# EXAMINING PATTERNS OF AQUATIC INVASION WITHIN THE ADIRONDACKS: AN OLS AND GLM APPROACH

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***ABSTRACT:*** *Non-indigenous species continue to pose major challenges to aquatic environments. Since the 1950s, the impacts of invasive species on native individuals, communities, and ecosystems have been investigated and acknowledged. In regions of abundant freshwater resources, it remains problematic to survey all lakes at the level required to detect aquatic invaders. Effective prioritization of conservation resources requires tools that identify where exotic species will most likely invade. Studies have found that anthropogenic causes can account for much of the dispersal, establishment, and spread of invasive species. While several analyses have focused on the establishment phase of aquatic invasion, there remain few investigations on the initial dispersal or subsequent spread. Small-craft boats and trailers have been found to be the primary vectors for propagating aquatic invaders. That said, there remain few empirical studies on the impacts lake access type (e.g., private vs. public launch), or landscape patterns (e.g., relative patch richness), are having on aquatic invasion. Assessing 26 lakes within the Adirondack region of New York, we use traditional regression to predict lake and landscape conditions in which aquatic invaders are most likely to persist. Using logistic regression, we also test models of association between presence of public boat ramps, private boat ramps, and a lake assessment program with lake and landscape characteristics. Our results reveal that land cover diversity and lake elevation are more important factors for understanding and managing aquatic invasion than boat ramp type. Findings from future studies could be used to predict, map, and prevent impending aquatic invasion.*

***Keywords:*** *Invasive species richness; landscape patterns; monitoring invasive species in lakes; public vs. private lake access; water resources management*

## INTRODUCTION

The current integrity of the planet is being stressed beyond its biocapacity, and understanding coupled human-environmental systems is more important now than ever. Changes in land cover, through the appropriation of natural landscapes to provide for human needs, are one of the most pervasive alterations to native ecosystems resulting from human activity (Vitousek et al., 1997; Foley et al., 2005; Liu et al., 2007). Landscape change influences natural systems by fragmenting landscape patches, isolating habitats, abridging ecosystem dynamics, introducing exotic species, controlling and modifying disturbances, escalating climate change, and disrupting energy flow and nutrient cycling (Foley et al., 2005; Liu et al., 2007; Alberti, 2008; Milly et al., 2008). Albeit, terrestrial waters are often those ecosystems most impacted by landscape change stressors (Foley et al., 2005; Novotny et al., 2005; Liu et al., 2007; Milly et al., 2008). For environmental management purposes, the forthcoming study attempts to improve understanding of complex coupled landscape-aquatic relationships.

"Invasive species (IS)" are non-indigenous flora and fauna that adversely impact the integrity of native ecosystems. Impacts of IS on native biota, communities, and ecosystems have been widely acknowledged since the late 1950s (Elton, 1958; Lodge, 1993; Simberloff, 1996), and are now considered a significant component of global change (Vitousek et al., 1996). IS damage the lands and waters that native plants and animals need to survive, and it has been argued that IS are second only to habitat loss as the greatest threat to biological diversity (Wilcove et al., 1998). The severe economic impact of these species is evident; estimated costs of IS worldwide total more than $1.4 trillion – 5 percent of the global economy (Pimentel et al., 2001). In the United States alone, estimated economic damages and control costs associated with IS amount to roughly $120 billion annually (Pimentel et al., 2005). In response, Executive Order #13112 directed several federal agencies "to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause" (Fed. Regist. 1993:6183-86).

Previous studies examining landscape-aquatic relationships have typically correlated changes in ecological integrity with simple aggregates of landscape cover (e.g. percent forest) (Alberti et al., 2007). This paradigm has been reaffirmed since Klien's (1979) seminal work with dozens of regional investigations on how land cover composition relates to aquatic conditions (Roth et al., 1996; Thorne et al., 2000; Morley and Karr, 2002; Alberti et al., 2007; Shandas and Alberti, 2009). Specific to aquatic invasion, other relevant predictors include: factors that influence water quality, number of game fish, number and type of boat ramps, and proximity to roads (Buchan and Padilla, 2000); distance to nearest invaded waterway, lake size, alkalinity, Secchi depth, and lake depth (Roley and Newman, 2008); riparian use, substrate material, and debris (Maezo et al., 2010); and wave action, water-level drawdown, euphotic zone depth, aquatic vegetation shading, and native species present (Olson et al., 2012). Recently, studies have implied the importance of incorporating configuration metrics into landscape-aquatic condition research (e.g. Alberti et al., 2007; Shandas and Alberti, 2009). Configuration studies quantify landscape fragmentation through spatially explicit metrics, and their results can help diagnose distributional effects of land use or land cover on ecosystem services (Shandas and Alberti, 2009). Although previous studies have acknowledged the connection between land cover and aquatic invasion (e.g., Buchan and Padilla, 2000), few have directly investigated how the *patterns* of land cover influence the dispersal, survival, or propagation of aquatic invaders.

Non-indigenous species that become invaders are a growing threat to aquatic ecosystems. The development of appropriate management strategies to protect freshwater resources and services from aquatic invasive species (AIS) requires a thorough understanding of coupled human-environmental systems that support their dispersal, establishment, and spread. Much of AIS transmission has been linked to the overland movement of small-craft boats (e.g., Leung et al., 2006; Rothlisberger et al., 2010). Small-craft boats are vessels less than 40 feet (12.2 m) in length, including canoes and kayaks, personal watercraft, powerboats, small commercial and recreational fishing boats, sailboats, and pontoon boats, that can be towed overland on trailers (Rothlisberger et al., 2010). The spread of AIS by boaters can be intentional (e.g., bait dumping) or unintentional (e.g., bilge water), and are often attached on boat exteriors (e.g., entangled on propellers). AIS are known to have considerable negative effects on the aquatic ecosystems they invade with impacts including: damages to fisheries, interference with raw water usage, decreased property values, extirpation of native species, and threats to human health (Rothlisberger et al., 2010).

Efforts to stop AIS focus on cleaning boats at uninvaded waters and educating stakeholders on actions they can take to reduce transporting AIS. Most boat inspection and education sites occur at public ramps due to their accessibility, traffic volume, and presumed effectiveness. This water resources management strategy may underestimate the impacts private lake access sites have on AIS. Although small-craft boats are a known vector for propagating aquatic invaders, few studies document lake access type (e.g., private vs. public launch) impacts.

This study explores the role various lake and landscape metrics have in explaining an indicator of aquatic condition in 26 lakes within the Adirondack region of New York. Lake metrics include physical geography (e.g., elevation, lake area) and anthropogenic (e.g., boat ramps, distance to interstate) descriptors. Landscape metrics include both the amount (composition) and the spatial pattern (diversity) of land cover within 200 meters of a lake. Specifically, we ask how lake and landscape characteristics explain aquatic invasive species richness (AISR) using traditional parametric regression (ordinary least squares; OLS). To elucidate the different impacts private vs. public lake access is having on lake condition, logistic regression (generalized linear model; GLM) is utilized. Specifically, presence of public boat launches, and presence of private boat launches, was modeled with AISR, lake and landscape features. To illuminate progress of water resources management, presence of a lake assessment program is assessed against a measure of lake and landscape factors. To address these questions we test four null hypotheses: (1) no significant relationships exist between lake or landscape characteristics and AISR; (2) no significant relationship exists between lake and landscape characteristics, and the presence of a public small-craft ramps; (3) no significant relationship exists between lake and landscape characteristics, and the presence of a private small-craft ramps; and (4) presence of New York Citizen Statewide Lake Assessment Program (CSLAP) is not significantly related to AISR nor lake and landscape characteristics.

## METHODS

### Study Area

Twenty-six lakes were selected from the 88 invaded waters documented in the Adirondack Park Invasive Plant Program (APIPP) 2012 Annual Report (Figure 1). The lakes of this study represent various sub-regions of the Adirondack Park, and eight of the Park's twelve counties have representation. The Adirondack Park of New York, established in 1892, acts as a patchwork of private and public land uses that encompass both the largest area of state-level protected wilderness in the contiguous United States, as well as over 100 towns and villages (APA, 2011). The Park spans over 6 million acres (2.6 million hectares), and is comprised of diverse geographic locales, including millions of acres of northern hardwood and boreal forest, dozens of towering peaks, over 10,000 lakes, and more than 30,000 miles (48,200 km) of rivers and streams (APA, 2011). The Park offers its unique blend of wilderness solitude, outdoor recreation, and community life to millions of visitors who, in increasing numbers, see the Park as a unique travel destination. The Park is home to 132,000 fulltime and 200,000 seasonal residences; moreover, it's location between New York City and Montreal attracts roughly six million visitors annually (Sharp et al., 2001; APA, 2011).

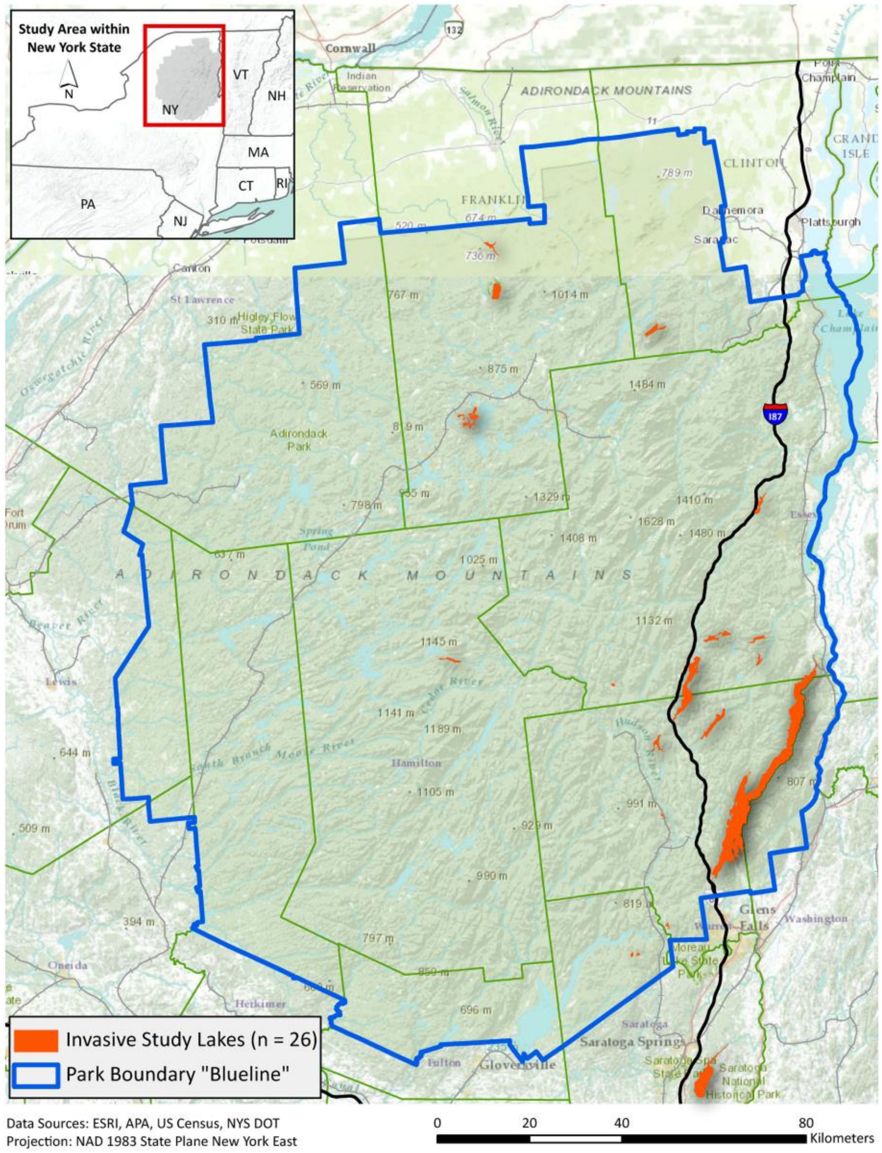


Figure 1. Study area location of 26 lakes within the Adirondack region of New York (43°56'N, 74°23'W).

The mixture of public and private lands is a distinguishing feature of the Adirondack Park. As of 2011, state ownership, private ownership, and water features account for 51%, 43%, and 6% of total Park area, respectively (APA, 2011). Major causes to aquatic impairment of the Adirondack Park are linked to poor land use practices, acidification of waters through regional deposition, and the spread of AIS. First documented in 1984 by the Adirondack Biota Project (ABP), 54% of the region's lakes have a pH below 5.5 (Nierzwicki-Bauer, 2010). Additionally, the Park receives levels of nitrate ($NO_3$-) and ammonium ($NH_4$+) deposition that are among the highest in the Northeastern United States (McNeil, 2006). Perhaps the greatest threat to biodiversity however (outside of direct habitat destruction), lies in the danger associated with invasive species. Aquatic and terrestrial invasive species in the region have the potential to completely disrupt the functioning of ecosystems, replace native species, and even destroy human-oriented constructions such as fisheries (Simberloff, 2005).

**Aquatic Invasive Species Richness**

In response to protecting the Adirondack region from the negative impacts of invading species, the Adirondack Partnership for Regional Invasive Species Management (PRISM) initiated APIPP in 1998. The Adirondack Chapter of The Nature Conservancy houses APIPP. APIPP coordinates two regional projects: the Aquatic Invasive Species Project and the Terrestrial Invasive Species Project. The forthcoming research uses data collected in 2012 by the Aquatic Invasive Species Project.

Over the past eleven seasons more than 597 APIPP volunteers surveyed 300 distinct waterways; 88 waterways are now recognized to have at least one non-native aquatic plant or animal present (APIPP, 2012). Currently, the number of "invasive-free" lakes surveyed by APIPP volunteers is more than 2.5 times that of infested lakes. Of the 88 invaded waterways, approximately 64 are considered public and 24 are private (APIPP, 2012). Since APIPP's inception, its volunteers have registered the following eleven aquatic flora and fauna throughout the region. Of those eleven AIS, nine were found present throughout the 26 lakes of this study: Asian Clam (*Corbicula fluminea*), Brittle Naiad (*Najas minor*), Curly-leaf Pondweed (*Potamogeton crispus*), Eurasian Watermilfoil (*Myriophyllum spicatum*), Fanwort (*Trapa natans*), Spiny Waterflea (*Bythotrephes longimanus*), Variable Leaf Milfoil (*Myriophyllum heterophyllum*), Water Chestnut (*Trapa natans*), Zebra Mussel (*Dreissena polymorpha*). An additive index of only the aquatic invaders found in each lake, AISR, is used in the ensuing analyses.

**Lake and Landscape Data**

The question of whether AIS are transmitted more through private or public boat ramps has rarely been asked. Although it can be assumed that the majority of small-craft boats are launched at public access points, AIS continue to be introduced into previously invasive free waterways. Examples of private launch sites seldom monitored include: private campgrounds, private marinas, waterfront residences, hotels and resorts. These rarely monitored launch sites create unregulated entry points that AIS can pass through. Further, to complicate aquatic management in the Adirondacks, most waterways have both private and public entry locations. To study the independent impact of access type, field data were collected for the 26 lakes. The following variables were collected for each lake in this study: elevation, depth, total boat access locations, percent private boat ramps, and percent public boat ramps. To collect field data, we used a 24' transient cruiser with 200 HP inboard/outboard (I/O) motor, 16' transient aluminum hull with 35 HP outboard motor, 6' inflatable zodiac with 4 HP outboard, and a 12' self-powered canoe. Geospatial field data were collected with Trimble Juno™ ST and Garmin E-trex™ GPS units for use during subsequent statistical analyses.

*Power metrics* consist of additive lake and landscape features. During *in situ* data collection, and cross-referencing a 30 m-resolution digital elevation model (DEM) provided by the USGS, lake elevation was recorded. Also during *in situ* data collection, mean lake depth was estimated using a Lowrance™ sonar for each of the 26 water-bodies. Using a 2004 hydrology dataset from the New York State Department of Environmental Conservation (NYSDEC), area and perimeter were calculated utilizing Geospatial Modelling Environment (www.spatialecology.com). Euclidian distance between nearest I-87 ramp and lake access point, and lake area was measured for each of the 26 lakes using ESRI's ArcMap 10.1.

*Landscape (composition)* and *(diversity)* were quantified using landscape ecology metrics developed for quantifying the spatial arrangement of land cover and land use (Turner et al., 2001; McGarigal et al., 2012). To establish a landscape-water interface, a 200 m buffer "lake landscape" was created for calculating landscape ecology metrics. This distance was chosen based on the inclusion of at least one entire adjacent property parcel to the lake. Land cover data were acquired through the National Land Cover Database (NLCD) (USGS, 2011). The 2006 NLCD land cover dataset was used for calculating land cover percent and diversity of each lake landscape. FRAGSTATS version 4.1 (McGarigal et al., 2012), free and publicly accessible software, was used for computing land cover compositions and landscape diversity for each lake landscape. NLCD land cover data were preserved at 30 m resolution. Sixteen land cover composition and six landscape diversity metrics were initially computed for each of the 26 lake landscapes. Landscape ecology metrics were calculated and then statistically reduced into a highly relevant subset. Details of landscape composition and diversity metrics can be found in McGarigal et al. (2012).

Pearson's correlation test was used to remove lake and landscape variables that exhibited a high degree of multicollinearity ($r > 0.75$). Six power, seven composition, and three landscape diversity metrics exhibited independence from each other and were used in the forthcoming OLS and GLM analyses (Table 1). In some cases, data distributions of predictor variables can be nonlinear (skewed). As in traditional regression, the results of a GLM can be significantly improved by transforming a skewed variable to linear distributions (Menard, 2002). To meet the assumptions of normality for all variables required during statistical tests, we used two types of transformation: arcsine square root (proportion data) and $\log_{10}$ (length/score data).

Table 1. Lake and Landscape Variables and Their Global Level of Spatial Autocorrelation

| Power metrics | Lake & landscape composition metrics | Landscape diversity metrics |
|---|---|---|
| Boat ramp total*** | % boat ramps - private*** | Relative patch richness (RPR)*** |
| Lake elevation** | % boat ramps - public | Simpson's diversity index (SIDI) |
| Lake area** | % Developed open space** | Simpson's evenness index (SIEI) |
| Lake mean depth** | % Deciduous forest | |
| Distance I-87 to ramp*** | % Evergreen forest | |
| AIS Richness | % Mixed forest* | |
| | % Woody wetland | |

*Denotes < 10 %, **Denotes < 5%, ***Denotes < 1% chance spatial pattern is random.

**Analysis**

In spatial environmental studies it is imperative to take into account spatial autocorrelation (Wagner and Fortin, 2005; Dormann *et al*., 2007; Rangel *et al*., 2010). Spatial autocorrelation is the lack of independence between pairs of observation at given distances in time and space, and is commonly found in environmental data (Legendre, 1993). Although other methods have been identified to assess spatial autocorrelation (e.g., Mantel's *r*-test), we selected the common and frequently used Global Moran's *I*-test. ESRI's ArcMap 10.1 Spatial Statistics toolbox was employed to assess the level of spatial autocorrelation of all variables of this study.

We tested relationships between the remaining fifteen independent lake or landscape metric and AISR using simple (OLS) regression. Models were compared and ranked based on their coefficient of determination ($R^2$) and corrected Akaike Information Criterion (AICc), respectively. As a preferred measure of model fit, the lower the AICc values the closer the approximation of the model is to reality; however a 'serious' difference between two models is when the difference in AICc differ by at least three (Fotheringham et al., 2004). We plotted regressions of the statistically significant models for each lake and landscape variable and AISR. The statistical software, JMP version 10 (SAS Institute, 2012), was implemented during this step of the analysis.

Geographers, ecologists, and environmental managers increasingly rely on predictive models as a means for estimating patterns of species distribution. In our case, logistic regression (GLM) was used to model the presence or absence of public small-craft ramps, private small-craft ramps, and CSLAP across 26 study area lakes. All possible combinations from the sixteen predictor variables were used to identify the most effective models for testing the aforementioned hypotheses. Logistic regression (Menard, 2002) is a statistical method that predicts the probability of an event occurring, in this case, the probability of public small-craft ramps, private small-craft ramps, or CSLAP occurring from various lake and landscape characteristics. Logistic regression is conceptually similar to OLS regression, because relations between one dependent variable and several independent variables can be tested. Whereas OLS returns a continuous value for the dependent variable, logistic regression returns the probability of a positive binomial outcome.

Logistic regression calculates several statistical parameters that determine the predictive success of the model (Menard, 2002). Identical to OLS, the p-values calculated can represent individual covariate statistical significance and overall significance of the logistic regression model. However, directional relationships, and the p-values of logistics regression often accompany a Chi-square score. We evaluated each GLM using McFadden's rho-squared ($\rho^2$), which is an attempt to approximate an OLS standard coefficient of determination ($R^2$). $\rho^2$ has the desirable property of ranging between 0 and 1, which makes it analogous to $R^2$; however estimates of $\rho^2$ and $R^2$ are not entirely equivalent, and it is commonly accepted that $\rho^2$ values greater than 0.2 indicate good fits (Terribile et al., 2009). All models were generated using the logistic regression module included in the free and publically available software Spatial Analysis in Macroecology (SAM) version 4 (Rangel et al., 2010).

## RESULTS & DISCUSSION

Taking all 26 sample lake locations into account, Global Moran's *I* analysis revealed varying levels of spatial autocorrelation across effect variables (Table 1). Nine of the sixteen lake and landscape variables had some degree of spatial clustering. Although the presence of spatial autocorrelation has been considered a shortcoming in hypothesis testing and prediction (Dormann et al., 2007), we include both spatially random and non-random predictors in the ensuing OLS and GLM analyses. To improve future AIS studies, autoregressive techniques should be considered and utilized where needed.

Results of the OLS regression analysis provided the basis for examining relationships between lake and landscape factors and AISR. From this study, aquatic invasion can be explained by lake power, landscape power, lake composition, landscape composition, and landscape diversity metrics. Of the fifteen models tested, nine independent lake and landscape predictors were found statistically significant (Table 2); four were power measures, two were composition metrics, and three were diversity measures (Figures 2 & 3). Four lake and landscape parameters were positively correlated with AISR: relative patch richness (RPR), lake area, total number boat ramps, and percent developed, open space. Five lake and landscape parameters were negatively correlated with AISR: lake elevation, Simpson's evenness index (SIEI), distance from I-87 to nearest boat launch, Simpson's diversity index (SIDI), and percent evergreen forest.

Table 2. Regressions between Lake and Landscape Predictors and Aquatic Invasive Species Richness (AISR)

| Model Rank | Parameter | Std. Beta Coeff. | t Ratio | Sig. | R-Square | AICc Value | Δ AICc |
|---|---|---|---|---|---|---|---|
| 1 | Lake elevation | -0.89 | -9.31 | *** | 0.78 | -62.97 | 0 |
| 2 | Relative patch richness (RPR) | 0.87 | 8.46 | *** | 0.75 | -59.16 | 3.81 |
| 3 | Lake area | 0.84 | 7.64 | *** | 0.71 | -55.29 | 7.68 |
| 4 | Total number of boat ramps | 0.76 | 5.72 | *** | 0.58 | -45.60 | 17.37 |
| 5 | Simpson's evenness index (SIEI) | -0.75 | -5.62 | *** | 0.58 | -45.06 | 17.91 |
| 6 | Distance: I-87 to boat ramp | -0.61 | -3.74 | *** | 0.37 | -35.17 | 27.80 |
| 7 | Simpson's diversity index (SIDI) | -0.48 | -2.70 | ** | 0.23 | -30.13 | 32.84 |
| 8 | % evergreen forest | -0.44 | -2.40 | ** | 0.19 | -28.82 | 34.15 |
| 9 | % developed, open space | 0.40 | 2.12 | ** | 0.16 | -27.68 | 35.29 |

** Significant at 5%. *** Significant at 1%.

Overall, the strongest power metric for explaining the variation of AISR was *lake elevation in meters* (Lake elevation, AICc = -62.97, $R^2$ = 0.78, $P < 0.001$). In the Adirondacks, streams connect many of the waterbodies suggesting that surface hydrology may be providing natural dispersal and accumulation pathways. Lake elevation, a surrogate for topography, could also be correlated with surficial and bedrock geology. Both of which have been found to be important factors governing water chemistry (Buchan and Padilla, 2000). The strongest composition metric for predicting AISR was the landscape land cover measure *percent evergreen forest* (% evergreen forest, AICc = -28.82, $R^2$ = 0.19, $P$ = 0.025). The negative relationship between evergreen forest and AISR is likely due to geochemical processes; moreover, increases in forest composition has been correlated with decreases in alkalinity (see Buchan and Padilla, 2000). Furthermore, increased abundance of evergreen forest may also reflect absence of land cover (e.g. agriculture) that influences trophic conditions. *Relative patch richness* (RPR), a popular landscape ecology measure of richness (McGarigal et al., 2012), was the strongest diversity measure for explaining the variation of AISR (AICc = -59.16, $R^2$ = 0.75, $P < 0.001$). The positive relationship between RPR and AISR reiterates the importance landscape plays in the hydrological system. The rise in land cover richness is likely linked to fragmentation of core habitat. Additionally, increases in land cover type suggest more human activity; changing levels of runoff, infiltration, temperature, and nutrients (e.g., phosphorus, nitrogen) that amplify lake invaders.

Thirteen lake and landscape GLMs were established for predicting the occurrence of public boat ramps (Table 3). Values of McFadden's $\rho^2$ ranged from 0.003 to 0.405 for predicting public boat ramps. Four variables had McFadden's $\rho^2$ values above the established threshold of 0.2; AISR, lake area, mean lake depth, and RPR were all positively associated to the presence of public boat ramps. This research supports that as lake area and depth increase so does their purpose, and thus the demand for more public small-craft launches. The positive association between presence of public boat ramps and RPR illuminates the connection between increased human activity and landscape fragmentation. The positive relationship between presence of public boat ramps and AISR reiterates that increased public lake access and use escalates the spread of aquatic invaders.

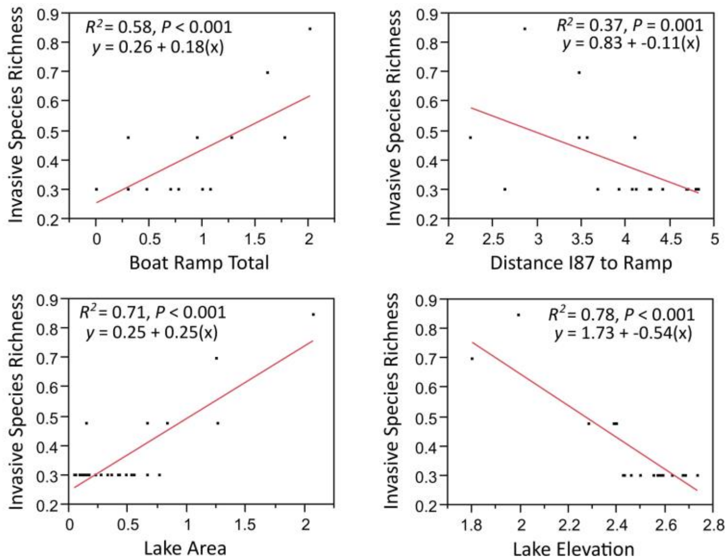


Figure 2. Scatter plots of lake metrics ($Log_{10}$ transformed) and aquatic invasive species richness (AISR) ($Log_{10}$ transformed) using bivariate regression.

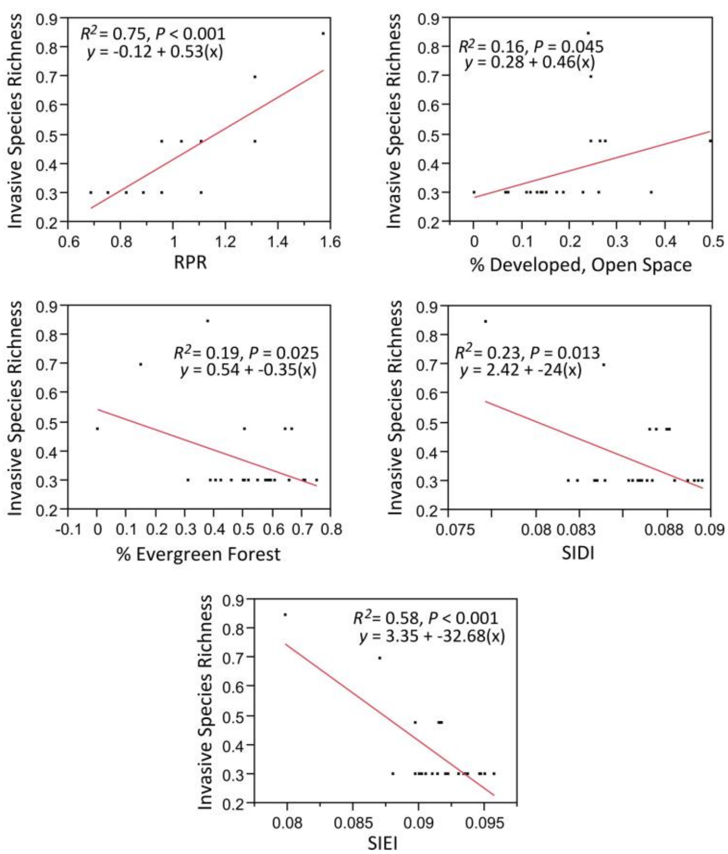


Figure 3. Scatter plots of landscape metrics (ArcSinSqrt transformed) and aquatic invasive species richness (AISR) ($Log_{10}$ transformed) using bivariate regression.

Table 3. Lake and Landscape GLMs Associated with Presence of Public Boat Ramps

| Effect variable | McFadden's rho-square | Chi-square | Std. Coeff. | *P*-value | True Skill Statistic (TSS) |
|---|---|---|---|---|---|
| **Invasive species richness** | **0.200** | **6.92** | **28.73** | **0.0085** | **0.38** |
| **Lake area** | **0.405** | **14.03** | **8.11** | **0.0002** | **0.59** |
| **Lake mean depth** | **0.251** | **8.71** | **3.00** | **0.0032** | **0.53** |
| Elevation | 0.099 | 3.44 | -2.13 | 0.0637 | 0.38 |
| **Distance I87 to ramp** | **0.122** | **4.21** | **-2.14** | **0.0402** | **0.28** |
| **% Developed open space** | **0.116** | **4.02** | **1.92** | **0.0451** | **0.58** |
| % Deciduous forest | 0.098 | 3.39 | -1.62 | 0.0655 | 0.21 |
| % Evergreen forest | 0.057 | 1.98 | -1.34 | 0.1596 | 0.19 |
| % Mixed forest | 0.020 | 0.70 | 0.74 | 0.4024 | 0.13 |
| % Woody wetland | 0.003 | 0.11 | -0.28 | 0.7393 | 0.00 |
| **RPR** | **0.209** | **7.23** | **3.68** | **0.0072** | **0.40** |
| SIDI | 0.010 | 0.36 | -0.52 | 0.5489 | 0.06 |
| **SIEI** | **0.158** | **5.47** | **-3.01** | **0.0194** | **0.34** |

Thirteen lake and landscape GLMs were established for predicting the occurrence of private boat ramps (Table 4). Values of McFadden's $\rho^2$ ranged from 0.005 to 0.431 for predicting private boat ramps. Two variables had McFadden's $\rho^2$ values above the established threshold of 0.2; distance from I-87 to ramp and elevation were both negatively associated to the presence of private boat ramps. Although below the established McFadden's $\rho^2$ threshold of 0.2, AISR was found positively associated with the presence of private boat ramps at the 95 percent confidence level. Distance from I-87 and elevation being negatively associated with presence of private boat ramps are likely due to increased demand of private recreational property within proximity of New York City. Although lower statistical support relative to public lake access, the positive relationship found between presence of private boat ramps and AISR elucidates their independent impacts on propagating aquatic invaders.

Table 4. Lake and Landscape GLMs Associated with Presence of Private Boat Ramps

| Effect variable | McFadden's rho-square | Chi-square | Std. Coeff. | *P*-value | True Skill Statistic (TSS) |
|---|---|---|---|---|---|
| **Invasive species richness** | **0.104** | **3.73** | **2.30** | **0.0533** | **0.27** |
| **Lake area** | **0.114** | **4.10** | **2.16** | **0.0429** | **0.29** |
| **Lake mean depth** | **0.105** | **3.77** | **1.65** | **0.0523** | **-0.02** |
| **Elevation** | **0.290** | **10.41** | **-4.75** | **0.0013** | **0.49** |
| **Distance I87 to ramp** | **0.431** | **15.48** | **-5.91** | **<0.0001** | **0.56** |
| **% Developed open space** | **0.158** | **5.65** | **2.27** | **0.0174** | **0.06** |
| **% Deciduous forest** | **0.158** | **5.68** | **-2.21** | **0.0172** | **0.13** |
| % Evergreen forest | 0.005 | 0.16 | -0.32 | 0.6886 | 0.00 |
| % Mixed forest | 0.077 | 2.77 | 1.52 | 0.0960 | 0.06 |
| % Woody wetland | 0.011 | 0.39 | 0.50 | 0.5325 | 0.00 |
| **RPR** | **0.184** | **6.62** | **2.93** | **0.0101** | **0.27** |
| SIDI | 0.013 | 0.47 | 0.55 | 0.4918 | 0.00 |
| SIEI | 0.007 | 0.28 | -0.43 | 0.5983 | 0.00 |

Fourteen lake and landscape GLMs were established for predicting the occurrence of a lake assessment program (Table 5). Values of McFadden's $\rho^2$ ranged from 0.002 to 0.491 for predicting CSLAP. Five variables had McFadden's $\rho^2$ values above the established threshold of 0.2. AISR and total boat ramps were both positively associated with the presence of CSLAP. Elevation, distance from I-87, and percent deciduous forest were all negatively associated with the presence of CSLAP. The positive relationships between AISR and total boat ramps with CSLAP denote that environmental management groups are self-organizing to waterbodies with increased human activities, and their correlated aquatic invaders. The negative variables associated with CSLAP suggest that geography is important for further understanding water resources management. Elevation and percent deciduous forest are connected to geochemical processes of water chemistry, which are likely controlling aquatic invaders. Distance from I-87 is directly related to proximity of New York City, and its distance decay influence on population density. Thus, as you get further from I-87 there are fewer stakeholders, and the absence of need for aquatic management, to develop a lake association.

Table 5. Lake and Landscape GLMs Associated with Presence of New York Citizens Statewide Lake Assessment Program (CSLAP)

| Effect variable | McFadden's rho-square | Chi-square | Std. Coeff. | *P*-value | True Skill Statistic (TSS) |
|---|---|---|---|---|---|
| **Invasive species richness** | **0.319** | **11.46** | **29.15** | **0.0007** | **0.50** |
| **Lake area** | **0.154** | **5.52** | **2.51** | **0.0189** | **0.25** |
| **Lake mean depth** | **0.178** | **6.38** | **2.25** | **0.0115** | **0.02** |
| **Elevation** | **0.491** | **17.62** | **-7.44** | **<0.0001** | **0.60** |
| **Distance I87 to ramp** | **0.460** | **16.50** | **-5.79** | **<0.0001** | **0.51** |
| **% Developed open space** | **0.156** | **5.61** | **2.24** | **0.0178** | **0.17** |
| **% Deciduous forest** | **0.407** | **14.59** | **-5.52** | **0.0001** | **0.35** |
| % Evergreen forest | 0.002 | 0.06 | -0.19 | 0.8115 | 0.00 |
| % Mixed forest | 0.024 | 0.86 | 0.75 | 0.3541 | 0.00 |
| % Woody wetland | 0.002 | 0.06 | -0.19 | 0.8128 | 0.00 |
| **RPR** | **0.160** | **5.73** | **2.39** | **0.0167** | **0.25** |
| SIDI | 0.018 | 0.64 | -0.64 | 0.4256 | 0.00 |
| SIEI | 0.072 | 2.59 | -1.51 | 0.1073 | 0.08 |
| **Boat ramp total** | **0.362** | **12.98** | **4.36** | **0.0003** | **0.58** |

## CONCLUSIONS

Our analysis provides empirical evidence that the spread of aquatic invaders is impacted by a multitude of lake and landscape variables across waterbodies in the Adirondack region of New York. Nine bivariate regression models between lake or landscape variables and AISR were found statically significant. Thus, the first null hypothesis of no significant relationships existing between lake or landscape characteristics and AISR is rejected. Many studies have addressed relationships between small-craft boats and the propagation of AIS, but few have directly asked how private verses public lake accessibility impact the spread differently. This study suggests that public launches are impacting aquatic systems slightly more than private launches, but both lake access types increase aquatic invasion. Since both the presence of public small-craft ramps and presence of private small-craft ramps were statically associated with lake or landscape characteristics, the second and third null hypotheses are also rejected. The fourth and final null hypothesis stated that presence of CSLAP is not significantly related to AISR nor lake and landscape characteristics. This null hypothesis is also rejected because both AIS richness and lake and landscape characteristics were statistically relevant to the presence of a lake association.

Although other aquatic invasion studies have investigated relationships with landscape composition, few have directly asked how landscape patterns influence their spread. Simple aggregated measures of landscape are only coarse predictors of aquatic ecological condition, thus providing a limited amount of information to environmental managers. Our results suggest that landscape *patterns* are more important predictors of aquatic invasion than broad composition measures. Agreeing with Alberti et al. (2007), landscape configuration and diversity measures provide much needed information to planners, natural resource managers, and landscape design specialists that cannot be addressed with simple aggregates of land cover. A more robust study of aquatic invasion could be used to create risk probability maps of regionally non-invaded waterways. Future studies of aquatic invasion should closely examine the mechanisms linking landscape class configuration with individual species. By doing so, an improved understanding of how and where to emphasize specific aquatic management measures (e.g., conservation zones) can emerge.

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