our base-model estimates. Assessed land and assessed property values are positively and significantly associated with property sales price, as is acreage, water clarity, and fishing endorsement. Milfoil continues to be generally negatively associated with sales price, though this is not a statistically significant relationship in any of the specifications of Figure 6. The exception is the third specification where the estimated coefficient on milfoil is positive; in this case, however, we cannot conclude that the value is any different than zero.

We also find that the estimated coefficient on zebra mussels is generally positive. If we examine our largest market definition of North Central Wisconsin inclusive of its contiguous counties, we find that a zebra mussel infestation is associated with an 11.5% increase in sales ($p = 0.005$). Overall, we find that the coefficient on zebra mussels is positive in five of the six specifications and statistically significant in three of them, even after controlling for milfoil infestations. Given our initial premise that it is unclear how property owners may view a zebra mussel infestation, this result is not entirely surprising.

5. Conclusions

The absence of hedonic studies of zebra mussels is surprising given the attention devoted to the invasive species in the United States and Canada. One of the reasons for this absence may be the confounding effects of zebra mussels on their environment. An infestation engenders both visible positive and negative effects on a lake. Zebra mussels improve water clarity and sports fishing while reducing suspended pollutants in the water. In contrast, zebra mussels also crowd out some fish species important to the Wisconsin fishing industry, notably sturgeon, and also deposit sharp shells along beaches. It therefore becomes an empirical question, whether lakefront homeowners suffer from an infestation.

In spite of their uniformly negative reputation, we find no evidence that zebra mussels are associated with decreased prices for lakefront properties, when examining the vacation region of North Central Wisconsin, including more than 1000 lakefront property sales over two and a half years. In fact, we generally find that an infestation is associated with a statistically significant increase in property value of about 10%, controlling for property, lake and water characteristics. While hedonic studies of environmental policies or characteristics often suffer from specification and endogeneity issues, as well as omitted variable bias, that we generate coefficient estimates consistent with previous studies for a second invasive species in our model, water milfoil, is suggestive that we have accurately captured the empirical impact of zebra mussels as well.

This finding has an important policy implication. Since most mitigation and control mechanisms require substantial changes in user behavior, the lack of a negative effect on property values suggests that it might be difficult to generate substantial levels of compliance. If lakefront home owners do not perceive a negative effect from zebra mussels, they are much less likely to regularly practice hot boat washes or regularly clean their boats, both of which are inconvenient and engender significant opportunity costs. These results may also indicate that mechanical or chemical control methods employed by lake associations for invasive species such as zebra mussels are unnecessary from a homeowner perspective.

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[1] While the expansion of zebra mussels may seem like a dynamic problem, several issues mean that it is difficult to statistically treat it as such. First, expansion is limited by the availability and suitability of ecosystems that can support them; e.g. not all lakes provide the appropriate environment. The corollary is that the infestation would spread much faster to popular lakes that provide suitable habitats. What we see in the data is that observed infestations occur in waves. A second issue is that Department of Natural Resource sampling practices are highly inconsistent and relies partly on random checks but more on homeowner reporting. So, while the true number of infestations every year is likely not 0, and therefore not entirely static, the level of dynamism or even the extent or direction of invasion in Wisconsin cannot be practically observed.

[2] The timeframe coincides with the launch of the Wisconsin Integrated Property Assessment System (IPAS), making the collection of cross county data on property sales possible.

[3] Leggett and Bockstael (2000) use fecal coliform counts as a measure of water pollution. Zhang and Boyle (2010) attempt to measure the extent (coverage) of a milfoil infestation in lakes in Rutland County, Vermont.

[4] Similar problems to those associated with zebra mussels confound Wisconsin DNR data on milfoil. Additionally, the visibility of milfoil is significantly affected by weather conditions and is unobservable between October and March in Wisconsin, meaning buyers during this period cannot assess an infestation. They only know if a lake is infested or not.

[5] We use the endorsement of the popular fishing guide, *Sportsman's Connection,* to represent common knowledge about the fishing quality of a lake.

[6] Region includes 25 properties on Lake Winnebago, which has 131,939 surface acres.

[7] While we are suprised to find a negative coefficient value on frontage, the size and the significance of the estimated coefficient suggest there is no relationship. We suspect this is because our measure of assessed land value already incorporates a value for frontage, and regressions including frontage but not assessed land value indicate a positive and statistically significant relationship