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Meta-Analysis of Wetland Valuation Studies in North America: Modeling Dependencies of Welfare Estimates across Space

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ABSTRACT

The primary purpose of this paper is to incorporate spatial econometric methods in a meta-regression analysis framework by investigating the spatial dependence among meta-data using simple spatial relationships. Comprehensive wetland valuation meta-data for North America forms the basis for spatial econometric modeling in the meta-analysis framework. Spatial dependencies among the data are identified by constructing different spatial weight matrices representing geographic proximity, wetland similarity, and economic similarity of studied wetland sites. In addition, this paper implements a bootstrap procedure to examine the robustness of spatial correlation by controlling for dependencies associated with multiple measures for the same wetland. Empirical results show that positive spatial correlation exists in wetland values for all three types of spatial neighborhood criteria, with the threshold distance defined correlation to be strongest, followed by ecological similarity and economic similarity. Sensitivity analysis on the threshold distance based models suggests that spatial correlation exists for wetlands as far as 150km away from each other. The threshold distance defined spatial dependence remains robust when controlling for intra-study dependence.

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Introduction

Wetland ecosystems, including rivers, lakes, marshes, and coastal areas, provide a range of services that contribute to ecosystem functioning and human well-being (Barbier et al. 1997). Since the 1970s, the ecological and social importance of wetlands to ecosystem and human health has increased as evidenced by the adoption of regulations to limit wetland losses and the amount of scientific research of them. A significant and growing body of research is the use of economic methods to derive empirical estimates of ecosystem services provided by a range of wetlands.

Despite the increasing amount of literature on economic valuation of environmental and natural resources, limited attempts have been found to explore the spatial dependence and spatial heterogeneity of value estimates, including wetland valuation. Wetlands are complex ecosystems that are not isolated from each other. The underlying ecosystem linkages between wetlands strongly determine the types of ecosystem functions they perform, and thus determine their ecological value. In addition, the welfare estimate of a wetland does not only depend on its ecological value, but also on linkages to local people and how they value wetland ecosystem services and environmental assets in general. Ignoring the spatial heterogeneity and spatial correlation of wetland welfare estimates to each other and to people could lead to biased and / or inefficient estimates of wetland values and increased error in benefit transfer.

Several economic valuation studies estimated values for wetlands in urban and rural settings, while other studies evaluated whether people residing in these different areas value wetland resources similarly. Mahan, Polasky, and Adams (2000) estimated the value of wetland amenities in the Portland metropolitan area using a hedonic price model. They found that the proximity to a wetland and the size of the nearest wetland is associated with increased residential values. Boyer and Polasky (2004) reviewed 30 papers on valuing urban wetlands, with a focus on urban wetlands. They found that wetlands carry many positive values for the ecosystem services they provide, and that a wide range in value estimates are provided depending on wetland attributes (e.g., type and size) and valuation methodology. A few hedonic studies (Doss and Taff 1996; Lupi, Graham-Tomasi, and Taff 1991; Mahan, Polasky and Adams 2000) in their review show that urban wetlands are more highly valued by nearby property owners than their rural counterparts. Bin and Polasky's (2004) comparison of wetland valuation studies showed that proximity to and larger wetlands are associated with reduced property values in rural locations, regardless of wetland type.

The accumulation of empirical estimates of wetland values enabled the application of meta-regression analysis (MRA) to synthesize this growing body of literature. A consistent motivation of MRA to wetland values is to explore the variations in empirical findings through econometric modeling of valuation methods, wetland characteristics, and study context, among other identifiable attributes. Initial wetland valuation MRAs accounted for spatial heterogeneity using coarse, simple identifiers of wetland location and size. Focusing solely on contingent valuation studies, Brouwer et al. (1999) was the first MRA of wetland valuation studies. Their meta-data consisted of 103 estimates from 30 valuations studies in North America and Europe. A statistically significant and positive dummy variable indicates that North American studies result in larger value estimates, ceteris paribus. Woodward and Wui (2001) conducted an MRA consisting of 65 estimates from 39 valuations studies in North America, Europe and Asia. The effect of acreage of the studied wetland was controlled in addition to study methodology, publication characteristics, and wetland ecosystem services valued. They found that the marginal value per acre of wetland statistically significantly declined with increased wetland size, ceteris paribus.

More recently, MRAs of wetland values evaluated the spatial heterogeneity of wetland value estimates by augmenting the meta-data with spatially-defined site specific variables in their analysis. Augmentation of meta-data improves MRAs by incorporating measures of study context that are constant within an individual study, but accounts for variations in results across studies (Moeltner et al. 2009). Brander et al. (2006) conducted a comprehensive MRA on 190 wetland valuation studies worldwide producing 215 value estimates. They augmented their meta-data with spatially defined geographic and socio-economic variables, including GDP, population density, wetland size, latitude and longitude, and a categorical variable indicating the continent where the wetland is located. They found that GDP per capita and population density surrounding wetland study sites were significantly associated with increases in marginal values per hectare, whereas wetland density in the surrounding area was significantly associated with decreases in marginal values per hectare, ceteris paribus. Latitude and longitude of wetlands were insignificant in their model. Ghermandi et al. (2010) conducted an MRA using 416 estimates from 170 valuation studies for wetland values worldwide with an emphasis on the value of constructed wetlands. Augmentations to their meta-data included a wetland substitution factor (wetland and lake areas within 50 km radius of the study area), GDP per capita, population density in 50km radius, and anthropogenic pressure measured as a composite index of hydrology type, protection status, and urban or rural setting. Similar to Brander et al. (2006), they found GDP per capita and population density to be significantly positively associated with wetland values and wetland density to be negatively associated with wetland values, although this latter measure was not robust to model specifications. Increases in anthropogenic pressures were significantly associated with increases in wetland values, ceteris paribus.

These MRAs encompass a large number of observations from a wide range of geographic areas and have augmented their data with spatially-defined variables to control for spatial heterogeneity among the meta-data. However, they have not attempted to measure any spatial relationship among the data through the use of spatial econometric models that explicitly model the spatial dependence of wetland welfare estimates. Ignoring spatial dependence among the meta-data may lead to biased and / or inefficient parameter estimates, leading to incorrect inferences from the data.

The primary purpose of this paper is to incorporate spatial econometric methods in a meta-regression analysis framework by investigating the spatial dependence among meta-data using simple spatial relationships. Comprehensive wetland valuation meta-data for North America forms the basis for spatial econometric modeling in the meta-analysis framework. Spatial dependencies among the data are identified by constructing different spatial weight matrices representing geographic proximity, wetland similarity, and economic similarity of studied wetland sites. In addition, this paper implements a bootstrap procedure to examine the robustness of spatial correlation by controlling for dependencies associated with multiple measures for the same wetland.

Spatial econometric meta-regression analysis model

Meta-regression analysis (MRA) is a statistical summary and synthesis of a body of research outcomes typically using multivariate regression-based methods. MRA was introduced to the economic toolbox by Stanley and Jarrell (1989) with an update by Stanley (2001). The first two MRAs on environmental and natural resource economic valuation literatures were by Smith and Kaoru (1990) on travel cost studies of recreation benefits and by Walsh et al. (1989, 1992) on outdoor recreation benefit studies. Since then, MRA has become a rapidly expanding method—Nelson and Kennedy (2009) identify and evaluate over 130 distinct applications of MRA in environmental economics, with the majority conducted since 2003.

The basic MRA model begins with relating the variation in the dependent variable $\boldsymbol{Y}$ (in this case modeled as a standardized wetland welfare estimate per hectare in 2010 USD) with independent or explanatory variables $\boldsymbol{X}$ using Ordinary Least Squares. The independent variables contained in $\boldsymbol{X}$ may include indicators or measures of valuation methods, wetland types and attributes, ecosystem services, and context variables such as wetland density, population density, accessibility, and other definable characteristics.

$$\boldsymbol{Y} = \boldsymbol{X\beta} + \varepsilon \qquad \text{(Equation 1)}$$

The β's are the regression coefficients to be estimated and $\varepsilon \sim N(0,\sigma^2)$ is the i.i.d. regression error.

Some of the research outcomes in a literature may be systematically related to each other based on their similar contexts; e.g., two wetland study outcomes may be related to each other through sharing a context within a watershed. Locational aspects may lead to two types of statistical problems: 1) spatial heterogeneity among the data; and 2) spatial dependence in the data (Anselin 1988). Spatial heterogeneity has been modeled in wetland valuation MRAs, as previously noted, by augmenting meta-data with spatially-defined characteristics of study site contexts. Spatial dependence emerges when there is correlation among the dependent variable (i.e., spatial lag) or among the errors (i.e., spatial error), both of which violate basic assumptions of uncorrelated variables and errors leading to biased, inconsistent and / or inefficient coefficient estimates $\boldsymbol{\beta}$.

Both forms of spatial dependence are modeled in the generic spatial autoregressive model:

$$\boldsymbol{Y} = \rho \boldsymbol{W_1 Y} + \boldsymbol{X\beta} + \varepsilon; \text{ and } \varepsilon = \lambda \boldsymbol{W_2}\varepsilon + \mu \qquad \text{(Equation 2)}$$

where $\mathbf{Y}$, $\mathbf{X}$ and $\boldsymbol{\beta}$ are defined in the same way as they are in the OLS model; $\mathbf{W}$ is the weight matrix; ρ is the spatial lag (or spatial autoregressive) parameter; λ is the spatial error parameter, and $\varepsilon \sim N(0,\sigma^2)$ is the i.i.d error term with no spatial error, or $\mu \sim$

$N(0,\sigma^2)$ is the i.i.d. error term in the presence of spatial error in ε. The weight matrices $\boldsymbol{W}_1$, $\boldsymbol{W}_2$ in the generic spatial model may represent the same or different spatial relationships (Anselin et al. 1996).

The generic spatial model is a good way to conceptually model and illustrate the two primary forms of spatial dependence, although it is typically unnecessary for valid specification modeling of spatially dependent data (Anselin 2005). After testing the spatial model specification using Lagrange Multiplier statistics, the spatial lag form fit the data the best. The spatial lag econometric model is stated as

$$\boldsymbol{Y} = \rho \boldsymbol{W}\boldsymbol{Y} + \boldsymbol{X}\boldsymbol{\beta} + \varepsilon \qquad \text{(Equation 3)}$$

where **Y**, **X**, $\boldsymbol{\beta}$, and ε are defined in the same way as they are in the OLS model; $\boldsymbol{W}$ is the weight matrix; and ρ is the spatial lag (or spatial autoregressive) parameter (Anselin 1988, 2003). The predicted variable, i.e. the standardized wetland welfare estimate, is defined as

$$\widehat{\boldsymbol{Y}} = (\boldsymbol{I} - \rho \boldsymbol{W})^{-1}\boldsymbol{X}\widehat{\boldsymbol{\beta}} \qquad \text{(Equation 4)}$$

where $\widehat{\boldsymbol{Y}}$ is the predicted standardized wetland value, $\boldsymbol{I}$ is an identity matrix, and $\widehat{\boldsymbol{\beta}}$ is the estimated coefficients through the spatial lag model. The $(\boldsymbol{I} - \rho \boldsymbol{W})^{-1}$ term is the spatial multiplier (Anselin 2005).

To model the spatial relationships of the wetland sites, three types of spatial weight matrices are constructed to represent how wetlands are neighbors with each other under different spatial neighborhood definitions. More specifically, the weight matrices employed model spatial relationships among geographically proximal sites, ecologically similar sites, and economically similar sites. Define an N x N spatial weight matrix **C**, where N is the total number of spatial entities. Each spatial weight element c_{ij} reflects the spatial influence of location j on location i, and

$$c_{ij} = \begin{cases} 1 \ if \ location \ i \ and \ j \ are \ neighbors \\ 0 \ if \ otherwise \end{cases}$$

All diagonal elements c_{ii} are set to zero to exclude self-influence. The matrix $\boldsymbol{C}$ is row standardized into matrix $\boldsymbol{W}$, where $w_{ij} = \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}}$.

The first type of weight matrix is threshold distance based. The centroids of each wetland site are used to calculate the Euclidean distance. Any two wetlands are considered as neighbors if the centroid-to-centroid distance is within a specified threshold. Multiple threshold distance matrices are constructed and tested. Threshold development began with a 50 km threshold with sensitivity analysis of incremental increases in the threshold distance to evaluate the extent of the spatial distance linkage. The economic similarity of two observations (wetland locations) is measured by the Euclidean distance (not in geographic but in mathematical sense) between two p- dimensional observations $\boldsymbol{X}' = [x_1, x_2, \dots, x_p]$ and $\boldsymbol{Y}' = [y_1, y_2, \dots, y_p]$, where p is the number of variables to characterize each observation (Johnson and Wichern 2001). The Euclidean distance between two observations is calculated as

$$
\begin{aligned}
d(\boldsymbol{X}, \boldsymbol{Y}) &= \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2 + \cdots + (x_p - y_p)^2} \\
&= \sqrt{(\boldsymbol{X} - \boldsymbol{Y})'(\boldsymbol{X} - \boldsymbol{Y})} \qquad \text{(Equation 5)}
\end{aligned}
$$

The second type of weight matrix characterizes the ecological similarity of wetland sites. Wetlands are complex ecosystems, yet ecological similarity may be simply modeled. Wetland ecological functions may be grouped broadly as habitat, hydrologic, or water quality (Novitski et al. 1996). The hydrology of a wetland determines what functions it will perform. Each wetland is unique, but those with similar hydrologic settings generally perform similar functions (Carter 1996). The geographic location of a wetland also may determine its habitat functions, and the location of a wetland within a watershed may determine its hydrologic or water-quality functions.

Wetland neighbors with ecological similarity are defined through hydrologic watershed boundaries. Two wetlands are defined as neighbors if they are located in the same watershed region. The Hydrologic Unit Digit 2 (HUC2) boundary is used to classify the wetlands in the meta-data. The HUC2 boundaries are defined by the US Geologic Survey[3]. According to the USGS hydrologic definition, the United States is divided and subdivided into different HUC units based on surface hydrologic features. The HUC2 unit, which is also the first level of the classification, divides the entire US into 21 regions (Figure 1). The next level of classification further divides the entire country into 221 sub-regions. The HUC2 is selected to group the wetlands given it is the only suitable HUC level that is big enough to not divide the area of any

[3] The HUC2 boundary data was derived from the United States Geological Survey, Hydrologic Unit Maps. http://water.usgs.gov/GIS/huc.html. Access date: 12.05.2012.

wetland in the meta-data. The HUC2 boundary data is downloaded from USDA National Resource Conservation Service spatial data warehouse (ftp://ftp.ftw.nrcs.usda.gov/pub/wbd/. Access date: Dec. 5th, 2012). The Canadian wetland sites are grouped using the Canadian hydrologic boundary GIS data defined as drainage basins. The spatial data including wetland shapes and locations and watershed boundaries are processed in ArcGIS to classify each wetland site into different watershed groups.

[*Insert Figure 1 here*]

The third type of weight matrix classifies wetland sites according to their socio-economic characteristics. Wetland sites located in areas with similar socio-economic characteristics may have correlated welfare estimates if latent factors that define how people value resources are a function of their socio-economic characteristics. Liu and Wang (2009) estimated a spatial econometric model on housing returns near cities in the US. They used an economic similarity weight matrix defined by the Pearson's Correlation of local GDP. In this study, economic similarity is defined based on four socio-economic factors associated with each wetland site: the county level average personal income, county level education attainment, the population size within 50km radius in the wetland study area, and the state level GDP of the wetland study area. Multivariate regression analysis and bivariate analyses are conducted to confirm the relationship between the wetland welfare estimates and each economic variable. Multivariate hierarchical clustering analysis incorporating these four factors is used to group the wetland sites.

The multivariate clustering analysis is a well-established statistical method to group observations into clusters that have similar values of measured variables.Hierarchical clustering with complete linkage is illustrated in Figure 2, known as a dendrogram. The dendrogram displays the mergers at successive levels according to the similarities of wetland sites (Johnson and Wichern 2001). The wetland sites are classified into 40 groups. Wetland sites that are classified into the same group are defined as neighbors. Note that the neighbors defined in this criterion are not necessarily the neighbors in a geographic sense. For example, Point Pelee and Long Point Marsh in Ontario, Canada are considered neighbors according to the economic similarity criterion. They are geographically close to each other as well, and both are located on the north shore of Lake Erie. However, the Terrebonne parish, a coastal wetland in Louisiana is also considered to be one of their economically similar neighbors, which is geographically very distant from the two wetland sites in Ontario.

[*Insert Figure 2 here*]

Spatial econometric model and specification tests

The econometric model estimates the measured wetland value per hectare as a function of the economic valuation methodology used, the ecosystem characteristics of the wetland, ecosystem services provided, and other context variables describing demographic, socio-economic and geographic characteristics for the wetland site.

More specifically,

$$ln(y_i) = \rho * \sum_{j=1}^{n} w_{ij} * ln(y_i) + \alpha_i + \beta_{1i} * x_{Mi} + \beta_{2i} * x_{Ei} + \sum_{k1} \beta_{3i} * x_{Fi} + \sum_{k2} \beta_{4i} * x_{Ci} + \varepsilon_i$$

(Equation 6)

where the independent variable $ln(y_i)$ is the standardized wetland monetary value estimates in natural log scale; α is the constant term; ρ is the spatial autoregressive parameter; w_{ij} is the $(i,j)^{th}$ element of the n x n weight matrix $\boldsymbol{W}$; x_{Mi} is the categorical variable indicating the economic valuation methodology used to obtain the wetland value; x_{Ei} is the categorical variable indicating the primary wetland type defined by the Cowardin System for wetland i; x_{Fi} is an indicator variable for one of the $k_1 = 9$ wetland ecosystem services valued; and $x_{Ci}$is a site specific context variable. In our model, there are $k_2 = 5$ context variables, including wetland area, accessibility, county level population, county level education, and wetland abundance in the nearby area.

Three groups of spatial econometric models with different weight matrices are estimated and compared to the OLS model. The significance of the spatial effect is tested for each econometric model using a log-likelihood ratio (LLR) test. Define the spatial lag model as the unrestricted model and the OLS model as the restricted model, which does not have the spatial lagged component $\rho\boldsymbol{WY}$. An LLR test compares the two models through

$$LLR = -2ln\left(\frac{l_U}{l_R}\right) = -2(L_U - L_R)$$ (Equation 7)

where L_U and L_R are the log-likelihood of the unrestricted and restricted model, respectively. The test statistic is asymptotically chi-squared distributed. A significant likelihood ratio test statistic indicates that the unrestricted model fits better than the restricted model. In other words, a significant LLR test indicates significant spatial dependencies of wetland value estimates defined by a specific spatial neighborhood criterion.

All analysis steps including the construction of spatial weight matrices, the multivariate clustering analysis, the spatial econometric analysis and specification tests are performed in the R software. The library *spdep* written by Bivand et al. (2014) was implemented for the spatial econometric analysis.

Data

Wetland values used in the analyses of this study are obtained from primary valuation studies that reported wetland welfare measures derived from wetland ecosystem services. These primary valuation studies reported welfare measures estimated from a variety of valuation methods, including stated preference (Contingent Valuation and Choice Experiment models), revealed preference (Travel Cost and Hedonic Price models), and non-utility theoretic based methods (Market Price, Replacement Cost and Production Function models).

The metadata are built upon previous datasets used in studies by Ghermandi et al. (2010) and Woodward and Wui (2001). The dataset was updated to publications until year 2011 through an in-depth search of literatures reporting an economic measure of wetland value in US and Canada following the MRA guidelines established in Stanley et al. (2013). The final meta-dataset used in the regression analyses has 163 observations collected from 67 empirical studies. The primary studies are comprised of journal articles, theses, dissertations, working papers, government agency reports, consulting reports, and proceeding papers. In addition, the dataset is augmented by incorporating external information of geographic, socio-economic and demographic characteristics in each of the primary study areas.

The dependent variable ln(y) is the log scaled wetland welfare estimate standardized to per hectare in 2010 US dollars. The relevant explanatory variables $\boldsymbol{X}$ are categorized into groups, including (1) study attributes and valuation methodology, (2) wetland ecosystem types and area for each type, (3) wetland ecosystem services valued, (4) geographic attributes such as wetland substitution effect and distance to the nearest city, and (5) socio-economic and demographic attributes such as personal income, population size and education level. Table 1 summarizes the variables included in the meta-analysis.

Using the wetland site specific information provided by primary studies as well as external sources such as the US National Wetland Inventory (NWI) and state level spatial databases, the location, size and shape of each wetland site was identified in geographic information system software, ArcGIS. The spatial information is used to identify the coordinate information for each wetland site, which is later used to construct different spatial weight matrices for spatial econometric analysis.

Socio-economic characteristics in the meta-data include information on the population size, personal income level and education level in the study area. Population size in the study area is characterized as the number of people residing within a 50 km radius of the wetland site.[4] Data are processed in ArcGIS, and the total population size in the 50km radius is calculated for each wetland site in the meta-data. The education level for observations in the US is evaluated as county level percentage of population over 25 years old that completed at least a bachelor's education or higher (averaged over 2005-2009). Education level for Canadian wetland sites is calculated as the percentage of total population aged 25 to 64 with at least a bachelor's degree or higher (averaged over 2009-2011).[5] The income level in the wetland study area is evaluated as the personal income in year 2010 in the county (counties) where the wetland is located.[6]

Spatial and geographic variables include the size of the wetland in hectares, the distance from the wetland site to the nearest urban center, wetland abundance in the nearby area and the protection level at the wetland site. The wetland size data are collected from primary studies. The distance to the nearest city is calculated in ArcGIS using the wetland

[4] Geospatial data is collected from the NASA Socioeconomic Data and Applications Center (SEDAC) hosted by CIESIN at Columbia University (http://sedac.ciesin.columbia.edu/data/sets/browse. Access date: 08.10.2012).
[5] Data for the US wetland sites are collected from the education attainment data from the US Census Bureau of the Department of Commerce (http://censtats.census.gov/cgi-bin/usac/usatable.pl. Access date: 08.16.2012). Data for Canadian wetland sites are collected from Statistics of Canada (http://www.statcan.gc.ca/pub/81-582-x/2012001/tbl/tbld6.3-eng.htm#n_8. Access date: 08.16.2012).
[6] Data for all US wetlands are collected from US Bureau of Economic Analysis of the Department of Commerce (http://www.bea.gov/iTable/iTable.cfm?ReqID=70&step=1&isuri=1&acrdn=4. Access date: 08.20.2012). Data for Canadian wetlands are collected from provincial governments. Specifically, these data are collected from the Ontario Ministry of Finance (http://www.fin.gov.on.ca/en/economy/ecupdates/factsheet.html. Access date: 08.20.2012), Bureau of Statistics in the Government of Saskatchewan (http://www.stats.gov.sk.ca/Default.aspx?DN=b2e511d6-2c66-4f7d-9461-69f4bffd3629. Access date: 08.20.2012), and the Government of Alberta (Alberta Government fact sheet. http://albertacanada.com/SP-EH_facts_on_Alberta.pdf. Access date: 08.20.2012).

location data and the US city center data.[7] Wetland abundance is characterized as total wetland area (in hectares) within 50km radius of the wetland study site. The data are calculated using the NWI wetland data and processed in ArcGIS using the buffer function. The wetland protection level is evaluated as whether a wetland is listed as internationally important by the RAMSAR convention.[8]

[*Insert Table 1 about Here*]

Econometric estimation results

Table 2 presents the econometric results using the three types of weight matrices, and compares them with the OLS model. The R-squared in the OLS model is 0.50. The value on the R-squared indicates a reasonable fitness of the OLS model. The decreased Akaike Information Criteria (AIC) and the highly significant likelihood ratio test statistics in all spatial lag models compared to the OLS model indicate that spatial models improve model fit.

The statistically significant likelihood ratio test statistics imply strong spatial spillover effects on wetland welfare estimates defined by these spatial neighborhood relationships. The spatial autoregressive parameter ρ is significant and positive in all spatial models, indicating significant and positive correlation in welfare estimates for wetland neighbors.

For the distance-based spatial models, sensitivity analysis was conducted by gradually increasing the threshold distance from 50 km to test for the extent of the distance effect. Significant spatial linkages in estimated wetland values were found for wetland sites within 150 km radius. The spatial autoregressive parameter ρ for the 50km, 100km and 150km models is 0.176, 0.143 and 0.138, respectively. The LLR test statistic is 17.280, 10.196 and 8.749 for 50km, 100km and 150km models, respectively. The significance level for the LLR test gradually decreases, and the p-value for the three distance models are <0.000, = 0.001 and =0.003, respectively. Note that the spatial autoregressive parameter ρ, the likelihood ratio test statistics and the significance level of the test statistic gradually decrease as the distance increases, meaning that the spatial dependence effect decays as the threshold distance increases,

[7] US City Center data is derived from the TIGER 2010 Urban Area shapefile published by US Census Bureau (http://www.census.gov/cgi- bin/geo/shapefiles2010/layers.cgi. Access date: 08.22.2012).
[8] The RAMSAR site information was collected from the RAMSAR Convention searchable database (http://ramsar.wetlands.org/Database/Searchforsites/tabid/765/Default.aspx. Access date: 10.12.2012).

disappearing when the distance goes beyond 150km.

The HUC2 model has a highly significant spatial lag effect as well. The LLR test statistic is 8.70 and is significant at less than 1% level (p-value = 0.003). However, the spatial correlation is about as strong as that in the 150km threshold distance model. Comparing the three groups of spatial models, the economic similarity model has the least significant spatial effect. This is reflected in the magnitude of the spatial autoregressive parameter ρ (ρ = 0.095), the significance level of the LLR test (p-value = 0.036), and an AIC value = 722.80. This result suggests that the spatial dependence of wetland values based on geographic similarity (defined by distances and watershed boundaries) is more significant than the effect based on economic similarity, which is not a geographically-defined measure.

[*Insert Table 2 here*]

The estimates and the significance level for explanatory variables are consistent and robust to the different models. However, ignoring the spatial autoregressive effect, i.e. the $(\boldsymbol{I}-\rho\boldsymbol{W})^{-1}$ component, would lead to biased wetland welfare estimates. Consistent with Woodward and Wui (2001), most valuation methods variables are statistically significant, although none of them were significant in Ghermandi et al.'s (2010) full model based on a much broader wetland values database.

An Economic literature dummy variable is included in the model to test whether results published in refereed economics journals were different from other sources of study outcomes (e.g., theses, reports, etc.) (see Rosenberger and Johnston 2009 for an overview of publication dummy variable testing in MRAs). Wetland values published in the refereed economic journals provide significantly higher wetland value estimates than non-economic studies. Survey design, estimation modeling, and study quality are critical to obtaining accurate monetary estimates of wetland ecosystem services. It is possible that the significantly different estimates are due to these characteristics being required in order to publish in refereed journals.

Wetlands in the meta-dataset fall into one of the four categories: estuarine, palustrine, riverine and lacustrine. Similar to Ghermandi et al. (2010), these wetland categories are generally not significant in the MRA. However, riverine wetlands have statistically significantly higher values than the estuarine wetlands, and this result is robust to model specifications. The preservation, recreational, and amenity wetland ecosystem services variables are significant. This result is consistent with the Woodward and Wui (2001) study, but not the Ghermandi et al. (2010) study that found very few ecosystem services significant and robust to model specifications. The proxy for wetland protection using RAMSAR classification was not statistically significant in any of the estimated models.

The spatial heterogeneity related variables were generally significant and robust to model specification, consistent with Ghermandi et al.'s (2010) results. The wetland abundance within 50 km radius is significant in all models and is negatively related to the wetland value, indicating a significant economic substitution effect (Ghermandi et al. 2010). Population within 50 km radius and distance of wetland site to the nearest city are highly significant in all models, indicating that wetland values are a function of the size of the affected population or market area. This result illustrates the importance of determining the spatial scale or extent of the market for certain wetlands, especially when using the literature to perform benefit transfers (Johnston and Rosenberger 2010).

Education level has a significant and positive impact on the wetland value. Education and distance to city interaction is significant in all models, with a negative sign. A significant interaction term means that the effect of education level on wetland values depends on the distance to city, and vice versa. The more distant a wetland is from an urban center, the education level becomes more important for wetland values. Equivalently, as education level increases in the area, the distance of the wetland to city becomes less important in determining the value of the wetland.

Sensitivity Analysis

Meta-data often comprise a panel data structure—multiple observations (i.e., measures of the dependent variable) are provided in a single publication resulting in intra-study correlation (Bateman and Jones 2003; Rosenberger and Loomis 2000). These multiple observations may be for the same wetland site (e.g., testing different model specifications on the same dataset) or for different wetland sites (e.g., using the same primary data collection instrument for more than one wetland site). The wetland valuation meta-data consist of 163 observations derived from 80 wetland sites, where 39 studies report multiple observations ranging from two to 16 observations. Thus, the wetland metadata comprise a highly unbalanced panel dataset.

Intra-study dependence may amplify the measures of spatial autocorrelation among the data. Each observation has an element in the spatial weight matrix that is derived from a wetland site and its defined neighbors. Thus, the observations from the same wetland site have the same location coordinates, and therefore are defined as neighbors to each other. The greater the number of observations for a single wetland site results in a greater weight on its spatial dependence. In other words, a question might be asked whether the significant spatial spillover effect is caused by the dependence between different nearby wetland sites or by the intra-study dependence of multiple estimates for the same wetland site.

According to other meta-analyses and econometric literature, two major approaches are used to solve the unbalanced panel estimation issue—regression-based weighting scheme (Bateman and Jones 2003; Rosenberger and Loomis 2000) and the avoidance scheme (Hunter and Schmidt 2004; Vista and Rosenberger 2013). In this paper, panel data regressions are not applied; instead an avoidance approach is applied that enables isolation of spatial autocorrelation without intra-study dependence. Avoidance schemes essentially derive one observation for each panel to form a smaller dataset for estimation. The single value could be an average or median measurement for each panel (Bijmolt and Pieters 2001; Doucouliagos and Ulubasoglu 2008; Hunter and Schmidt 2004; Rosenthal 1991; Rosenthal and Rubin 1986) or through a random selection of one observation from each panel (Bijmolt and Pieters 2001; Lodish et al. 1995). Ghermandi et al. (2010) evaluated intra-study dependence on their wetland valuation metadata by comparing a parsimonious model that treated all observations as independent, a panel weighted model, and a randomly selected single estimate per study model. They found that the parsimonious model that treated all observations as independent performed equally well and consistently as models that incorporated approaches to intra-study dependence. Vista and Rosenberger (2013) evaluated intra-study dependence in North American fishing valuation metadata by comparing regression-based models and single value models. They found modest improvements in model performance when avoidance methods were used; however, there is a trade-off with loss of degrees of freedom. These two studies provide evidence that MRA's general results are robust to regression-based intra-study correlation models, thereby providing confidence in using an avoidance approach to isolate the effect of spatial autocorrelation when controlling for intra-study dependence.

To test the robustness of spatial autocorrelation when intra-study dependence is controlled, a bootstrap process that randomly draws one observation per study is developed. Specifically, the analysis is conducted by randomly drawing one sample from each wetland site, and then repeating the process 1000 times. Thus, 1000 datasets are generated where each dataset has a single observation for each wetland site. Spatial weight matrices are generated for each sample and spatial lag regressions are conducted. An LLR test of the spatial lag operator is estimated for each dataset and summarized for each spatial weight matrix model. The number of significant likelihood ratio tests out of 1000 spatial regressions is recorded for each spatial weight matrix defined model. A binomial test is conducted for the count of the significant LLR tests for each spatial weight matrix model.

The binomial test tells us whether spatial autocorrelation occurs by chance in 1000 samples. Define two categories of the LLR test results: significant and insignificant spatial lag parameters. The null hypothesis of the binomial test is that two categories are equally likely to occur. In other words, rejecting the binomial test means the spatial effect occurs not by chance and concludes that there is strong spatial dependency in wetland welfare estimates for the single value model. Table 3 summarizes the count of significant LLR tests and the binomial test results for each spatial weight matrix defined spatial model.

[*Insert Table 3 here*]

Results in Table 3 show that the threshold distance-based spatial lag parameters are highly significant, but declining as the threshold increases. For the 50 km threshold distance, 93% of the spatial lag parameters are significant at the 0.05 level or better and 98% significant at the 0.10 level or better. The percentages decline in the 100 km threshold distance model to 91% and 96%, respectively, and for the 150 km threshold distance model 75% and 87%, respectively. Thus, there is strong spatial dependence among geographically close wetland sites.

The spatial weight matrices based on ecological similarity and economic similarity are not robust to intra-study dependence. This is evidenced by failing to reject the null hypothesis in Table 3. In fact, at best these spatial lag parameters are significant in less than 10% of the random draws. These results suggest that the HUC 2 boundaries are too broad in the ecological similarity weight matrix resulting in weak neighborhood interactions. In contrast, the significance of economic similarity results in Table 2 is a function of multiple observations for wetland sites.

Conclusions

This paper integrates spatial econometric methods in a meta-regression analysis framework. Spatial dependencies among the metadata are identified by constructing three different spatial weight matrices representing geographic proximity (i.e., 50, 100, and 150 km threshold distances), ecological similarity (i.e., residing in the same HUC2 boundary), and economic similarity (i.e., cluster analysis of local population attributes). These models are applied to wetland valuation metadata for North America.

The spatial econometric output and specification test results show that positive spatial spillover effect exists in wetland values for all three types of spatial neighborhood criteria. The threshold distance defined relationship is the strongest and most significant of the spatial lag models estimated. Sensitivity analysis of the threshold distance shows that spatial dependencies among wetland values decrease as the threshold distance increases, and finally turns insignificant when wetlands are more than 150km away from each other.

The estimated direct effects of covariates in all models (i.e., OLS and spatial lag models) are robust to defined spatial relationships in both significance and magnitude. However, the indirect effects of covariates as they are filtered through the spatial lags of dependent variable are significant as evidence by the LLR tests. Thus, the total effect of covariates on wetland values is the sum of the direct and indirect effects. Relying on the OLS results without spatial autocorrelation would underestimate total effects (i.e., the spatial autoregressive parameters are positive in the models).

The paper further explores the spatial correlations between different wetland sites by removing the effect of multiple measures from the same wetland sites using a bootstrap procedure. After the potential within-site correlation is removed, results suggest that ecological and economic similar wetlands have inconclusive evidence of spatial correlation in estimated values. The threshold distance models stay robust—strong evidence of positive spatial correlation is found in all three threshold distance models.

Spatial modeling using meta-data faces certain limitations. First, wetland sites are predetermined by the meta-data. Therefore, there is little control on the spatial data in terms of their location, size and ecosystem types. For example, due to the heterogeneity of wetland sizes, the HUC2 is the only feasible hydrology boundary to define ecological neighbors. In addition, spatial modeling using meta-data can be lack of flexibility. In threshold distance based models, for example, identified wetland neighbors are few due to the sparse sampling in primary valuation studies of the population of wetland sites.

Future research is needed to explore whether spatial patterns found in this application are consistent across different valuation literatures, or conversely whether different spatial models such as Generalized Method of Moments (Conley 1999; Kelejian and Robinson 1997), geographically weighted regression (Fotheringham, Brunsdon, and Charlton 2002), and Bayesian spatial autoregressive models (LeSage 1997, 2000) result in similar outcomes for the wetland metadata. In addition, expanding the metadata internationally would further complicate the delineation of spatial dependency among the data. That is to say, when studies are beyond geographic thresholds, are ecological functions and economic markets sufficient for improving international transfers?

References

Anselin, L. 1988. *Spatial Econometrics: Methods and Models* . New York, NY: Springer Publishing. 284p.

Anselin, L. 2003. Spatial externalities, spatial multipliers, and spatial econometrics. *International Regional Science Review* 26(2): 153-166.

Anselin, L. (2005). *Spatial Regression Analysis in R–A Workbook*. Urbana, IL: University of Illinoi, Urbana-Champaign, Dept. of Agricultural and Consumer Economics, Spatial Analysis Laboratory. 84p..

Anselin, L., Bera, A., Florax, R., and Yoon, M. 1996. Simple diagnostic tests for spatial dependence. *Regional Science and Urban Economics* 26(1):77-104.

Barbier, E. B., Acreman, M., and Knowler, D. 1997. *Economic Valuation of Wetlands: A Guide for Policy Makers and Planners*. Gland, Switzerland: Ramsar Convention Bureau. 138p.

Bateman, I. J., and Jones, A. P. 2003. Contrasting conventional with multi-level modeling approaches to meta-analysis: Expectation consistency in U.K. woodland recreation values. *Land Economics* 79(2):235-258.

Bijmolt, T. H. A., and Pieters, R. G. M. 2001. Meta-analysis in marketing when studies contain multiple measurements. *Marketing Letters* 12(2):157-169.

Bin, O., and Polasky, S. 2004. Effects of flood hazards on property values: Evidence before and after Hurricane Floyd. *Land Economics* 80(4):490-500.

Bivand, R., Anselin, L., Berke, O., Bernat, A., Carvalho, M., Chun, Y., et al.. 2014. *spdep: Spatial Dependence: Weighting Schemes, Statistics and Models*. Version 0.5-74. URL: http://cran.r-project.org/web/packages/spdep/spdep.pdf..

Boyer, T., and Polasky, S. 2004. Valuing urban wetlands: A review of non-market valuation studies. *Wetlands* 24(4):744-755.

Brander, L. M., Florax, R. J. G. M., and Vermaat, J. E. 2006. The empirics of wetland valuation: A comprehensive summary and a meta-analysis of the literature. *Environmental and Resource Economics* 33(2):223-250.

Brouwer, R., Langford, I. H., Bateman, I. J., and Turner, R. 1999. A meta-analysis of wetland contingent valuation studies. *Regional Environmental Change* 1(1):47-57.

Carter, V. 1996. *Wetland Hydrology, Water Quality, and Associated Functions*. In Fretwell, J.D., Williams, J.S. and Redman, P.J. (compilers), 1996, *National Water Summary on Wetland* Resources, Water Supply Paper 2425.USGS Water Supply Paper 2425. Reston, VA: U.S. Geological Survey. Pp. 35-48.

Conley, T. G. 1999. GMM estimation with cross sectional dependence. *Journal of econometrics* 92(1):1-45.

Doss, C. R., and Taff, S. J. 1996. The influence of wetland type and wetland proximity on residential property values. *Journal of Agricultural and Resource Economics* 21(1):120-129.

Doucouliagos, H., and Ulubasoglu, M. A. 2008. Democracy and economic growth: A meta-analysis. *American Journal of Political Science* 52(1):61-83.

Fotheringham, A. S., Brunsdon, C., and Charlton, M. 2002. *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. Chichester, UK: Wiley. 284p.

Ghermandi, A., Van Den Bergh, J., Brander, L. M., de Groot, H. L. F., and Nunes, P. 2010. Values of natural and human-made wetlands: A meta-analysis. *Water Resources Research* 46(12):1-12.

Hunter, J., and Schmidt, F. 2004. *Methods of Meta-Analysis: Correcting Error and Bias in Research Findings.* Second Edition. Thousand Oaks, CA: Sage Publications. 582p.

Johnson, R. A., and Wichern, D. W. 2007. *Applied Multivariate Statistical Analysis*,5th Edition.: Englewood Cliffs, NJ: Prentice Hall. 800p.

Johnston, R. J., and Rosenberger, R. S. 2010. Methods, trends and controversies in contemporary benefit transfer. *Journal of Economic Surveys* 24(3):479-510.

Kelejian, H. H., and Robinson, D. P. 1997. Infrastructure productivity estimation and its underlying econometric specifications: A sensitivity analysis. *Papers in Regional Science* 76(1):115-131.

LeSage, J. P. 1997. Bayesian estimation of spatial autoregressive models. *International Regional Science Review* 20(1-2):113-129.

LeSage, J. P. 2000. Bayesian estimation of limited dependent variable spatial autoregressive models. *Geographical Analysis* 32(1):19-35.

Lodish, L. M., Abraham, M., Kalmenson, S., Livelsberger, J., Lubetkin, B., Richardson, B., and Stevens, M. E. 1995. How TV advertising works: A meta-analysis of 389 real world split cable TV advertising experiments. *Journal of Marketing Research* 32(2):125-139.

Lupi, F., Graham-Tomasi, T., and Taff, S. J. 1991. *A Hedonic Approach to Urban Wetland Valuation.* Staff Paper P91-8. St. Paul, MN: University of Minnesota, Dept. of Agricultural and Applied Economics. 29p.

Mahan, B. L., Polasky, S., and Adams, R. M. 2000. Valuing urban wetlands: A property price approach. *Land Economics* 76(1):100-113.

Moeltner, K., Johnston, R. J., Rosenberger, R. S., and Duke, J. M. 2009. Benefit transfer from multiple contingent experiments: A flexible two-step model combining individual choice data with community characteristics. *American Journal of Agricultural Economics* 91(5):1335-1342.

Nelson, J. P. and Kennedy, P. E. 2009. The use (and abuse) of meta-analysis in environmental and resource economics: An assessment. *Environmental and Resource Economics* 42(3):345-377.

Novitski, R., Smith, R. D., Fretwell, J. D., Fretwell, J., Williams, J., and Redman, P. 1996. *Wetland Functions, Values, and Assessment.* In Fretwell, J.D., Williams, J.S. and Redman, P.J. (compilers), 1996, *National Water Summary on Wetland* Resources, Water Supply Paper 2425. Reston, VA: U.S. Geological Survey. Pp. 79-86.

Rosenberger, R. S., and Johnston, R. J. 2009. Selection effects in meta-analysis and benefit transfer: Avoiding unintended consequences. *Land Economics* 85(3):410-428.

Rosenberger, R. S., and Loomis, J. B. 2000. Panel stratification in meta-analysis of economic studies: An investigation of its effects in the recreation valuation literature. *Journal of Agricultural and Applied Economics* 32(3):459-470.

Rosenthal, R. 1991. *Meta-analytic Procedures for Social Research*. Revised Edition. Newbury Park, CA: Sage Publications. 155p.

Rosenthal, R., and Rubin, D. B. 1986. Meta-analytic procedures for combining studies with multiple effect sizes. *Psychology Bulletin* 99(3):400-406.

Smith, V. K. and Kaoru, Y. 1990. Signals or noise? Explaining the variation in recreation benefit estimates. *American Journal of Agricultural Economics* 72(2)::419-433.

Stanley, T. D. 2001. Wheat from chaff: Meta-analysis as quantitative literature review. *Journal of Economic Perspectives* 15(3):131-150.

Stanley, T. D. and Jarrell, S. B. 1989. Meta-regression analysis: A quantitative method of literature surveys. *Journal of Economic Surveys* 3(2):161-170.

Stanley, T. D., Doucouliagos, H., Giles, M., Heckemeyer, J. H., Johnston, R. J., Laroche, P., Nelson, J. P., Paldam, M., Poot, J. Pugh, G., Rosenberger, R. S., and Rost, K. 2013. Meta-analysis of economics research reporting guidelines. *Journal of Economic Surveys* 27(2):390-394.

Vista, A. B., and Rosenberger, R. S. 2013. Addressing dependency in the sportfishing valuation literature: Implications for meta-regression analysis and benefit transfer. *Ecological Economics* 96:181-189.

Walsh, R. G., Johnson, D. M. and McKean, J. R. 1989. Issues in nonmarket valuation and policy application: A retrospective glance. *Western Journal of Agricultural Economics* 14(1):178-188.

Walsh, R. G., Johnson, D. M. and McKean, J. R. 1992. Benefit transfer of outdoor recreation demand studies: 1968-1988. *Water Resources Research* 28(3):707-713.

Woodward, R. T., and Wui, Y. S. 2001. The economic value of wetland services: A meta- analysis. *Ecological Economics* 37(2):257-270.

Table 1. Summary statistics for the variables included in the meta-regression model (N = 163).

	Mean	St. Dev.	Min	Max
Wetland welfare estimate/ha in 2010 USD –log scaled	5.85	2.65	-1.50	11.81
Wetland area (ha) - log scaled	8.46	4.02	0.05	16.73
Economic literature dummy	0.63	0.48	0	1
Regional study dummy	0.42	0.50	0	1
Valuation methodology (binary variables)				
CVM	0.24	0.43	0	1
Choice Experiment	0.04	0.19	0	1
Travel Cost	0.19	0.39	0	1
Hedonic Price	0.05	0.22	0	1
Market Price	0.28	0.45	0	1
Replacement Cost	0.09	0.28	0	1
Production Function	0.12	0.33	0	1
Wetland ecosystem type (binary variables)				
Estuarine	0.40	0.49	0	1
Riverine	0.10	0.31	0	1
Palustrine	0.39	0.49	0	1
Lacustrine	0.11	0.31	0	1
Ecological function valued (binary variables)				
Preservation	0.14	0.35	0	1
Restoration	0.05	0.22	0	1
Water quality	0.07	0.26	0	1
Flood control & water supply	0.10	0.31	0	1
Amenity	0.09	0.28	0	1
Recreational fishing & hunting	0.23	0.42	0	1
Non-consumptive recreation	0.12	0.33	0	1
Biodiversity	0.07	0.26	0	1
Commercial fishing & hunting	0.15	0.36	0	1
Geographic and socio-economic characteristics				
Ramsar Site dummy	0.29	0.46	0	1
Wetland area in 50km radius (ha)	236832.30	244033.30	85	783930
Population in 50km radius	616957	970885	5661	370000
Education (county level)	23.66	9.26	11	45.4
Distance to city (km)	14.80	56.02	0	496.364

Table 2. Meta-regression results for the OLS model and the spatial lag models.

Variable	OLS	Spatial Models				
		Threshold Distance			Ecological Similarity	Economic Similarity
	Estimate	50 km lag Estimate	100 km lag Estimate	150 km lag Estimate	Estimate	Estimate
Intercept	-3.72	-3.71*	-3.80*	-3.93***	-4.90**	-3.98*
Wetland area (ha) – log-scaled	-0.12	-0.08	-0.13**	-0.12*	-0.05	-0.12*
Economic literature dummy	1.19**[1]	0.90*	0.94*	0.95*	0.95*	0.99*
Regional study dummy	0.67	0.61	0.85**	0.82*	0.14	0.61
Valuation Methodology (Travel Cost Method as the reference group)						
CVM	1.66**	2.01***	2.08***	2.06***	1.84***	1.60**
Choice Experiment	3.14**	3.54***	3.49***	3.52***	3.39***	3.34***
Hedonic Price	7.13***	6.80***	7.24***	7.40***	6.71***	6.86***
Market Price	1.99**	2.13**	2.13**	2.28**	2.20**	1.81**
Replacement Cost	4.27***	4.26***	4.22***	4.45***	4.49***	3.99***
Production Function	1.20	1.95**	1.85**	1.89**	1.85**	1.49*
Wetland Ecosystem Type (Estuarine as the reference group)						
Riverine	2.00*	1.00	1.75**	1.82**	1.81**	1.62**
Palustrine	0.50	0.39	0.57	0.60	0.76	0.55
Lacustrine	0.94	0.88	1.09*	0.95	0.82	0.91
Ecological Function Valued						
Preservation	2.89**	2.77**	3.00***	3.08***	3.04***	2.82**
Restoration	1.49	1.74	1.92	1.84	1.92	1.42
Water quality	1.85	2.15*	2.17*	1.95*	1.88*	1.78
Flood control & water supply	1.30	1.16	1.51	1.53	1.56	1.30
Amenity	-2.69**	-2.64***	-2.52**	-2.46**	-2.32**	-2.64***
Recreational fishing & hunting	2.58**	2.28**	2.54**	2.62**	2.58**	2.34**
Non-consumptive recreation	3.26***	3.05***	3.34***	3.42***	3.11***	3.01***
Biodiversity	1.37	1.47	1.65	1.64	1.68	1.46
Commercial fishing & hunting	1.47	1.04	1.48	1.47	1.53	1.28
Geographic and Socio-Economic Information						
Ramsar Site dummy	0.19	0.46	0.37	0.35	0.08	0.00
Wetland area in 50 km radius (ha)/1000 – log-scaled	-0.26*	-0.30**	-0.29**	-0.30**	-0.27**	-0.27**
Population in 50 km radius – log-scaled	0.40**	0.26*	0.27*	0.27*	0.25*	0.38**
Education (county level)	0.06**	0.07***	0.06***	0.06**	0.08***	0.06**
Distance to city (km)	0.07**	0.10***	0.08***	0.08***	0.08***	0.08***
Education * Distance to city	-0.002**	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***

Variable	OLS	Spatial Models				
		Threshold Distance			Ecological Similarity	Economic Similarity
	Estimate	50 km lag Estimate	100 km lag Estimate	150 km lag Estimate	Estimate	Estimate
N	163	163	163	163	163	163
R^2	0.50					
ρ (spatial autoregressive parameter)		0.176	0.143	0.138	0.179	0.095
Likelihood ratio test statistic		17.280	10.196	8.749	8.700	4.419
p-value for the LLR test		< 0.000	0.001	0.003	0.003	0.036
AIC	725.70	710.02	717.10	718.55	718.60	722.80

1. Significance code: *** p<0.01, ** p<0.05 and * p<0.1.

Table 3. Binomial tests of spatial autocorrelation controlling for intra-study dependence through 1000 bootstrapped samples.

Weight Matrix	**Significant LLR tests @ $p \leq 0.05$**	**Binomial test**	**Significant LLR tests @ $p \leq 0.10$**	**Binomial test**
50 km threshold	933	$p < 0.00$	984	$p < 0.00$
100 km threshold	908	$p < 0.00$	957	$p < 0.00$
150 km threshold	747	$p < 0.00$	874	$p < 0.00$
Ecological similarity	49	$p = 0.58$	107	$p = 0.24$
Economic similarity	12	$p = 1.00$	45	$p = 1.00$

Figure 1. The HUC2 boundaries defined by the United States Geological Survey.

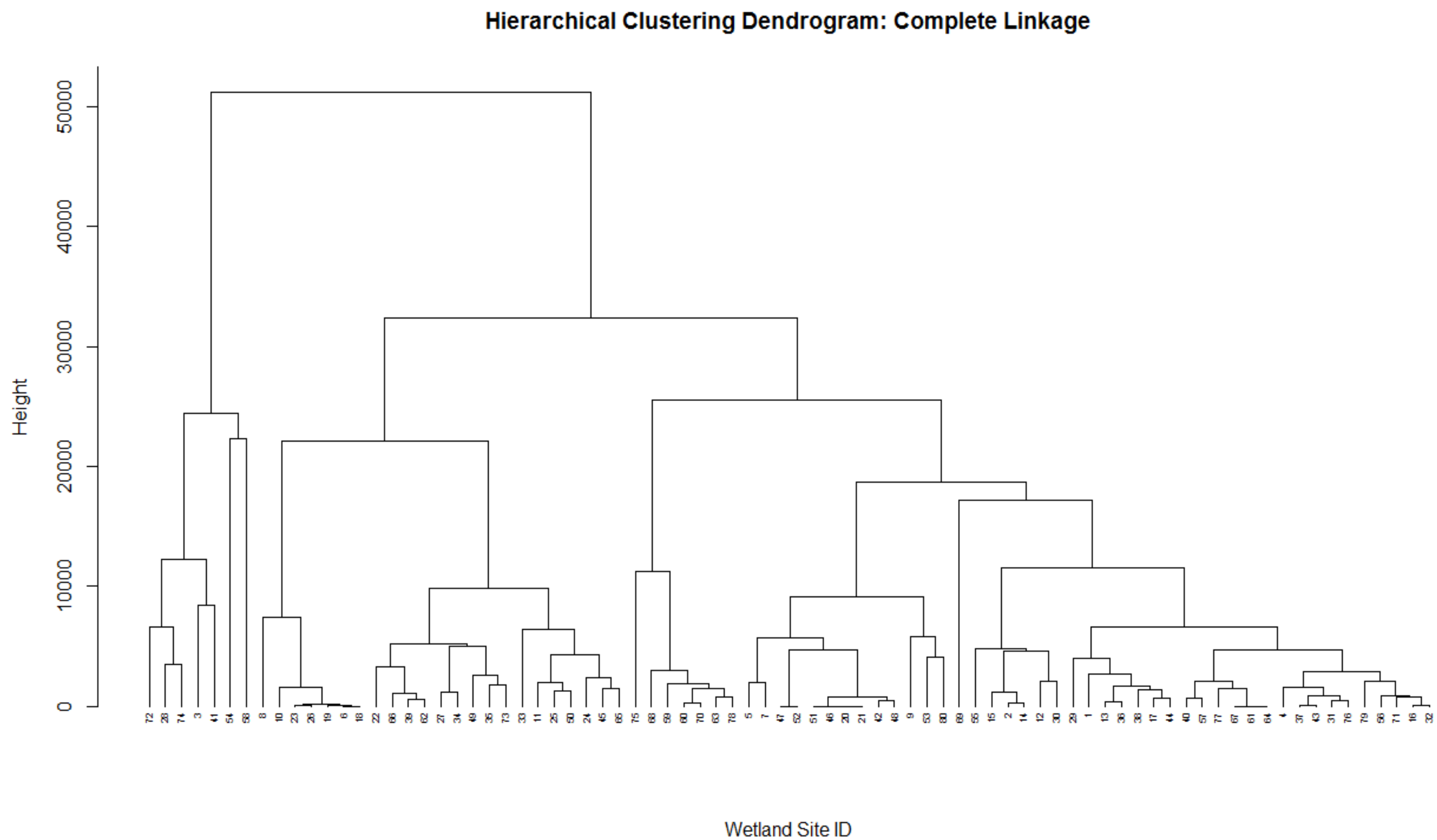

Figure 2. A hierarchical clustering dendrogram for wetland sites grouped using multivariate clustering analysis