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The Effects of Ambient Water Quality and Eurasian Watermilfoil on Lakefront Property Values in the Coeur d'Alene Area of Northern Idaho, USA

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Abstract: Amenity value of water resources has become a major driving force of recent population growth in the region centered on Coeur d'Alene Lake in northern Idaho, USA. Despite regulatory measures aimed to protect lake water quality, surface water quality is increasingly threatened by lakefront development and invasions of Eurasian watermilfoil (*Myriophyllum spicatum*), a non-indigenous aquatic plant species. We used hedonic modeling to estimate the effects of ambient water quality and the presence of Eurasian watermilfoil on lakefront property values of single-family homes in the Coeur d´Alene area. We find that property values are positively associated with Secchi depth (a proxy of water quality or clarity), and negatively related to the presence of watermilfoil. Results of spatial regime analysis indicate the geographical variations of these associations. The presence of watermilfoil was related to a 13% decline in mean property value, corresponding to $64,255 USD, on average, lower property sales price. Our study demonstrates that proactive mitigation approaches to cope with potential environmental degradation in lake ecosystems could have significant economic benefits to owners of lakefront properties and local communities.

Keywords: water quality; Eurasian watermilfoil; hedonic analysis; Coeur d'Alene

1. Introduction

In the United States (U.S.), the Federal Pollution Control Act of 1948, amended in 1972 and commonly known as the Clean Water Act (CWA), is the primary federal law governing water pollution [1]. Under this law, billions of dollars have been directed to improve and protect water quality; however, today nearly 50% of rivers and streams, and 66% of lakes and reservoirs are still considered impaired for one or more uses [2]. Another major expenditure of protecting water quality and the health of lake ecosystems is associated with the control of non-native aquatic plants and animals [3–5], as invasive species often reduce biodiversity in lake ecosystems and contribute to decreases of recreational values and aesthetics of water bodies [6,7].

Eurasian watermilfoil (*Myriophyllum spicatum*, and milfoil hereafter) is a submersed aquatic plant native to Europe, Asia and northern Africa that now occurs in countless lakes across North America, and is present in all U.S. states [4]. The plant has feather-like leaves arranged in whorls (circles) on the stem and 12 to 21 pairs of leaflets per leaf [8]. It grows from the lake bottom in depths of approximately 2 m (6.5 ft) to the surface, then branches and grows immediately under the surface at prolific rates which creates dense aggregations that interfere with other plants [8,9] and recreational uses, e.g., swimming and boating [6,7]. Its ability to tolerate and grow in a wide range of water temperatures, depths, and turbidities contributes to its success as an invader [9,10]. In addition, dense beds of milfoil may negatively affect fishing because the canopy interferes with gear and fish access to invertebrates [11,12]. The costs of controlling milfoil are mainly related to the application of aquatic herbicides, managing water levels, biological control, and suction removal using divers, all of which can cost millions of dollars annually [3,4,13]. Notably, despite these expenditures, little is known about the economic benefits of controlling milfoil infestation and water quality improvement because these impacts tend to be diverse and non-market in nature [14–17].

We estimated a hedonic price model to evaluate the potential economic impacts of lake water quality and aquatic invasive species on lakefront properties, contributing to a growing body of literature on economic valuation of ecosystem services (e.g., water clarity) and disservices (e.g., invasive species) [18–20]. We focused on lakefront properties in the Coeur d'Alene region of northern Idaho. Since the 1990s, amenity value of water resources has become a major driver of urban population growth in the region, making Coeur d'Alene, what Barbara Walters called, "a little slice of heaven" [21]. Based on the land use data derived from the U.S. National Land Cover Database (NLCD), urban land in Kootenai County where the majority of the Coeur d'Alene Lake is located, increased by approximately 20% from 2001 to 2011. The total population in Kootenai County has seen a 111% increase since 1990. According to the 2010 census, 144,265 residents lived in the metropolitan area centered on the city of Coeur d'Alene, which has become the second largest metropolitan area in the state of Idaho.

Increased development in the catchment and along the lakefront threatens water quality and the health of the lake ecosystem [22]. For example, a recent joint survey by the Idaho Department of Environmental Quality (IDEQ), the Coeur d'Alene Tribe (Tribe hereafter), and Avista, a large utility company in the Pacific Northwest and a major stakeholder in the management of Coeur d'Alene Lake, showed that milfoil infestations prevailed in at least ten out of 28 bays during the summers of 2011–2014 [23]. While protecting Coeur d'Alene Lake is a major concern of local stakeholders, little information is available about the economic impact on property values in relation to water quality improvement or milfoil invasions. Thus, empirical evidence of such impacts from changes in lake ecosystems will provide a tangible base for communities to make meaningful and deliberate land use planning decisions. Locally, results will help stakeholders, such as the county planning commission and the Tribe, to demonstrate to private property owners that it is in their own interests to protect Coeur d'Alene Lake water quality and prevent the future spread of milfoil.

2. Related Literature

Water bodies, such as lakes and rivers, are an integral part of biogeochemical and hydrologic processes, providing vital ecosystem services to society [24,25]. Water-related landscapes are also known to be the visual amenity drawing the strongest preference from the general public [26]. Variance in water quality often plays a key role in determining cultural services and amenity benefits provisioned to people in their decision to live close to lakes to enjoy recreational uses (e.g., swimming, boating, and fishing) [4,5,27,28]. Thus, surface water quality is closely associated with lakefront property values [29,30]. Poon *et al*. [31] identified that one milligram per liter change in total suspended solids and dissolved inorganic nitrogen were associated with reductions in lakefront property values by $1086 and $17,642, respectively, in a small localized watershed in a southern Maryland county. Clapper and Caudill [32] reported that in northern Ontario, Canada, buyers were willing to pay about 2% more for each one-foot increase in water clarity. Bin and Czajkowski [28] summarized that both technical and non-technical water quality measures mattered when valuing water quality-centered services by hedonic pricing analysis. Because changes in water clarity are a measure most likely to be observed by home buyers, Secchi disk measurements of clarity are widely used as a variable to indicate water quality [3,14,30,33].

In addition to ambient water quality, aquatic invasive species, such as milfoil, can severely damage freshwater ecosystems and subsequently affect lakefront property values [4,34,35]. A number of researchers have employed hedonic modeling to quantify the economic impacts of milfoil infestations with respect to property values [3,4]. For example, Zhang and Boyle [4] found that the presence of milfoil in five Vermont lakes (USA) was directly associated with reduction in property values by <1% to 16%, depending on the level of infestation. In northern Wisconsin, similar economic effects were reported for 170 lakes; lakefront property values in these rural and recreational areas can decline by approximately 8% after milfoil invasion [5]. It should be noted that these studies were focused on rural properties where the majority of houses were vacation homes. However, Olden and Tamayo's [3] study in King county, Washington, indicated that average property values were 19% lower around lakes with milfoil than lakes without. Additional research efforts are needed to evaluate economic impacts of water quality or clarity and milfoil infestations in lake ecosystems that have experienced rapid population growth and urbanization.

3. Methodology

3.1. Study Region

Our study region extends from the downtown Coeur d'Alene lakefront to the rural area of Kootenai County, Idaho and its administrative boundary with Benewah County, Idaho (Figure 1). Lakefront development is spread around different bays and the shoreline of the lake, and is intersected by state highway 95 (north–south) and Interstate 90 (west–east) [4,5]. Specifically, the bays throughout Kootenai County are located along a distinct north–south urban–rural land use gradient. The city is named after the Coeur d'Alene people, an indigenous tribe living along lakes and rivers of the region, first encountered by French fur traders in the late 18th and early 19th century [36]. The Tribe and IDEQ are the governing entities responsible for lake water quality, while Kootenai County exercises land-use planning authority for the majority of the lakefront development.

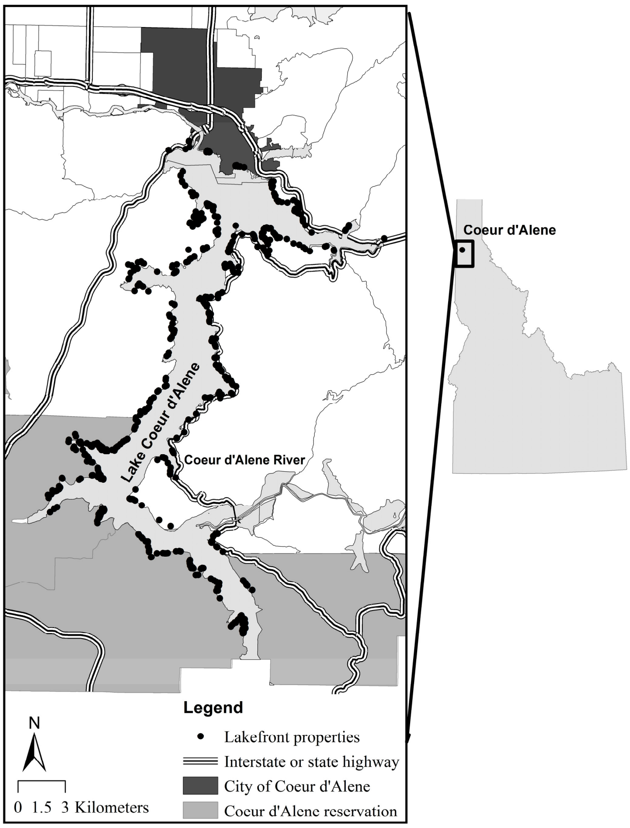

Figure 1. Location of lakefront properties, the Coeur d'Alene Lake, and the city of Coeur d'Alene in the state of Idaho, USA.

Mining for lead and silver was a major economic driver of local development in the Coeur d'Alene area until the 1980s when the Bunker Hill mining district on the lake's Coeur d'Alene River tributary and areas downstream—including the bed of Coeur d'Alene Lake was listed on the National Priority List for remediation and restoration under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA - Superfund) [37]. The Tribe owns and protects water quality in the southern third of the lake (Figure 1), while IDEQ is responsible for lake water quality in the northern part. The mission of each governing entity—State, Tribe, County—differs distinctly; the Tribe is focused on protecting the lake as its cultural heartland; IDEQ is attempting to meet its obligations under the CWA; and county government is focused on economic development and the protection of private property rights. The geographical and multi-jurisdictional settings in the region distinguish our work from other similar studies that primarily focused on lakefront properties (mostly vacation homes) in rural landscapes and lakes governed by unified or aligned entities.

3.2. Data

IDEQ and the Tribe provided data on the water quality of Coeur d'Alene Lake for the period 2010–2014. Consistent with previous investigations and for the ease of interpretation [3,14,30,33], water quality was proxied by Secchi depths collected during the summer months from 22 IDEQ monitoring stations throughout the lake. Milfoil data were obtained from a 2014 summary report published by Avista Corporation, which included a comprehensive survey of the occurrence of milfoil in Coeur d'Alene Lake from 2010 to 2014 [23]. The exact date when milfoil invaded is unknown [2]. By overlapping the locations of lakefront properties and the spatial distribution of milfoil invasions, a dummy variable was derived as a proxy of presence/absence of milfoil in the nearest bays (Figure 2).

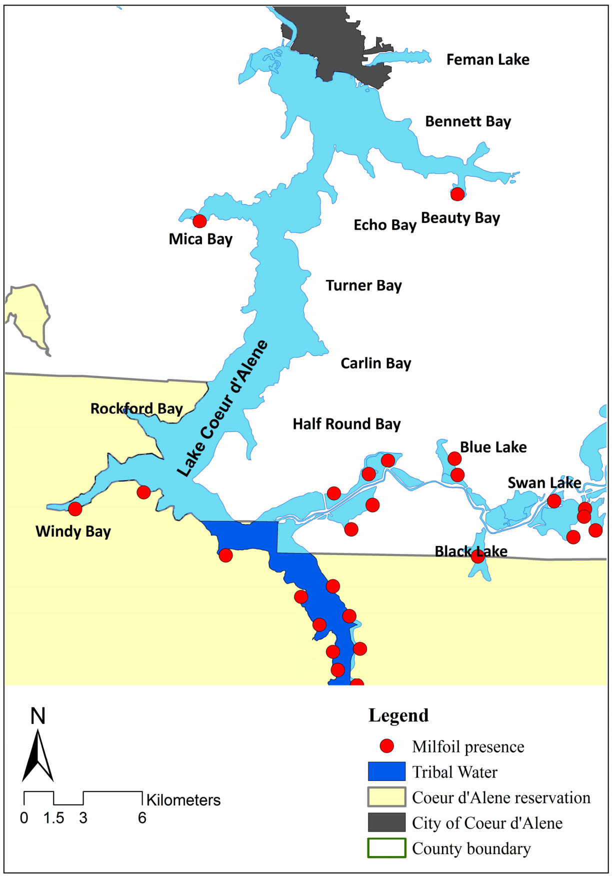

Figure 2. Milfoil occurrence in Coeur d'Alene Lake, ID, USA for the period 2010–2014.

We assessed the economic impacts of water quality and the presence of milfoil by comparing 614 lakefront property sale transactions of single-family houses during the period 2010–2014. Information on property sales and housing characteristics were gathered from transfer tax records held in the Kootenai County's Assessor's office. The data were geocoded and overlaid in ESRI ArcGIS 10.2.2 with shape files from the Assessor's office. Based on the Kootenai County Comprehensive Plan, lakefront properties were defined as properties within 152 m (500 ft) of Coeur d'Alene Lake that include lands directly adjacent to shorelines of the lake. The sale prices were deflated to 2010 dollars using the housing price index (purchase only) from the U.S. Federal Housing Finance Agency [38].

Data included detailed property information, such as historical sale prices, date of construction, sizes of the structure and parcel, and the number of bedrooms and bathrooms, *etc*. which are summarized in Table 1. The data used to describe the physical characteristics of the lakefront property included: a central air conditioning dummy (CENTRALAIR), number of bedrooms (BEDRM), number of full bathrooms (FULLBATH), number of half bathrooms (HALFBATH), the age of the house (HOMEAGE), and the total lot water frontage (LAKEFRONTAGE) (Table 1). Locational characteristics included: distance to downtown Coeur d'Alene (DIS2CBD), distance to nearest highway (Idaho State Highway #95 or Interstate 90; DISTHWY), and proximity to the superfund site (DIST2MINING). The mean housing price of lakefront properties was approximately $500,000, while the most expensive house costs almost $5 million dollars. Water quality records in Coeur d'Alene Lake indicate the mean value of lowest Secchi depth in summer months was approximately 6 m (20 ft) during the study period with a range of 4–9 m (13–29 ft), indicating evident variations of water quality or clarity across different bays. Milfoil was observed in proximity to 143 out of the 614 lakefront property sales.

Table 1. Description of variables and summary statistics for residential property sales around Coeur d'Alene Lake, Idaho during the period 2010–2014.

Name	Description	Mean	S.D.	Data Source
Water-quality characteristics and invasive species				
LNWQ	Ln (water clarity measured by Secchi disk depth, in meters)	1.86	0.25	IDEQ
MILFOIL	0,1 = presence of milfoil in the nearest bay	0.23	0.42	Avista
Spatial characteristics				
LNDISTCBD	Ln(distance to downtown, in meters)	10.23	0.65	KCG
LNDISTHWY	Ln(distance to nearest highway, in meters)	8.26	1.08	KCG
LNDISTMINING	Ln(distance to the historical mining district, or superfund site, in meters)	10.83	0.08	IDEQ
Property characteristics				
LNREALPR	Ln (assessed property values, in 2010 constant dollars)	12.91	0.65	KCG
LNLIVING	Ln (living area, in square feet)	2195	1,425	KCG
LNLOT	Ln (lot size, in acres)	1.62	4.94	KCG
BEDRM	Number of bedrooms	3	1.30	KCG
FULLBATH	Number of full bathrooms	2	1.16	KCG
HALFBATH	Number of half bathrooms	0.32	0.58	KCG
HOMEAGE	Home age (years)	40	25	KCG
CENTRALAIR	0,1 = central air conditioning	0.08	0.27	KCG
LAKEFRONTAGE	Total frontage on the lake, in feet	71.49	96.04	KCG

Note: KCG = Kootenai County Government; IDEQ = Idaho Department of Environmental Quality.

3.3. Model Specifications

Rosen (1974) developed a hedonic pricing model for product differentiation based on the assumption that goods, such as houses, are valued for their utility-bearing attributes or characteristics [39]. The hedonic model was extended to applications in ecosystem service valuation ranging from air quality, water pollution, and landscape aesthetics provided by public lands and water resources [40–43]. In the hedonic model, a house is seen as a bundle of characteristics of the goods, and the property value can be used to gauge the values of these environmental goods and services like amenities and dis-amenities that are commonly not priced independently in the market [44]. In this study, a semi-logarithmic functional form was used to estimate the hedonic price function expressed as:

$$Ln\ (SP_i) = \beta_0 + \beta_1\,(Milfoil_i) + \beta_2 ln\,(WQ_i) + r'\mathbf{X}_i + \delta_t\prime\mathbf{T}_{i,t} + \varepsilon_i \quad (1)$$

where $\boldsymbol{SP}_\mathbf{i}$ is the assessed price of the i^{th} property in 2010 dollars; $\beta_0, \beta_1, \beta_2, r'$, and δ'_t are fitted constants; $Milfoil_i$ is the value for the presence of milfoil; WQ_i is the log-transformed Secchi depth; $\mathbf{X}_i$ represents property and locational characteristics; and $\mathbf{T}_{i,t}$ refers to a set of time-series dummy variables. Secchi depth measurements were log transformed because people generally cannot perceive changes in water quality at deep compared to shallow depths [4,30]. To quantify the impacts of milfoil presence and ambient water quality on lakefront property values, separate hedonic models were estimated for the variables pertinent to the presence of milfoil and ambient water quality (Models 1 and 2 in Table 2), and then a combined regression model including both variables was run (Model 3 in Table 2).

We then used a spatial regime analysis method (Equations (2) and (3)) to further investigate the spatial heterogeneity of the effects of water-quality and milfoil presence on lakefront property values and to explore possible interactions between the two water-quality related variables and the above mentioned geographical and jurisdictional divisions of the Coeur d'Alene Lake [45]. In Equations (2) and (3), the north–south division and the distinction between tribal and non-tribal jurisdictions in Coeur d'Alene Lake (see Figure 2) provided two samples, which allowed coefficients of the two water-quality related variables, *i.e.*, $Milfoil_i$ and WQ_i , to vary across two different regimes (A and B): a regime of lakefront properties closer to the northern part of the lake that is administrated by IDEQ, and a regime of properties in proximity to the Coeur d'Alene reservation and tribal waters (Figure 2).

$$Ln\ (SP_i) = \beta_0 + \beta_{1A}\,(Milfoil_i) + \beta_{2A} ln\,(WQ_i) + r'\mathbf{X}_i + \delta_t\prime\mathbf{T}_{i,t} + \varepsilon_i\ \boldsymbol{i} \in \text{Regime A} \quad (2)$$

$$Ln\ (SP_i) = \beta_0 + \beta_{1B}\,(Milfoil_i) + \beta_{2B} ln\,(WQ_i) + r'\mathbf{X}_i + \delta'_t\mathbf{T}_{i,t} + \varepsilon_i\ \ \boldsymbol{i} \in \text{Regime B} \quad (3)$$

4. Results

Estimation results for base models with all explanatory variables included in Equation (1) are presented in Table 2. Akaike's Information Criterion (AIC) and Schwartz's Bayesian Information Criterion (BIC) statistics were employed to compare models' goodness-of-fit balanced with model parsimony. Coefficient estimates associated with the variables used to describe property characteristics (LNLIVING, LNLOT, FULLBATH, HALFBATH, and LAKEFRONTAGE) were significantly related to property values (Table 2). Coefficients of living area (LNLIVING), lot size (LNLOT), and numbers of full/half bath rooms (FULLBATH and HALFBATH) were significant and positive in all models. LAKEFRONTAGE coefficients indicated an evident price premium for more frontage on the lake, reflecting the unique structural attributes of lakefront properties; for a 3 m (10 ft) increase in lake-frontage, the property value can increase by approximately 3% (Table 2).

Table 2. Hedonic estimation results.

Variables	Model 1		Model 2		Model 3	
	Coef.	T-value	Coef.	T-value	Coef.	T-value
LNLIVING	0.279 ***	5.648	0.268 ***	5.469	0.276 ***	5.654
LNLOT	0.062 ***	3.580	0.062 ***	3.489	0.061 ***	3.495
CENTRALAIR	0.023	0.310	0.013	0.193	0.022	0.314
HOMEAGE	−0.001	−1.149	−0.001	−1.125	−0.001	−0.678
FULLBATH	0.065 ***	2.673	0.073 ***	2.957	0.070 ***	2.851
HALFBATH	0.127 ***	3.625	0.125 ***	3.562	0.128 ***	3.655
BEDROOMS	−0.008	−0.458	−0.003	−0.178	−0.005	−0.291
LAKEFRONTAGE	0.003 ***	13.282	0.003 ***	13.071	0.003 ***	12.973
LNDISTMINING	1.552 ***	5.747	1.353 ***	5.309	1.599 ***	5.951
LNDISTHWY	−0.130 ***	−0.854	−0.038	−1.516	−0.034	−1.358
LNDISTCBD	−0.024 ***	−3.206	−0.112 **	−2.550	−0.095 **	−2.143
LNWATER	0.275 ***	3.178			0.232 **	2.754
MILFOIL			−0.145 ***	−3.146	−0.119 **	−2.537
Year Dummy (reference: year of 2010)						
Year of 2011	−0.050	−0.792	−0.049	−0.776	−0.052	−0.827
Year of 2012	−0.029	−0.521	−0.031	−0.560	−0.028	−0.513
Year of 2013	−0.086	−1.523	−0.081	−1.425	−0.085	−1.511
Year of 2014	0.063	1.062	0.056	0.949	0.060	1.014
CONSTANT	−5.287	−1.718	−2.587	−0.938	−5.967	−1.987
AIC	721.523		721.730		715.964	
BIC	801.083		801.290		799.944	
Log likelihood	−342.280		−342.865		−338.982	
Adjusted R^2	0.567		0.567		0.572	
N. of observations	614		614		614	

Notes: * Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level. It should be noted that Ordinary Least Square (OLS) regression models could not control for spatially auto-correlated residuals that are prevalent in housing data which could bias coefficient estimates [14,46]. Thus, we also estimated a set of spatial hedonic pricing models using spatial econometric techniques (e.g., spatial filtering) [47] for which results (available upon request) showed that spatial dependence in the data was moderate (Moran's *I* test for spatial autocorrelation in residuals generated values less than 0.09 in the three models). Therefore, applying advanced spatial econometrics was unnecessary in this study.

The sign of the coefficient estimates for the distance to downtown Coeur d'Alene was negative and significant, implying that a 10% decrease in distance from the downtown or central business district (CBD) can increase property value by 1%. In addition, with an increase in distance from the historical mining area (Bunker Hill) Superfund site of 10%, we may expect to see a 16% increase in the property value (Table 2). As noted above, the lake is part of the Bunker Hill Superfund site, and other research has shown that living near mining districts within a Superfund site is deemed undesirable because of potential environmental hazards [37]. All year dummy variables were insignificant, which was unexpected given the fluctuations of housing prices during the study period (2010–2014). However, the negative coefficient for the dummy variables in 2011, 2012, and 2013, and the positive coefficient in 2014 might likely indicated the influence of economic swings during this period (Table 2).

The water quality coefficient (proxied by Secchi depth) was positive and significant (Model 1 in Table 2). This indicates that a 10% increase in Secchi depth can increase the lakefront property value by 2.2%. The milfoil dummy variable yielded significant negative coefficients (Model 2 in Table 2), indicating property value reduction of approximately 12.6%, which could be attributable to the presence of milfoil. These results empirically support the hypothesis that the presence of milfoil can significantly affect home buyers' willingness to pay, as milfoil infestation could easily be observed by potential market participants when visiting lakefront parcels.

As shown in Table 3, several interesting findings emerged from the spatial regime analysis. First, AIC and BIC statistics suggested that models with the two spatial regimes were statistically superior to models without spatial regimes, but coefficient estimation with respect to locational and structural characteristics of lakefront properties was largely consistent with the results of OLS models (Tables 2 and 3). Second, the effects of water-quality and milfoil presence exhibited spatial heterogeneities, referring to the spatial variations in their associations with property values (Table 3). The association between Secchi depth and lakefront property values was generally less sensitive to the north (IDEQ)–south (tribal water) division of the Lake, although the coefficient of Secchi depth was marginally significant in the model dedicated to the lakefront properties close to the tribal waters in the southern part of the Lake. The magnitudes of the two coefficients regarding Secchi depth suggest possible confounding effects of better access to urban amenities provided by the city center in the north and water-quality improvement (Table 3). Third, the association between the presence of milfoil and lakefront property values was confined to the southern part of the lake (Table 3). However, milfoil can propagate rapidly once established [48], primarily through fragmentation, but also sexual means [49], and could easily be spread by trailered boats and boating equipment [7,50] to other parts of the lake, especially the north [23]. This would result in significant economic loss with respect to lakefront property values in the future.

Table 3. Spatial-regime hedonic estimation results.

Variables	**Model 1**		**Model 2**		**Model 3**	
	Coef.	T-value	Coef.	T-value	Coef.	T-value
LNLIVING	0.284 ***	5.788	0.271 ***	5.517	0.280 ***	5.731
LNLOT	0.059 ***	3.324	0.057 ***	3.156	0.059 **	3.297
CENTRALAIR	0.025	0.355	0.018	0.262	0.023	0.326
HOMEAGE	−0.001	−0.914	−0.001	−1.110	−0.001	−0.624
FULLBATH	0.067 ***	2.743	0.074 ***	2.999	0.070 **	2.864
HALFBATH	0.128 ***	3.644	0.122 ***	3.468	0.129 ***	3.66
BEDROOMS	−0.008	−0.428	−0.004	−0.225	−0.006	−0.302
LAKEFRONTAGE	0.003 ***	12.555	0.003 ***	12.764	0.003 ***	12.449
LNDISTMINING	1.977 ***	6.027	1.350 ***	5.301	1.925 ***	5.485
LNDISTHWY	−0.038	−1.487	−0.038	−1.516	−0.042 *	−1.668
LNDISTCBD	−0.087 *	−1.875	−0.101 **	−2.244	−0.069	−1.465
LNWATER (northern lake, near non-tribal waters)	0.220 ***	2.624			0.223 ***	2.596
LNWATER (southern lake, near tribal waters)	0.165 *	1.755			0.166 *	1.758
Milfoil (northern lake, near non-tribal waters)			−0.082	−0.942	−0.115	−1.286
Milfoil (southern lake, near tribal waters)			−0.140 **	−2.574	−0.095	−1.555
Year Dummy (reference: year of 2010)						
Year of 2011	−0.047	−0.753	−0.050	−0.798	−0.049	−0.788
Year of 2012	−0.021	−0.370	−0.026	−0.470	−0.023	−0.409
Year of 2013	−0.078	−1.378	−0.078	−1.380	−0.080	−1.406
Year of 2014	0.068	1.147	0.058	0.973	0.064	1.082
CONSTANT	−10.150 **	−2.748	−2.693	−0.977	−9.669 *	−2.46
AIC	711.74		714.22		713.71	
BIC	791.30		793.78		797.69	
Log likelihood	−337.87		−339.110		−337.857	
Adjusted R^2	0.574		0.573		0.574	
N. of observations	614		614		614	

Notes: * Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.

The econometric results demonstrate the positive association between water quality and property values (Table 2). These modeling results were used to further estimate the implication value or marginal willingness to pay (MWTP) of increased water quality and the aggregated benefits for all lakefront properties surrounding Coeur d'Alene Lake. Table 4 reports the property-value impacts from lake water quality in dollar terms, based on the coefficient estimates for the non-linear specification of the water quality variable (Model 3 in Table 2). Marginal values were computed, using the mean property values, for each of the five increments on Secchi depth (*i.e.*, 4 → 5, 5 → 6, 6 → 7, 7 → 8, 8 → 9). Marginal prices for increases in Secchi depth (a proxy of water quality) ranged from $14,127 to $27,096, corresponding to percentage increases in property values from 2.77% to 5.97% (Table 4).

Table 4. Interpretation of coefficients for all lakefront properties.

Water-Quality Related Attributes	% Change at Mean Property Values	Marginal Implicit Price (in 2010 Constant Dollars)
Secchi depth (1 meter increase)		
4 meters → 5 meters	5.31%	$27,096
5 meters → 6 meters	4.32%	$22,033
6 meters → 7 meters	3.64%	$18,568
7 meters → 8 meters	3.15%	$16,406
8 meters → 9 meters	2.77%	$14,127
Invasive species		
Milfoil (presence->no presence)	12.60%	$64,255

Notes: mean property value = $509,962; these results are calculated based on Model 3 presented in Table 2.

Marginal implicit prices were also estimated using mean lakefront property value for the presence of milfoil which revealed that the average lakefront property located along the shoreline in proximity to milfoil would sell for $64,255 less than one located along a shoreline without milfoil, all else being equal.

5. Conclusions and Implications

Despite the long and continued effort to regulate and control pollution from point and nonpoint sources via the CWA and expenditures to control the infestation and spread of aquatic invasive species, issues related to water quality and lake ecosystems remain an important public concern in the U.S. Our research quantified the association among water quality (as proxied by Secchi depth), an aquatic invasive plant species (milfoil), and lakefront property values in the Coeur d'Alene region of northern Idaho. In general, our results demonstrate a positive association between water quality and lakefront property values, which could be used to incentivize private property owners to contribute to programs that maintain high water quality in the lake. Our study also suggests that the amenity value of the water body with respect to property value can diminish by approximately 13% with the presence of milfoil. This result corroborates recent public survey and opinion polls in the Coeur d'Alene area that indicate residents are concerned about the invasion of milfoil [23]. By taking into account the geographical and jurisdictional settings in the region, the results of spatial regime analysis further revealed the geographical variations of the economic impacts of ambient water quality and the presence of milfoil on lakefront properties (Table 3).

The study has specific implications for management strategies in Coeur d'Alene Lake and other lakes facing rapid amenity-driven lakefront development and, at the same time, potential environmental degradation. First, declining water quality and increased invasion of aquatic plants may result in a decrease in lakefront property values. Thus, it is critical that the economic benefits of maintaining high water quality be included in land-use planning decisions and stakeholder engagement. For instance, the funds committed to the removal of milfoil in the more infested Tribal waters in the southern third of the lake is about $140 thousand each year [51]. Failure to control milfoil in Tribal waters may speed spread to non-Tribal waters closer to the urban center. Our study indicates that the total reduction of lakefront property values due to the possible spread of milfoil infestation into the northern part of the lake could amount to $257 thousand annually (using a 5% discount rate). Hence, our study may help the efforts to protect water quality and prevent the potential spread of milfoil be funded and supported by owners of private lakefront properties. Second, given the unique jurisdictional framework in Coeur d'Alene Lake, the effort to protect water quality and sustain the Coeur d'Alene Lake ecosystem needs to holistically integrate land-use policy, natural resource management, and interests of multiple stakeholders, including the IDEQ, the Tribe, the county government and lakefront property owners.

Lastly, the research could be further improved in several aspects. First, the milfoil dataset we used did not have information about a 'severity' of invasion. Incorporating more detailed information about the infestation of milfoil could help better understand economic impacts of invasive aquatic species and potential changes in water quality associated with them [4]. Second, the presence of milfoil concentrates in the southern part of the study area, which overlaps with shallower water depth, and previous studies found that milfoil is most successful in shallow waters [52]. Thus, the potential economic impacts of milfoil invasions could be overestimated, as deeper water in the northern lake may preclude milfoil establishment. Future hedonic analyses could include physical limnology interaction terms to guard against potential spurious correlations related to lake morphometry and water depths. Furthermore, studies have found that the presence of milfoil or other submerged vegetation or seagrass actually increase water clarity by physically baffling and reducing water velocity, which enhances depositions of particles and increases the flux of suspended sediment from the water column to the benthos [53,54]. Unfortunately, water-clarity or quality data used in this research were gathered from monitoring stations in the centers of lakes or bays, while milfoil surveys were focused on nearshore areas. Potential interactions between milfoil invasion and water clarity deserves more nuanced investigations when data appropriate for such an analysis becomes available. Third, additional research is needed to advance our understanding about how water quality-related issues may potentially associate with non-lakefront property values, and economic development in the region as a whole [31].

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