LAND USE AND AQUATIC INVASIVE SPECIES:

RELATIONSHIPS IN SOUTHEASTERN WISCONSIN LAKES

By

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ABSTRACT

Submerged aquatic vegetation provides many ecological services to waterways, including water quality control, erosion control, and habitat for small fish and invertebrates. When an exotic species is introduced, it can alter the services that native vegetation provides by growing densely. This invasive aquatic vegetation is managed in several different ways; such as cutting, pulling, herbicides, and biological control. Since these species spend their entire lives underwater, they are impacted by the water quality and nutrients in their waterway. Controlling nutrient influxes to waterbodies could theoretically be another management technique for invasive aquatic vegetation. In this study, densities of invasive plants within lakes were compared to the amount and spatial relationships of land use within the lake's sub-watershed. Low densities of invasive plants were correlated with high percentages and nearness of natural areas; except for forested areas, which had an inverse relationship. These results suggest that implementing natural buffers could potentially reduce populations of aquatic invasive plants.

1. INTRODUCTION

Annually in the United States, non-native aquatic plants cause an estimated 10 million dollars in losses and damages in lakes, rivers, and oceans; and another 100 million dollars in costs to attempt to control the species (Pimentel 2005). Invasive species have caused native species to be added to threatened and endangered species lists due to competition with these invasive species (Wilcove 1998). Every year, new species are being introduced to the U.S. despite prevention efforts. The key to managing invasive species is to understand what factors help them flourish. Certain effects, such as pollution due to human activities, may be negatively impacting native species while enhancing the growth of invasive species in some areas. For example, a study involving barnacle species and varying copper concentrations in the water found that increasing copper concentrations negatively impacted native species richness while exotic species richness remained steady until the highest concentration, where richness dropped (Crooks et al. 2010).

Aquatic species are an interesting case because they have different modes of dispersal and different environmental influences than their terrestrial counterparts. These differences mean that research into management of aquatic plant species needs to be approached from a different viewpoint than terrestrial plants. For aquatic invasives, some species can flourish in one water body but can do poorly in another. One of the major determinants of invasive success is the amount of human interaction with the water body. An important means of interaction is the runoff from human land uses into the water body. While runoff does affect all species in the water body, it can give a competitive advantage to invasives that have higher pollutant tolerances, helping them to further out-compete the already stressed native species. The following research makes connections between land-use within sub-watersheds of lakes and the densities of aquatic invasive plants found within those lakes. In addition to amounts of each land-use type within a sub-watershed, different spatial relationships between the land-use and the lakes were also considered. These connections are important for understanding how invasive aquatic plants react to environmental conditions changes caused by humans and for initiating policy action for better managing land-use near waterways.

2. LITERATURE REVIEW

2.1 Invasive Species

Species have been making their way around the globe for hundreds of millions of years, long before humans aided the process. However this process can be slow and is considered to be a natural progression of species dispersal. For example, to account for the plant diversity on the Galapagos Islands, one plant species would need to establish itself every 7,600 years; for the Hawaiian Islands this would need to happen once every 20,000 – 30,000 years (Pauchard & Shea 2006). Many physical and biological barriers across the globe prevent dispersal across continents and oceans, which have, in turn, lead to the patterns of global biodiversity that exist today. When humans began to spread across continents and eventually oceans, they themselves became a dispersal mechanism. The difference between natural and human dispersal of organisms is time and distance. Human dispersal is generally faster and occurs over longer distances because of technological advancements such as ships, automobiles, and airplanes. In general human dispersal causes larger changes to the recipient ecosystem. The functions that non-native species have in their new ecosystems have been heavily debated in the study of biogeography.

A prime example of this long distance movement is the European settlement of the Americas. The European settlers brought with them their crop seeds and farm animals, but also unintentionally brought their associated weeds and pests. This highlights the issue of purposely versus accidentally introduced species. Some species are brought to new areas for purposes like the provision of food or use as landscaping, for more sentimental reasons or simply due to familiarity. Unintentional vectors of movement include seeds of plants stuck to clothing or footwear, caught in the ballast water of ships, or carried in the cargo of ships or airplanes. Accidental introduction is not limited to transoceanic movement, but also occurs when a species is moved across a barrier that it would be unable to cross on its own. An example of this is the movement of the rusty crayfish (*Orconectes rusticus*). The rusty crayfish's native range is the Ohio River Basin; however it now has a disjunct distribution across North America due to its use as fish bait (Hobbs et al. 1989).

Until somewhat recently, the United States encouraged the introduction of new species (Sagoff 2005). To many this seemed to be a good idea, including President Thomas Jefferson who believed that it was a great service to introduce a new useful plant to the culture (Sagoff 2005). President John Quincy Adams adopted a policy that declared the United States should bring in any plants that are useful to humans in any sort of way; a policy that would stand for over 150 years (Sagoff 2005). The government went so far as to put certain protections on introduced species, even if at the expense to native species. The Lacey Act of 1900 was introduced to protect crops and other cultivated plants from any "wild" organisms that could harm the plants (Sagoff 2005). The law prohibits the introduction of wild animals and birds that the Secretary of Agriculture deemed dangerous to important plants (Sagoff 2005). At the time, little emphasis was placed on protecting wild animals or ecosystems. Many of these cultivated plants began to cause harm to ecosystems themselves and remained mostly unchecked.

However, arriving at a new area is only half of the battle for non-native species. The next step for the organism is to successfully establish itself in the new environment. There are many factors that contribute to successful establishment and they are very similar, if not the same, for a species that makes its way to an island on its own. However, the difference is that a species that is introduced by humans is likely moved past barriers that it could never cross by itself. Shea and Chesson (2002) suggest that there are three major factors that contribute to the success of a non-native species: available resources, number of natural enemies, and physical environment. How the species interacts with these factors determine if the species will thrive (Shea & Chesson 2002). One challenge non-native species face is bottlenecking of genetic diversity, i.e. when a population of a species is shrunk for some reason, which leads to a reduction in genetic diversity of remaining population. This effect will be particularly strong if all individuals come from the same source population (Sakai et. al. 2001). Multiple introductions reduce this effect by increasing genetic diversity and lead to further success of the species in its new environment (Sakai et. al 2001).

Once a species establishes itself, the next step is to disperse. The period of slow growth between the initial introduction and rapid population growth is interpreted as an ecological phenomenon called the lag time (Sakai et. al. 2001). The lag time is likely due to bottlenecking of genetic diversity, inbreeding, and required adaptations for survival in the new environment. Once dispersal starts, not much can be done to try to eradicate the species. Dispersal rates are different for every new non-native species but they often disperse rapidly because there is little restriction on population growth in their new environment because they are able to avoid natural predators from their native ecosystem (Shea & Chesson 2002).

2.2 Runoff and Pollution Effects on Aquatic Species

There are many factors that aid non-native species success in an ecosystem; e.g. lack of predators, prolific reproduction, and status as a generalist species. In addition, other environmental influences that help them further assist non-natives both directly and indirectly. In aquatic ecosystems, runoff can play a major role in determining the ratio of native to non-native species populations. Higher pollution caused by runoff can negatively impact native species populations, while aiding the growth of non-natives (Trombulak 2000). This results because most successful non-native species are generalists, while native species tend to be more specialized to their ecosystem (Keane 2002). Non-natives can tolerate a wide range of environments and environmental change, in general, while native species cannot typically tolerate change as well. Native species' densities then decline due to the introduction of pollution, which allows non-natives to fill their place, typically becoming invasive in the ecosystem. This process can be amplified as native species still deal with predation, as non-natives typically have few to no predators in a new ecosystem.

Research on non-native small invertebrates has confirmed this trend; non-native species were observed to fare better than natives under higher levels of different types of pollution. Crooks et al. (2010) compared species richness of aquatic invertebrates at different copper pollution levels in the San Francisco Bay. They found that as copper levels increased, native species experienced a significant decrease in richness while non-natives showed no significant richness change.

However, this study is focused on submerged aquatic vegetation, specifically the non-natives Eurasian watermilfoil and curly-leaf pondweed. John Masden (1998) compared 102 lakes and their populations of Eurasian watermilfoil to different environmental variables. These lakes were located in Vermont, New York, Michigan, Wisconsin, Minnesota, Washington, Oregon, Alabama, Ontario, and British Columbia. He found that Eurasian watermilfoil dominance increases as phosphorus in the water column increases in the lakes. This is attributed to Eurasian watermilfoil generally being limited by nitrogen, and the plant uptake of phosphorus from sediment instead of the water column (Masden 1998). These findings support the trend that pollution negatively affects native species, allowing non-natives to take control of the ecosystem.

Buchan and Padilla (2000) developed a model to attempt to determine the likelihood of Eurasian watermilfoil in Wisconsin lakes. They determined that factors associated with water quality were the most important in finding the probability of Eurasian watermilfoil in lakes for all their models. Land-cover types around the lakes were also found to be an important determinant of water quality; they found the amount of forest cover within a lake watershed to be consistently important (Buchan and Padilla 2000). Their findings help support assumptions that I am making about land-cover in relation to water quality along with showing further evidence of invasive species performing well under varying water qualities.

2.3 Connections between Land Cover and Water Quality

Silva and Williams (2001) compared land use within watersheds and buffers along rivers to the water quality of those bodies of water. Their study sites were rivers feeding into Lake Ontario in Canada. They found that urban land use had the highest influence on water quality and that forested land-use showed the most mitigating effects while agricultural land use had mixed and inconsistent mitigation effects (Silva and Williams 2001). Their results also show that land use within the catchment scale were more highly correlated to water quality than land-use at the buffer scale.

Herlihy et al. (1998) also examined the relationship between stream chemistry and land cover within a stream's watershed in the mid-Atlantic region. Land-uses were separated into five major classes: forests, agriculture, urban, wetland, and barren and the percent watershed composition of each land-use was calculated. Results showed that all of the water quality variables, including total N and total P which are essential for plant growth, were significantly related to land cover (Herlihy et al. 1998). However they found, contrary to Silva and Williams (2001), that agricultural land use showed higher correlations with greater nutrient and sediment yields than urban land-use (Herlihy et al. 1998). This research occurred in the mid-Atlantic region of the U.S., while Silva and Williams' (2001) research occurred in southeastern Canada; the differing results show how land cover effects waterways differently in different regions.

Collecting data about the different levels of pollution and amounts of non-native species is both time consuming and expensive. If correlations between land use within a lakeshed and densities of invasive species can be made, these findings could reduce time and costs in determining lakes that are at risk for high densities of invasives. Since land use within the lakeshed is being used as a proxy for water quality in that lake, it is important to point out studies that reflect this assumption.

HYPOTHESIS

In this study, lakes with high percentages of natural areas in their lakesheds will likely have lower densities of invasive species due to the natural areas filtering pollutants before they reach the water. High densities of invasive species will be correlated with high percentages of human influenced land-use within their lakesheds. High species richness will be associated with natural areas because invasive species densities will be lower. Higher water quality will aid native species by allowing them to compete with non-natives without struggling with the effects of pollution. Plant density data from six lakes in Kenosha County, Wisconsin and land use within the lake’s sub-watersheds will be used to compare these suspected relationships.

3. METHODS

3.1 Aquatic Sampling

3.1.1 Site Selection

Vegetation sampling occurred over four summer periods in western Kenosha County, Wisconsin (2009-2012). This data was collected in connection with the Carthage College Invasive Species Working Group, led by professors Dr. Tracy Gartner and Dr. Scott Hegrenes with sampling done by a rotating group of undergraduate students (Carthage College, accessed 2013). Sites were chosen based on differing sizes, boat access/traffic, connectivity to other lake sites, as well as accessibility for sampling (Figure 3.1). Selections based on these characteristics attempted to span a range of densities of various aquatic plants and environmental conditions.

In 2009, four lakes were sampled: Silver Lake, George Lake, Mud Lake and Kull Lake. Silver Lake is a large lake (464 acres) with public boat access and has businesses and homes situated around about half of the lake. George Lake is a medium-sized lake (59 acres) with public boat access and residential homes situated around three-fourths of the lake. Mud Lake is a small lake (22 acres) with no public boat access, but access is available to residents who surround about one-fourth of the lake. Kull Lake is a small lake (15 acres) with no public boat access, no residential development, and small human impact (Table 3.1).

	Kull	Mud	KD	Rock	George	Silver
Acreage	15	22	40	46	59	464
Public Access	No	No	No	Yes	Yes	Yes
Type of Access	Private	Private	Private	Trail	Roadside	Boat Ramp

Table 3.1. Lake characteristics of sampling sites ordered by size.

During the second season (2010), access was lost to Kull Lake due to a change in ownership of the property. Two new lakes were added to the sampling sites - Rock Lake and KD Lake. Rock Lake is a medium-sized (46 acres) private lake with non-motorized boat access to its residents. Residential homes surround three-fourths of Rock Lake. KD Lake is an old quarry that has been filled in by streamflow and rainwater. It is medium-sized at about 40 acres. At the time of sampling, there were no residential houses around the lake, and the lake was closed to the public (Table 3.1). The beginning stages of a park were being constructed at the site. KD Lake was not sampled again.

Between 2009 and 2010, changes occurred at George and Mud Lakes. According to local residents, herbicides were used at George Lake and aquatic vegetation was significantly diminished (Pichler, 2011). At Mud Lake, the water level was raised by beavers that constructed a dam along the lakes outlet stream (Pichler, 2011). Because of this, vegetation shifted a few feet outward and species distributions changed (Pichler, 2011).

3.1.2 Submerged Aquatic Vegetation Data

Data on the amount and type of aquatic vegetation was gathered by throwing a double sided rake from shore, pier, or boat near the shore towards the middle of the lake. The throwing points were chosen at random in areas accessible by the sampling team. The sample's macrophytes were then identified, sorted by species, and percent of the total sample was estimated for each species. These estimates were based on the coverage of each macrophyte in the sample. Both native and non-native plants were counted for each sample. Six samples were taken from each lake site. Samples were acquired once per summer session and steps were taken to ensure most samples at each lake site were taken during the same day. Some lakes (Silver, George, and Mud) were sampled during four consecutive years and Rock Lake was sampled 3 consecutive years. Kull and KD lakes were sampled only one year. In analysis, data from each sampling year for a lake will averaged and will be used as one sample point, creating 17 lake year points.

3.2 Spatial Analysis of the Lakesheds

3.2.1 Creation of the Lakesheds

I created the lakesheds, defined as all landscape positions draining to a lake, using a 30m resolution digital elevation model and ArcGIS's Watershed tools. To quantify the amounts of each land-use type within the lakesheds, I used the National Land Cover Dataset (NLCD). The NLCD database, provided by the USGS, was created by classifying Landsat imagery for the years 1992, 2001, and 2006. The NLCD uses a hierarchical land-cover classification system, which divides land-cover into different intensities and types of developed space, forests, farmland, and wetlands.

For this analysis, I used the most recent land-cover classification (2006) and aggregated classes into five general categories (Table 3.2). The Impervious Surface general category contains the Developed classes (Open Space, Low, Medium, and High intensity). The Cultivated Crops general category contains only the Cultivated Crops NLCD

Classification. The Impervious Surface and Cultivated Crops general categories make up the broad category of Human Influenced land uses. The Forest general category is made up of the Deciduous, Evergreen, and Mixed Forest classifications. Woody and Emergent Herbaceous Wetlands make up the Wetland general category. Lastly, the Grassland general category includes Shrub/Scrub and Grassland/Herbaceous. These three categories are then contained by the Natural broad category.

Broad Category	**General Category**	**NLCD Classification**
Human	Impervious Surface	Developed, Open Space
		Developed, Low Intensity
		Developed, Medium Intensity
		Developed, High Intensity
	Cultivated Crops	Cultivated Crops
Natural	Forest	Deciduous Forest
		Evergreen Forest
		Mixed Forest
	Wetland	Woody Wetlands
		Emergent Herbaceous Wetlands
	Grassland	Shrub/Scrub
		Grassland/Herbaceous

Table 3.2. Categories of the National Land Cover Dataset used in analysis.

Three other NLCD classes were excluded in the spatial analysis. One of these was the Barren Land (Rock, Sand, Clay) classification. It was not used because it only occurred in three of the lakesheds and at very small percentages (less than 1%). The Pasture/Hay classification was also omitted from analysis because of its conflicting category status. While these areas are vegetated, they are also human impacted. The Pasture/Hay class occupied no more than 22% of any lakeshed. The third classification that was not used in the quantitative analysis was the Open Water classification. For the most part, nearly all of any lakeshed's open water was in the lake itself. The largest values occurred for George and Silver Lake which had 1.73% and 1.07% of the lakeshed containing open water outside the lake respectively.

3.2.2 Computation of Spatial Distribution Variables

In addition to percent of each class within a lakeshed, the spatial distribution of classes within a lakeshed can be important. For example, an impervious area adjacent to a lake will have a different impact than that same area far removed from open water. This analysis attempts to capture such effects using the average distance to lake of each land use type, and the percent of lake perimeter occupied by each type. To account for differing lake size, distance was normalized by the average pixel distance. Percent lake perimeter for each land use category was calculated by determining if each pixel of a certain category was adjacent to water or not. Thus a pixel adjacent to a stream feeding a lake was considered as adjacent to the lake.

3.3 Regression Tree Analysis

Regression tree analysis uses an algorithm that performs stepwise splitting on a data set (Wilkinson 1998). Given the entire sample or a subset, the algorithm creates two groups that are maximally homogenous with respect to a dependent variable. In particular, to form a split the algorithm examines all independent variables and selects the single variable that produces groups with the smallest within-group sum of squares. Those groups are further decomposed until there is no significant reduction in the sum of squares (Wilkinson 1998). Every split creates groups whose total sum of squares is smaller than that of the original pool. The relative change in the sum of squares provides a measure of prediction improvement called the proportional error reduction. The results section will report this measure in addition to predicted values (i.e., the group means).

I performed regression tree analysis on the data with three different dependent variables: native species richness, average percent of Eurasian watermilfoil, and average percent of curly-leaf pondweed. Three different groupings of independent variables were used. The first group included all available variables: area, pH, percentage of make-up of each broad and general land-use category of the lakeshed (refer to Table 3.2.), normalized average distance of each category, and percent perimeter make-up of each land-use category. The second group was composed of just the land-use variables (i.e., area, pH and the two spatial distribution variables were excluded). The spatial distribution variables made up the third group of predictors.

The maximum number of splits for each tree was set to ten. Because of the small sample size, the minimum number of samples at the end of each node was set at two. The minimum proportion reduction in error allowed at any split and minimum split value allowed at any node were left at the default of 0.05.

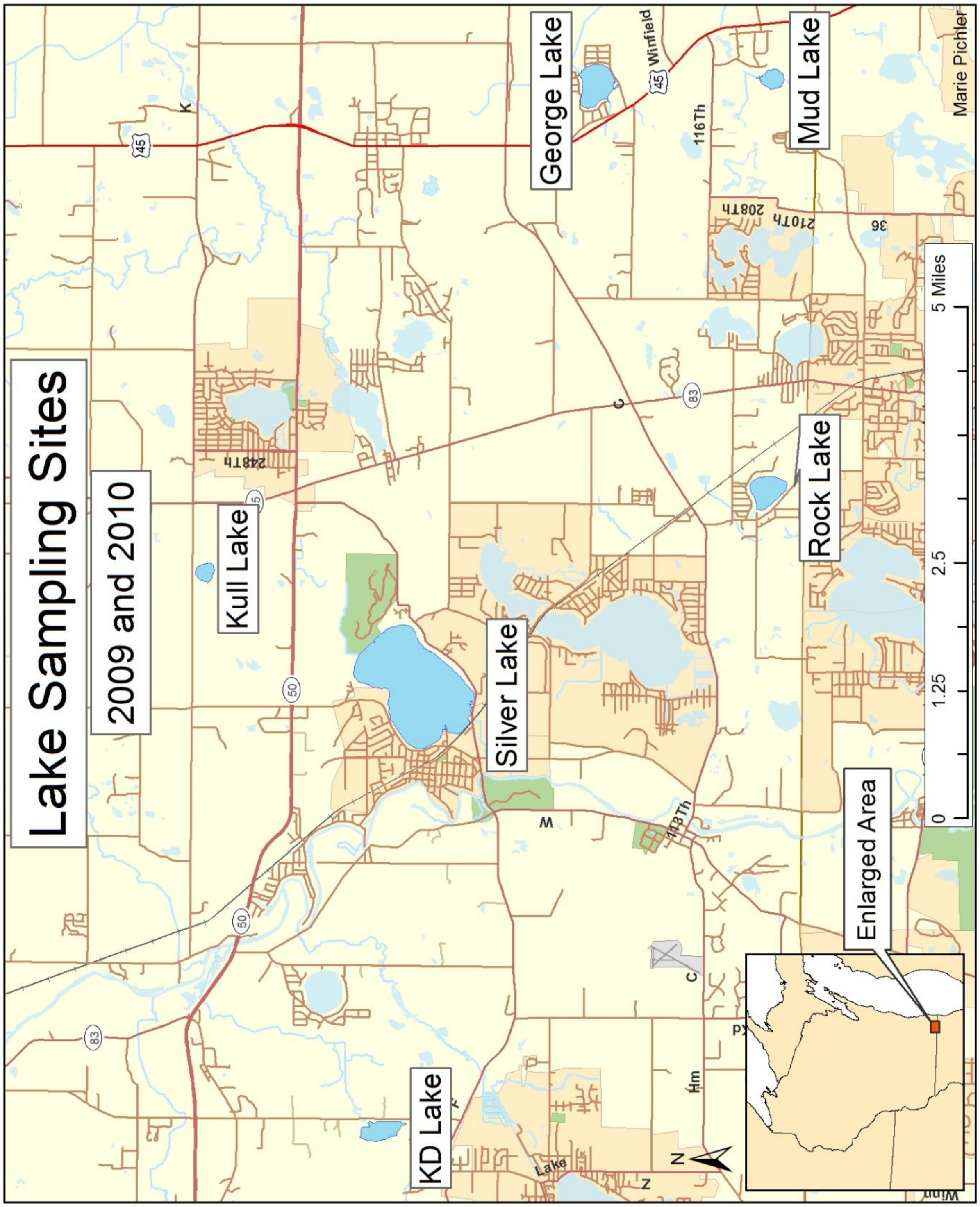

Figure 3.1. Sampling site map. Sites located in western Kenosha County in Southeastern Wisconsin

4. RESULTS

4.1 Lakeshed Composition

The area of lakesheds varied by more than an order of magnitude, from 418,680 m^2 to 35,700 m^2 (Table 4.1). Kull Lake and its lakeshed is completely within the Silver Lake lakeshed. The lakesheds had differing land-use compositions (Figure 4.1). Rock Lake had the largest percentage of impervious surfaces, constituting over 60% of the lakeshed. Mud Lake had the highest percentage of wetlands but also the second highest percentage of impervious surfaces. Silver Lake, which is the largest of the lakes and thought to be the most urban, had the second lowest percentage of impervious surfaces. After running the watershed analysis, most of the urban areas around the lake drain away from the lake.

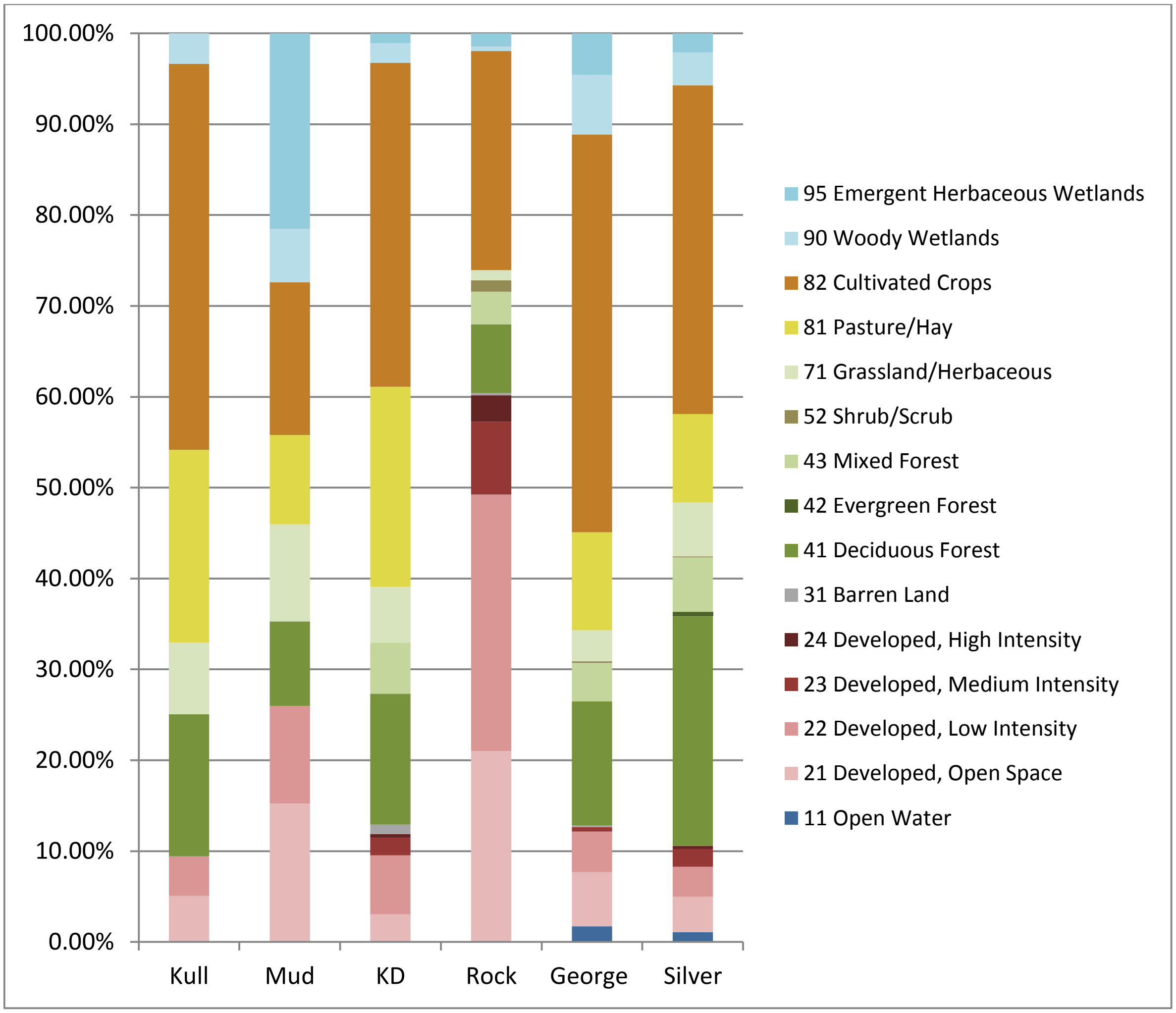

Figure 4.1. Land-use composition of the lakesheds for the six lakes in the study, lakes ordered smallest to largest. Category numbers and titles correspond to the NLCD classification system.

	Kull	Mud	KD	Rock	George	Silver
Lake Size (m^2)	2010	2820	4440	6450	8910	68520
Lakeshed Size (m^2)	41430	35700	103320	64380	291150	418680
Lakeshed to Lake Size Ratio	20.61	12.66	23.27	9.98	32.68	6.11
Average Distance of Pixel to Water (m)	728.28	616.62	876.30	972.53	498.08	703.83

Table 4.1. Summary statistics of spatial lake results.

4.2 Decision Trees

4.2.1 Average Curly-leaf Pondweed Percent

I ran two tree regressions, one with land-use variables as the only predictors and another with all variables (including land-use). Only land-use variables were significant predictors, thus the decision trees were identical for the two regressions (Figure 4.2). Lakes with over 55% of the lakeshed composed of human impacted land-use had on average more than four times the percentages of curly-leaf pondweed than lakes with less than a 55% human impacted land-use composition. Curly-leaf pondweed was not found in samples at KD Lake but was observed to be in the lake by the sampling crew. Using percent human impacted land-use as a predictor, the proportional reduction in error was 16%.

I ran another regression using only spatial distribution variables as predictors. The only significant variable was distance to wetland (Figure 3.3).This regression divided lakes into the same two groups as seen in Figure 3.2, and of course predictions errors were identical. Lakes with wetland areas far away had a greater average percentage of curly-leaf pondweed than those with wetlands close to the lake. Again, curly-leaf pondweed was seen in KD Lake but did not appear in the samples.

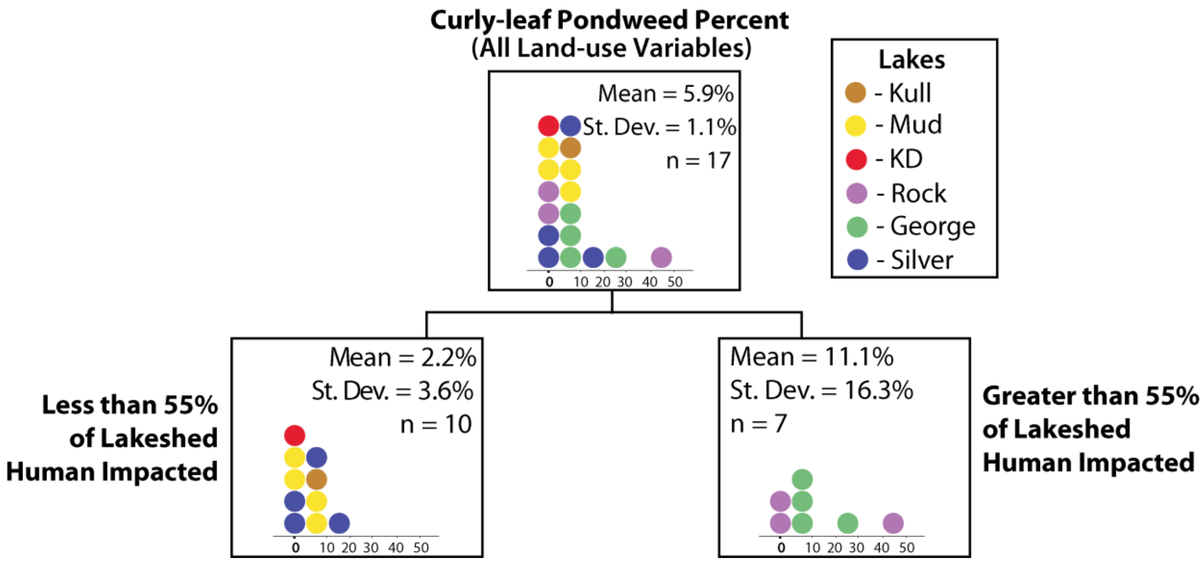

Figure 4.2. Average curly-leaf pondweed decision tree results for two sets of independent variables (all variables and land-use only variables). Histograms inside each node represent the data points in that node. Lakes with multiple dots represent multiple sampling years.

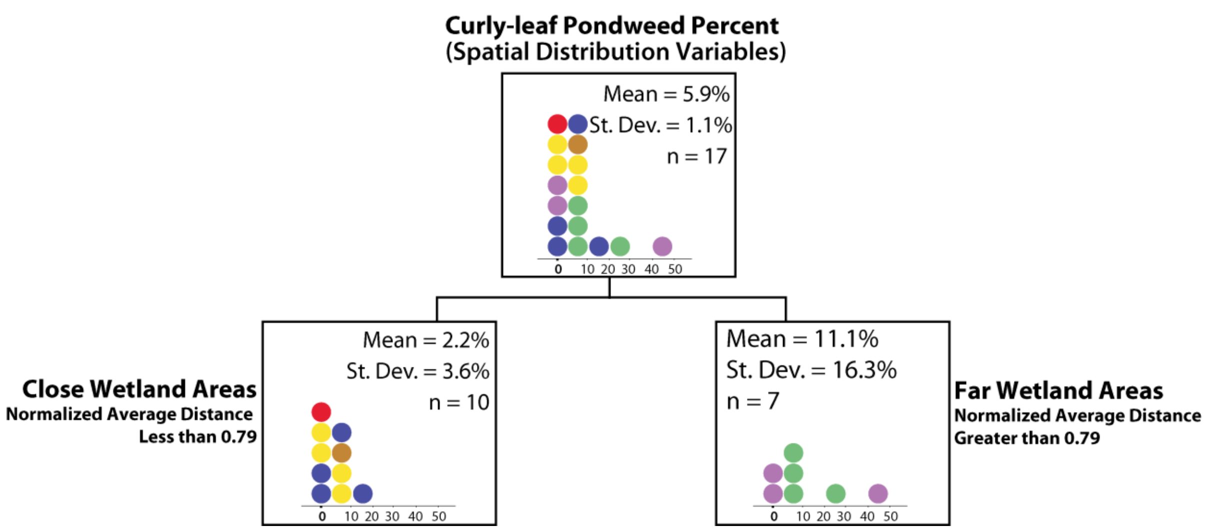

Figure 4.3. Average curly-leaf pondweed decision tree results for spatial distribution variables (average distance of a land-use to the lake and lake perimeter). Histograms inside each node represent the data points in that node. Lakes with multiple dots represent multiple sampling years. Close wetland areas have a normalized average distance of less than 0.79 and far wetland areas have a normalized average distance of greater than 0.79.

4.2.2. Average Eurasian Watermilfoil Percent

For Eurasian watermilfoil, I once again ran two tree regression models, one with all variables as predictors and another with only land-use variables. The resulting trees were identical because only land-use variables were shown to be significant (Figure 4.4). Lakes with less than 6% of the lakeshed composed of grasslands (Rock, George, and Silver Lake) had on average five times the percent of Eurasian watermilfoil as lakes with greater than 6% lakeshed composition of grassland (KD, Kull, and Mud Lake). It should be noted that Eurasian watermilfoil was not found to be present at Kull or KD Lake. Using percent grassland as a predictor, the proportional reduction in error was 29.7%

I ran another regression tree using only spatial distribution variables as predictors. The tree had the same lakes in the same places as the former tree but split by a different predictor variable (Figure 4.5). This time those lakes with close forested areas (Rock, George, and Silver Lake) had a higher average percentage of Eurasian Milfoil than lakes with forested areas farther away (KD, Kull, and Mud Lake). Once again, note that KD and Kull Lake did not have Eurasian watermilfoil present in the samples.

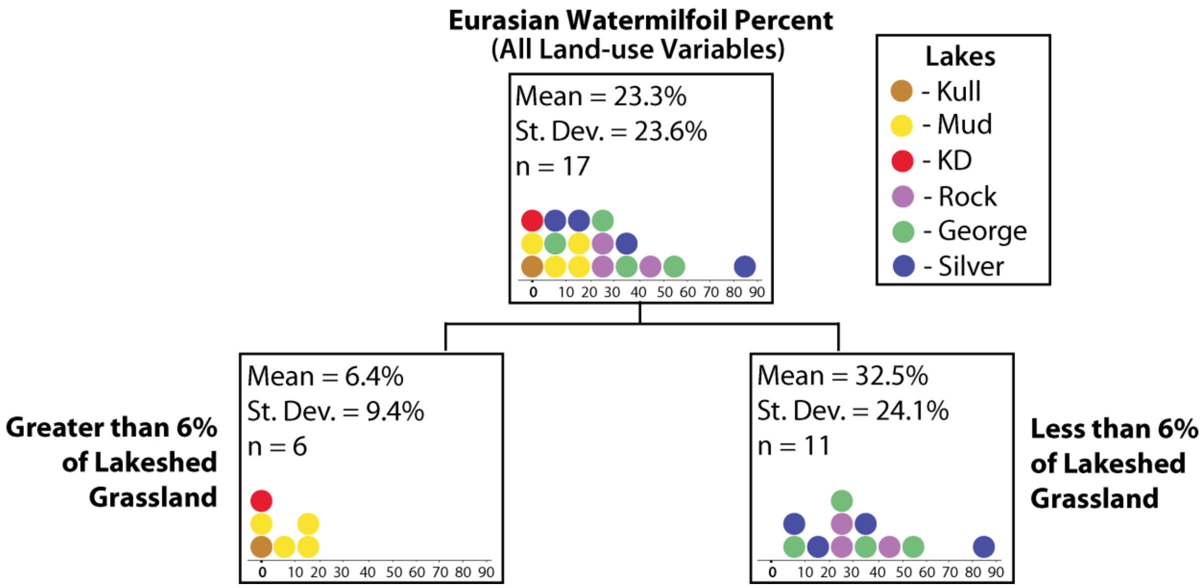

Figure 4.4. Average Eurasian milfoil decision tree results for two sets of independent variables (all variables and land-use only variables). Histograms inside each node represent the data points in that node. Lakes with multiple dots represent multiple sampling years.

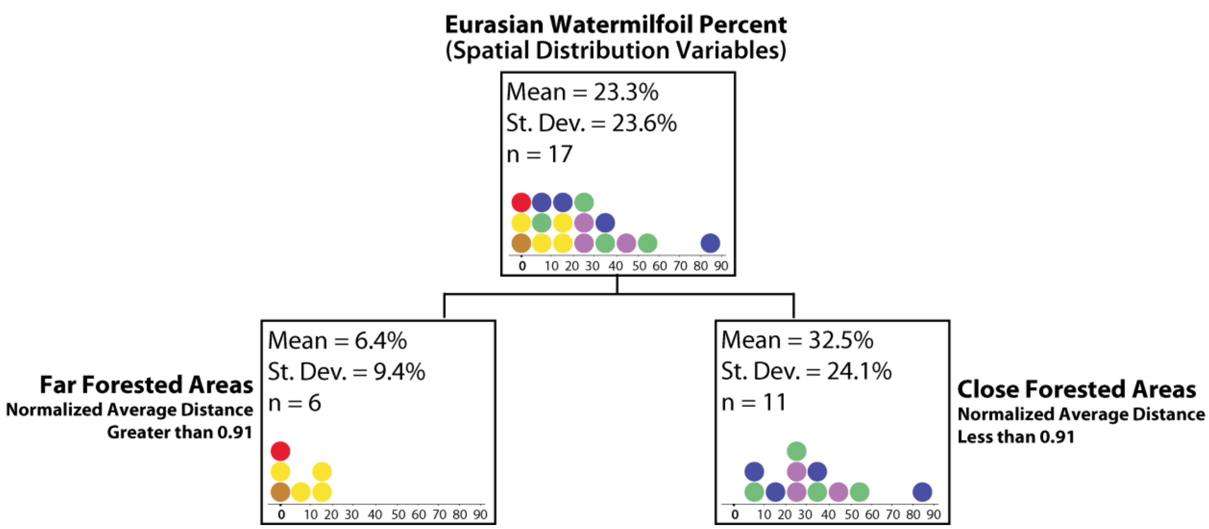

Figure 4.5. Average Eurasian milfoil decision tree results for spatial distribution variables (average distance of a land-use to the lake and lake perimeter). Histograms inside each node represent the data points in that node. Lakes with multiple dots represent multiple sampling years. Far forested areas had a normalized average distance greater than 0.91 and close forested areas had a normalized average distance less than 0.91.

4.2.3 Native Species Richness

I ran three tree regressions, one with only spatial distribution variables, the second with only land-use variables, and the last one with all variables. Only spatial distribution variables were significant, resulting in identical regression trees for each of the groups (Figure 4.6). Distance of impervious surfaces to the lake was the first predictor selected, with the lake with close impervious surfaces (Silver Lake) having a higher species richness than those with impervious surfaces farther away. Using distance of impervious surfaces as a predictor, the proportional reduction in error was 53.8%. Out of those lakes with impervious surfaces further away, lakes with natural areas far away from the lake had about twice the species richness as the lake with close natural areas (Mud Lake). After including distance of natural areas as a predictor, the proportional reduction in error was improved by 10.5%, bringing the proportional reduction in error for the whole tree up to 64.3%.

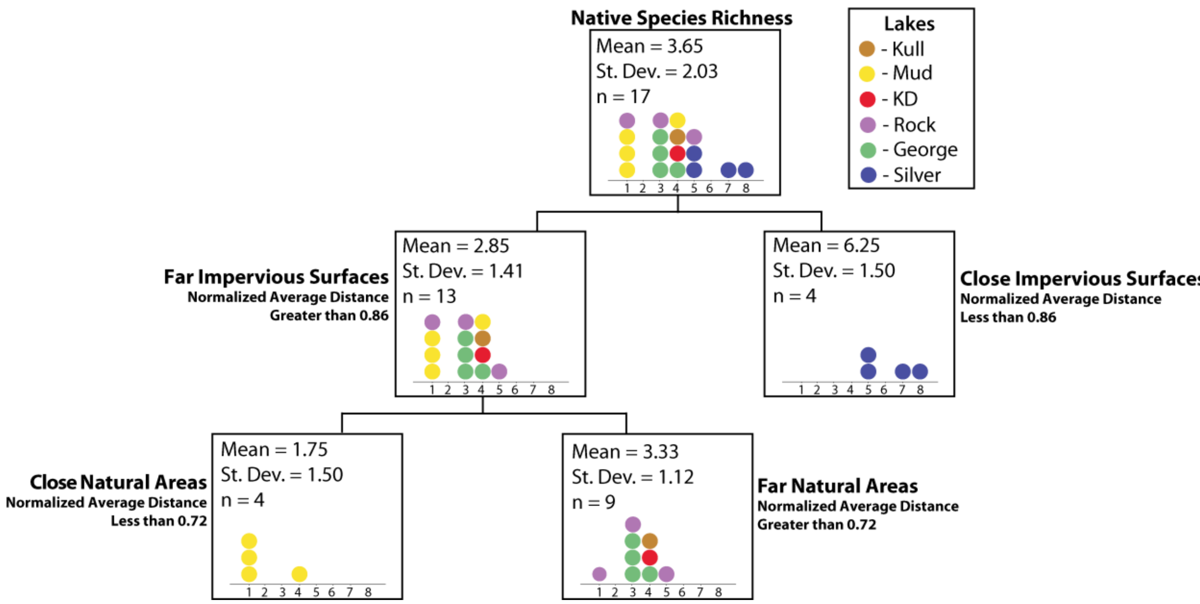

Figure 4.6. Native species richness decision tree results. Histograms inside each node represent the data points in that node. Lakes with multiple dots represent multiple sampling years. Far impervious surfaces had a normalized average distance greater than 0.86 and close impervious surfaces had a normalized average distance less than 0.86. Close natural areas had a normalized average distance less than 0.72 and far natural areas had a normalized average distance greater than 0.72.

5. DISCUSSION

5.1 Curly-leaf Pondweed

Overall, most of the lakes sampled had relatively low densities of curly-leaf pondweed; which brings into question the importance of curly-leaf pondweed in the ecosystems of these lakes. However, lakes such as George Lake and Rock Lake had high variation in densities of curly-leaf pondweed from year to year. These lakes also had the two highest densities sampled (26% at George Lake and 42% at Rock Lake). These data suggest that year-to-year environmental condition changes may be affecting this species at these sites. Events such as a large storm or warmer/colder temperatures could be reasons for this fluctuation.

In the land-use variables decision tree, the importance of human influenced land use as a predictor suggests that pollution coming from these areas may be aiding curly leaf pondweed negatively affecting native vegetation. In the tree with only the spatial distribution variables, the same two groups of lakes emerged with distance to wetland as the predictor. These results suggest that wetlands are important for controlling curly-leaf pondweed presence. This may be due to cleansing the incoming water of the lakes by the wetlands in a way that helps native plants and keeps curly-leaf pondweed in check. This connection aligns with what a study on Great Lakes coastal marshes in Canada found. In their study, coastal areas surrounded by wetlands had clearer water and lower nutrient levels, as well as denser more diverse submerged plant communities (Lougheed, Crosbie, and Chow-Fraser 2001).

5.2 Eurasian Watermilfoil

Densities of Eurasian watermilfoil were higher on average than densities of curly-leaf pondweed in the sampled lakes (23.3% compared to 5.9%) and had a higher standard deviation (23.6% compared to 1.1%). The higher densities of Eurasian watermilfoil suggest that it may be having a larger impact on the ecosystem than curly-leaf pondweed. The year-to-year variation in the data shows that yearly environmental differences have an effect on the densities of the species.

The land-use variable decision tree showed that lakes with low amounts of grassland within the lakeshed (less than 6% composition) had higher densities of Eurasian watermilfoil than lakes with a higher grassland composition. These results suggest that grasslands could be helping keep pollutants out of the waterways by letting water infiltrate the ground, cleansing the water before it gets to a lake or stream. Osborne and Kovacic (1993) determined that grass buffers retain total and dissolved phosphate, keeping the phosphate out of the waterway. In order to reproduce prolifically, Eurasian watermilfoil, like most other plants, its growth is limited by phosphorus (Smith and Barko 1990). By keeping phosphates out of the lake, grasslands within the lakeshed can help prevent the creation of high Eurasian watermilfoil densities.

Nearness of forested area generated the same split, with lakes whose forests are closer having higher densities of Eurasian watermilfoil. This outcome is interesting because although forests are classified as natural areas, they seem to be having a positive impact on this invasive plant. This could potentially be the case because most of the forested areas in the study area are made up of deciduous trees, whose leaf litter could provide excess nutrients to lakes and waterways. Trees also can deposit branches, or whole trees, into the water from storms or die-off which can also contribute to nutrient influxes in the lake. However, this contradicts findings stated earlier by Buchan and Padilla (2000) who found that lakes in Wisconsin with higher amounts of forested areas within their drainage basin had lower densities of Eurasian watermilfoil. Another possible explanation of the correlation with forested areas in this study is that the lakes with closer forested areas, also happen to be the three lakes with public access, which might be playing a bigger role than the forested areas themselves. In further analysis, differences between public and private lakes should be included.

5.3 Native Species Richness

The first split of the native species richness decision tree is misleading. The algorithm found that nearness of the impervious surfaces was the most significant divider with lakes having impervious surfaces farther away having a lower species richness than the lake with close impervious surfaces, which was Silver Lake. Silver Lake is almost eight times larger than the next largest lake; George Lake is 59 acres while Silver Lake is 464 acres. Larger lakes have more niche space for different species and is most likely driving up the native species count. Even though lake size was used as a predictor, the algorithm did not pick it up. Perhaps if native species richness was standardized by lake size or size of available potential habitat (for example: area of lakebed under a certain depth required for plant growth), this issue may not have happened. The nearness of natural areas came up as the second split off of the node with lower native species richness node. In particular the lake with close natural areas (Mud Lake) had a lower species richness than the lakes with natural areas farther away. This result is difficult to reconcile with ecological theory. The results of this tree suggest that land-use within the lakeshed is not the primary driver when it comes to native species richness. Other variables such as lake depth, clarity, and the species composition of the lake is probably more likely the force behind the native species richness of a lake.

5.4 Limitations, Future Research, and Directions

This survey contained only six sites, which is a limitation of the data that is used for analysis. To create a more complete dataset, more lakes should be sampled in further work. However, at the same time, these lakes were in close proximity to each other with similar climate and geologic features which created a control in the study. Adding more lakes to a study of land-use composition would create more variance between sites if they are spread over a large area. In summary, case studies of regional or smaller areas are important when trying to pinpoint effects of land-use on aquatic vegetation in lakes.

6. CONCLUSIONS

Lower densities of invasive plants were correlated to high percentages or nearness of natural areas in exception to forested areas. High percentages or close proximity of forested areas were associated with higher densities of invasive plants in the lake. Further studies should analyze what nutrients these forests are adding to lakes and how those nutrients effect native and non-native aquatic vegetation. Land-use composition within a lakeshed does not appear to be a driver of the aquatic macrophyte species richness of a lake. Additional work could be done to determine what factors are related with species richness in these lakes. These conclusions suggest that using natural areas as buffers around lakes could be used as a management technique against aquatic invasive vegetation.

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