PREDICTIVE ANALYSIS OF INVASIVE SPECIES - THE CASE OF *PHRAGMITES AUSTRALIS* (COMMON REED) ALONG THE RAPPAHANNOCK RIVER BASIN

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ABSTRACT

This paper uses statistical predictive analysis to explore likely locations in Essex County, Virginia for *Phragmites Australis*, an invasive wetland species that has expanded its range since 1960 to an additional 18 US States. Over forty geospatial factors were used in the analysis which generates a likelihood surface predicting where additional stands of this species may be expected. Factor metrics that reveal geospatial signatures from hotspot areas sharing similarities with those signatures from sampled data are compared using weighted likelihood, mean contribution, and contrast measures. Future research will test model accuracy through field investigation of the predicted high-likelihood locations, and examine hyperspectral vegetation indices for those areas. This research contributes to improved *Phragmites* detection methods using remote sensing and GIS technology.

***Phragmites australis* overtaking a wetland**

Source: http://www.nps.gov/plants/alien/fact/pdf/phau1-powerpoint.pdf

INTRODUCTION AND OBJECTIVES

This research presents the results of a geospatial predictive analysis of the invasive species *Phragmites australis* [Cav.] Trin. ex Steud, or “common reed”, along the Rappahannock River, a region which overlays nine counties in Virginia where aerial surveys were taken in 2006 and 2007 by the Virginia Department of Conservation and Recreation (VCUCES et al., 2007). The modeling tool inductively calculates the empirical relationship between the measured events, or sample data, and factors found in the environment by revealing spatial patterns (SPADAC, Inc., 2008). The model adjusts for the relative contribution of each of forty-three (43) spatial factors, from land cover, elevation, slope, soil, geologic structure, and anthropogenic features such as road type, road intersections and shoreline built structures such as docks and protective features (riprap, groins). Limitations of the model mainly relate to those inherent in sampled data, and the edge effects caused by limiting the study area to the administrative boundary of Essex County, Virginia.

The results produce a raster surface consisting of 250m grid cells, showing higher geospatial signature similarity in some areas that were not surveyed. The model's contrast measure, weighted likelihood and relative contribution of each factor produce an overlay that may point conservation scientists and land planners to where additional *Phragmites* patches may be found. The mode of expansion and the environmental conditions suitable for colonization, as well as ecological effects of this species will be discussed. Knowledge of such environmental conditions and effects were used to guide the collection of geospatial factors expected to play a role in identifying unsampled locations, and may help in reducing management costs.

HISTORY AND BACKGROUND OF AN INVADER

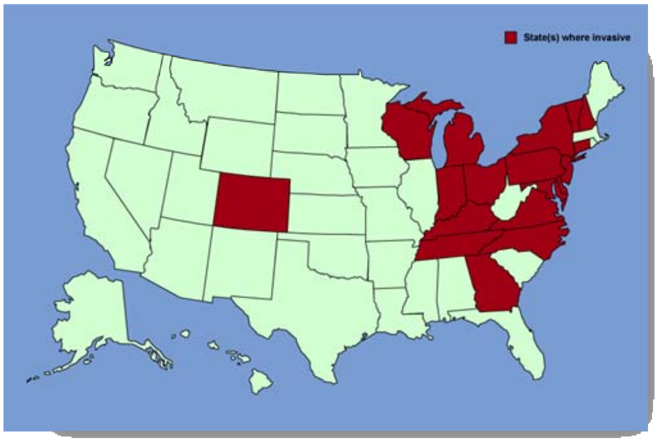


Figure 1. Source: Plant Conservation Alliance, US National Park Service.

Phragmites australis, listed in the US Department of Agriculture National Invasive Species Information Center, is considered invasive in eighteen states, as depicted in Figure 1. *Phragmites australis*, hereafter referred to as simply *Phragmites,* is a tall, perennial, rhizomatous grass that often grows in dense monotypic stands effectively out-competing other vegetation (Richburg, et. al, 2001). In wetlands, it has a negative effect on species richness. Additionally, its height at maturity, approximately 3m tall, tends to obscure sunlight from lower strata (Prisloe, et. al, 2006), and the buildup of litter from previous years' growth restricts the germination of alternate species (Univ. of Me., 2004). Despite its demonstrated historical existence (Saltonsall, 2002, Darwish & Awad, 2002, Nierin & Warren, 1977), scientists began to question whether increasing *Phragmites* abundance may be due to a genetic drift which allowed the species to live at lower elevations than previously possible (Amsberry, 2000). Amsberry (2000) revealed that *Phragmites* has expanded across elevation gradients in salt marshes. It spreads through rhizome growth to lower elevations, a mode of vegetative expansion observed largely in the past three decades. Orson (1999) concluded the spread of the non-native *Phragmites* implied either genetic adaptation, or a change in environmental conditions more favorable to abundance of this species. This paper analyzes the factors contributing to many of those environmental conditions.

Conditions Suitable for Phragmites Invasion and Their Ecological Effects

The following factors and ecological effects were suggested to explain the apparent resurgence of *Phragmites* populations along the Eastern seaboard and the Minnesota Interstate highway system: 1) restriction of tidal flow caused by human constructed barriers, 2) increased sedimentation in marshes (again, caused by soil disturbances that result from construction activity), 3) increased road salt runoff (a natural result of more roadbuilding and treatment), and 4) increased nutrient runoff from farms and treated urban greenery (Pellegrin, 1999). It is suggested these ecological and environmental conditions allow the species to compete more successfully than other macrophytes, resulting in invasive spread, and that limiting marsh disturbance is the best way to control *Phragmites* since disturbance-affected areas tend to have less vegetation to begin with which allows the *Phragmites* to expand (Amsberry, 2000).

Researchers have continued to evaluate how changes in wetland ecology may create conditions more favorable to the invasive form of *Phragmites*. There has also been a noticeable increase in the detection of *Phragmites* growing along roadside drainage ditches (Jodoin, et. al., 2008). Such habitats result from the disturbance of road-building, which creates a favorable habitat for this generalist species. Pellegrin (1999) noted the increase in *Phragmites* in Minnesota over the Atkinson's Marsh region was correlated with the construction of a new interstate highway over the marsh. Lelong et. al., (2007) revealed strong association of highway expansion to *Phragmites* growth in Quebec, Canada in the last 20 years whereby the introduced strain has replaced its native counterpart. The results of these studies and others point us to the need to utilize geospatial factors in our analysis which might serve as indicators of disturbance.

GEOSPATIAL FACTORS SELECTED FOR THE PREDICTIVE ANALYSIS

The above discussion of the ecological effects of *Phragmites* infestation and the conditions favorable to its spread formed the basis for selecting possible contributory factors in a geospatial predictive analysis. The forty-three geospatial factors selected were represented by both raster and vector data. These data can be organized into the main categories of *anthropogenic disturbances* (roads classified by road type, road intersections, road-stream intersections, shoreline built structures, impervious surface cover, census block polygons), *wetland indicators* (wetlands from National Wetlands inventory, streams, census hydrologic boundaries, water land cover, palustrine emergent wetland cover, estuarian emergent wetland), *geologic structure* (elevation, slope (0 to 2m, 2 to 6m, 6 to 15m, 15 to 50 m)) and *soils and land use* (loamy composition, sandy composition). All factors were saved in WGS84 Datum and projected to UTM 18N before modeling. Table 2 describes the factors used in the analysis, their datatype, source, and factor type function values as well as their contrast measure and

Table 1. Factors used to predict Phragmites likelihood

FACTOR	DATATYPE	SOURCE
Anthropogenic Disturbance		
Shoreline Defense Structure (Bulkhead, Riprap, Marina)	Polyline	VA Institute of Marine Science
Struct. Height 0-5ft	Polyline	VA Institute of Marine Science
Struct. Height 5-10ft	Polyline	VA Institute of Marine Science
Struct. Height > 10ft	Polyline	VA Institute of Marine Science
Beach Eroding = Y	Polyline	VA Institute of Marine Science
Bank Eroding = Y	Polyline	VA Institute of Marine Science
Marsh Eroding = Y	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 6 (bare)	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 5 (commercial)	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 4 (residential)	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 3 (grass)	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 2 (scrub-shrub)	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 1 (forested)	Polyline	VA Institute of Marine Science
Riparian Land Use FEATURE = 10 (agriculture)	Polyline	VA Institute of Marine Science
Impervious Surface	Raster	USGS
Essex Surrounding Census Blocks	Polygon	US census Tiger/Line shapefiles
Essex Streams Intersecting roads	Point	Created from Census Tiger/Line and hydrology data
Essex Road Intersections	Point	Created from Census Tigerline
Essex Road Endpoints (to represent cul-de-sacs)	Point	Created from Census Tigerline
Shoreline Defense Structures	Polyline	VA Institute of Marine Science
Shoreline Access to Recreation	Polyline	VA Institute of Marine Science
Essex Urban Roads	Polyline	Census Tiger/Line
Essex Hydroline	Polyline	Census Tiger/Line
Essex Tertiary Roads	Polyline	Census Tiger/Line
Essex Secondary Highway	Polyline	Census Tiger/Line
Essex Primary Highway	Polyline	Census Tiger/Line
Essex New Roads	Polyline	Census tigerline
Wetland Indicators		
Essex Streams	Polyline	USGS
Unconsolidated Shoreline	Polyline	Virginia Institute of Marine Science
Palustrine Emergent Wetland	Point	National Wetlands Inventory Program
Estuarine Emergent Wetland	Point	National Wetlands Inventory Program

Essex Wetlands	Polygon	National Wetlands Inventory Program
Water Landcover	Polygon	
Geologic Structure		
Digital Elevation Model	Raster	USGS from 7.5' DEMS, with each cell representing 30m
Slope 0 – 2 meters	Polygon	SSURGO Soil Data Mart
Slope 2 – 6 meters	Polygon	SSURGO Soil Data Mart
Slope 6 – 15 meters	Polygon	SSURGO Soil Data Mart
Soils and Land Use		
Land Cover in Essex County	Raster	NOAA's Ocean Service, Coastal Services Center (CSC)
Sandy Soil	Polygon	SSURGO Soil Data Mart
Loamy Soil	Polygon	SSURGO Soil Data Mart

METHODS

The Signature Analyst™ model was used to load all 43 factors (SPADAC, 2008). The distance values between each event cell and the included factors, and the AOI cells and the included factors were calculated for raster and vector data using Nearest Neighbor Value, Nearest Neighbor Category (for categorical data), and for several vector data, Nearest Neighbor Distance was used. The AOI grid was reduced from the entire county footprint, shown as the original red polygon outline, to a wetlands-only boundary roughly buffering the Rappahannock river basin (shown in blue in Figure 2), with contributions from the York River basin wetlands in the southern portion of the county removed. The small green dots mark each *Phragmites* sample point.

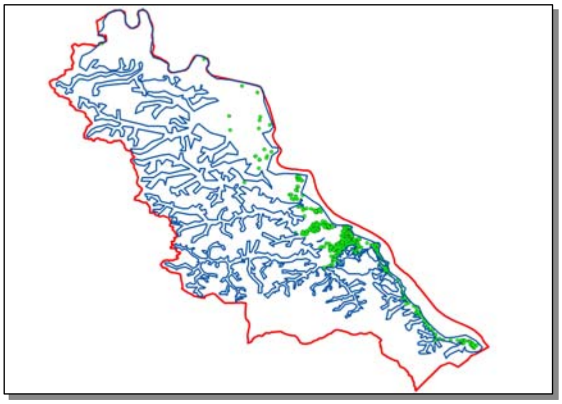


Figure 2. Wetland-derived Area of Interest Buffer.

This allowed the model to run against an AOI reduced in size by 58.1% from the entire size of Essex County, effectively masking out non-wetland areas where the species is not found, and reducing initial computation build time to only 3 minutes on a dual-core L770 1.8Ghz tablet PC.

Phragmites data were collected via helicopter overflights during July and August of 2006 and 2007 using GPS to record patch area in the Rappahannock River watershed as well as the Atlantic seaside of Virginia (Myers, et. al, 2007). Phragmites patch samples designated as 'invasive' and only those intersecting the 2006 census boundary of Essex County, Virginia were extracted from the dataset, generously provided by the Virginia Department of Conservation and Recreation (see VDCR web site: http://128.172.160.130/phrag/). It is the only available geospatial data directly measuring the extent of *Phragmites* infestation along the Rappahannock, which is considered a key part of the Chesapeake Bay watershed. The 553 sampled "event" points were represented by the centroids of each *Phragmites* patch, with baseline patch statistics listed in Table 2. There is wide variation in patch size, with σ of 87m^2. However, patch complexity is low due to the many simple circular patch shapes recorded in the original data collection.

Table 2 – Phragmites Patch Statistics

# of samples	Mean Sample Area	Largest Patch	Smallest Patch	σ	Edge Density (Patch Complexity)	Total Area	Total Perimeter
553	51.6 m^2	337 m^2	6m^2	87 m^2	6.8%	1,474,502m	99,795m

A dendrogram was calculated to visually cue on clustering of the points in feature space. Although some clusters appear more dense than others, we do not see any anomalies showing strong sample point dissimilarity, revealing limited utility of the dendrogram shown in Figure 3 for evaluating clustering for this large sample set.

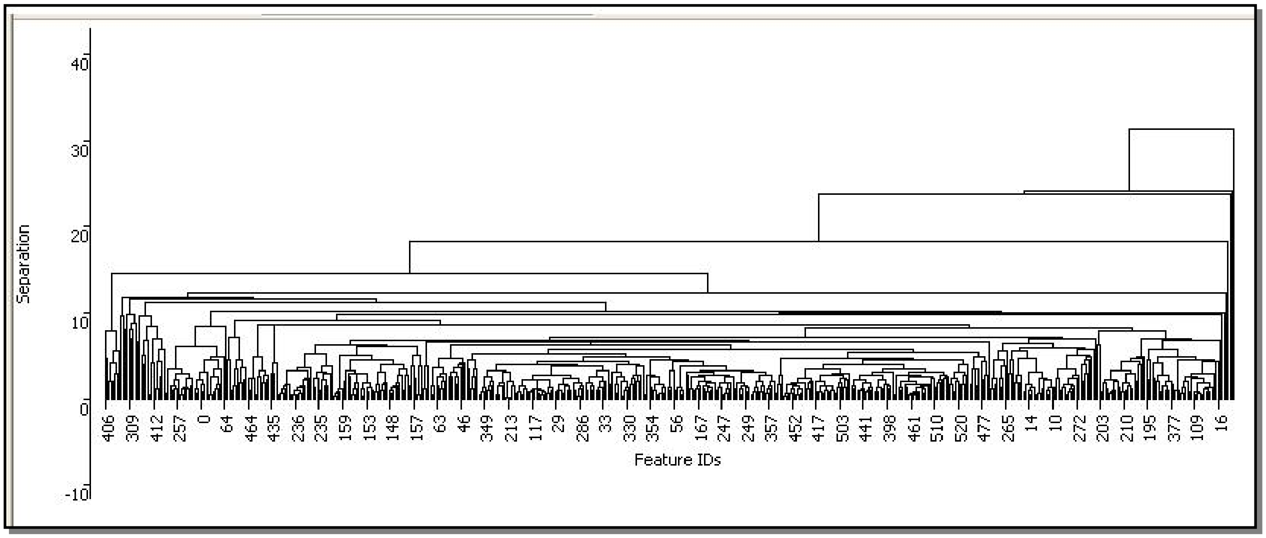


Figure 3. Dendrogram of Phragmites Patches.

Figure 4 shows the wetlands and rivers intersecting the Essex County boundary. The National Wetlands Inventory data from tiles intersecting Essex County were mosaicked for use in the analysis. The Rappanannock River is portrayed in pink flowing from the Northwest to the Southeast portion of the figure.

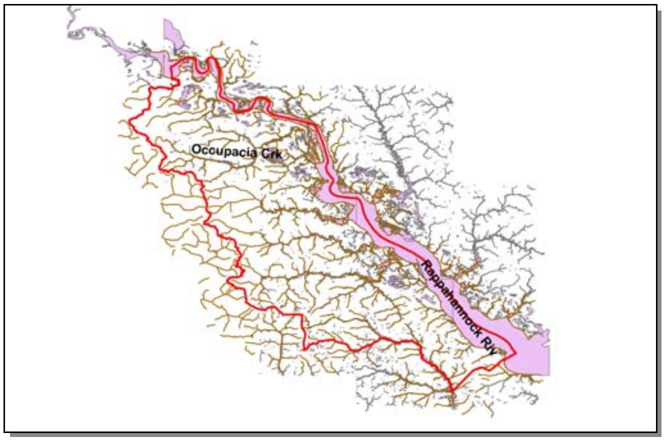
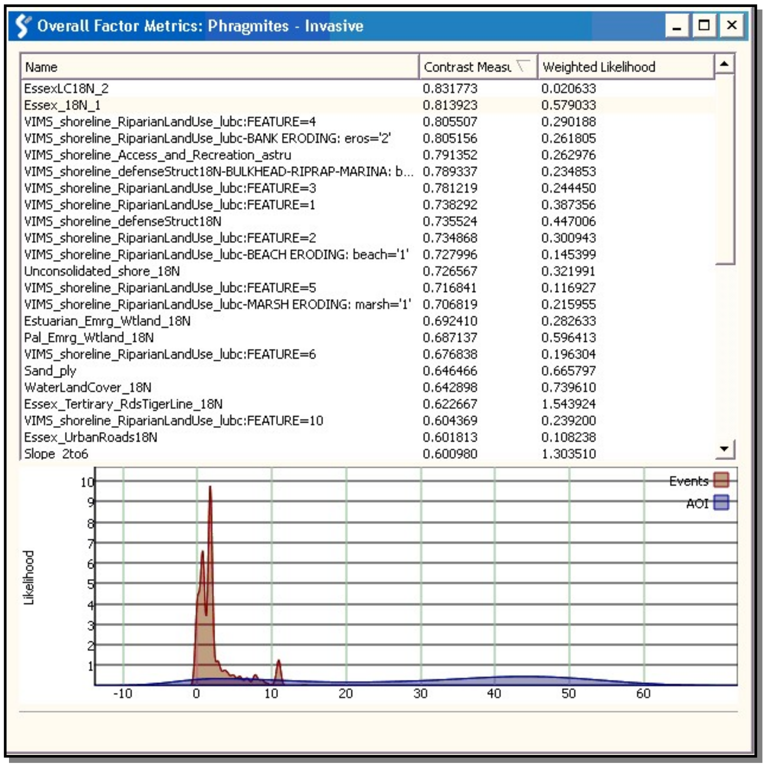


Figure 4. Wetlands areas in brown, Rappahannock in pink.

DISCUSSION

Factor metrics produced by the model to be considered here include *contrast measure*, *contribution*, and *weighted likelihood. Contrast measure* calculates the difference between the sampled patch location probability density function (PDF) and the PDF for the entire area of interest. Greater differences produce a greater value, meaning the factor plays a greater role in distinguishing differences with background landscape (SPADAC, Inc., 2008). The Digital Elevation Model factor, for example, shows marked contrast from the entire AOI, with two PDF peaks at elevations of approximately 1 meter and again at almost 2 meters, displayed in Figure 5. This is an expected result for a wetland species. Also very high in contrast are several factors developed from the Virginia Institute of Marine Science dataset. These are riparian areas classified as 'RESIDENTIAL' (FEATURE value = '4'), followed by areas where the river bank is classified as 'ERODING' (EROS='2'), and then areas where recreational structures have been built for access to the shoreline (Berman, et. al., 2001) with contrast measures of 0.81, 0.81 and 0.79 respectively. One may conclude the disturbance caused by residential construction and its concomitant shoreline erosion from increased impervious surface runoff display better explanatory power in the model.



Name	Contrast Measu	Weighted Likelihood
EssexLC18N_2	0.831773	0.020633
Essex_18N_1	0.813923	0.579033
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=4	0.805507	0.290188
VIMS_shoreline_RiparianLandUse_lubc-BANK ERODING: eros='2'	0.805156	0.261805
VIMS_shoreline_Access_and_Recreation_astru	0.791352	0.262976
VIMS_shoreline_defenseStruct18N-BULKHEAD-RIPRAP-MARINA: b...	0.789337	0.234853
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=3	0.781219	0.244450
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=1	0.738292	0.387356
VIMS_shoreline_defenseStruct18N	0.735524	0.447006
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=2	0.734868	0.300943
VIMS_shoreline_RiparianLandUse_lubc-BEACH ERODING: beach='1'	0.727996	0.145399
Unconsolidated_shore_18N	0.726567	0.321991
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=5	0.716841	0.116927
VIMS_shoreline_RiparianLandUse_lubc-MARSH ERODING: marsh='1'	0.706819	0.215955
Estuarian_Emrg_Wtland_18N	0.692410	0.282633
Pal_Emrg_Wtland_18N	0.687137	0.596413
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=6	0.676838	0.196304
Sand_ply	0.646466	0.665797
WaterLandCover_18N	0.642898	0.739610
Essex_Tertiary_RdsTigerLine_18N	0.622667	1.543924
VIMS_shoreline_RiparianLandUse_lubc:FEATURE=10	0.604369	0.239200
Essex_UrbanRoads18N	0.601813	0.108238
Slope 2to6	0.600980	1.303510

Figure 5. DEM PDF, showing factors with highest contrast measure, or model explanatory power.

In terms of average *contribution* to the model result, the top five factors are soil type = 'Loam', Slope 0 to 2 m, Tertiary Roads (similar to neighborhood streets), Slope 2 to 6 m, and Wetland areas, with mean contributions over the entire area of interest of 0.308, 0.28, 0.277, 0.23 and 0.219, respectively. *Contribution* subtracts the global minima of an assessment layer from the weighted likelihood, L_w, of a factor, helping to de-emphasize those factors having minimal relative variance.

The third value associated with the model's assessment is the *weighted likelihood*. First, the model calculates the likelihood in units of probability density (*probability of occurrence / area*) of any area of geographic space by normalizing the sum of likelihoods. This value is multiplied by a factor's weight in the model, to produce the weighted likelihood, which does change over geographic space. A *weighted likelihood* in one area of the Essex County AOI would be different than another area. In this case, the weight used was equivalent to the factor's contrast measure, producing the following:

$$L_w = C * (P / A)$$

where L_w = weighted likelihood, C = contrast measure, and (P/A) represents likelihood probability density (SPADAC, 2008).

LIMITATIONS OF MODELING PROCESS

Limitations of this study include possible Type II errors in the collection of training points, and the lack of samples collected from portions of the York River basin that extend into the Southern part of the Essex county, whose possible influence on model outcome was not considered. Despite several studies evaluating the importance of water quality in *Phragmites* expansion, the sampling site data available for water quality were too course. This was not a temporal study of modal dispersion, but instead a predictive analysis assuming a single point in time, therefore no conclusions can be drawn regarding species rate of expansion. Additional data that would have been helpful but which were not available were feature samples of companion species often found in the same relative habitat as *Phragmites* such as *Typha spp.* (cattails), and *Spartina patens* (saltmeadow cordgrass) (Prisloe et. al, 2006). Hyperspectral imagery over this same small area would also have provided yet another data source for comparison, and will be sought for future efforts evaluating the spectral reflectance of the *Phragmites* patches in comparison to the Signature Analyst™ model outcome.

RESULTS AND CONCLUSIONS

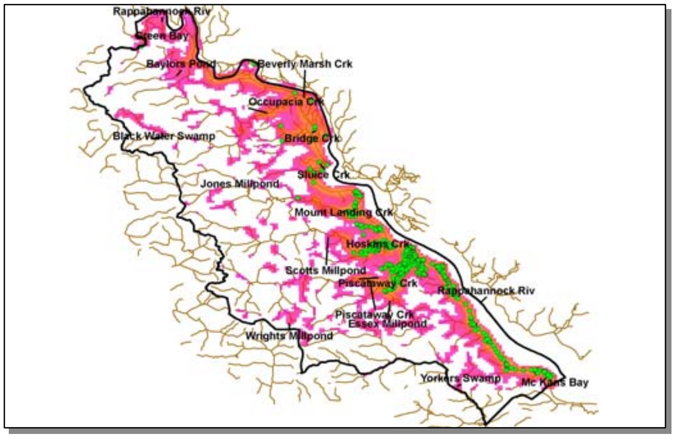
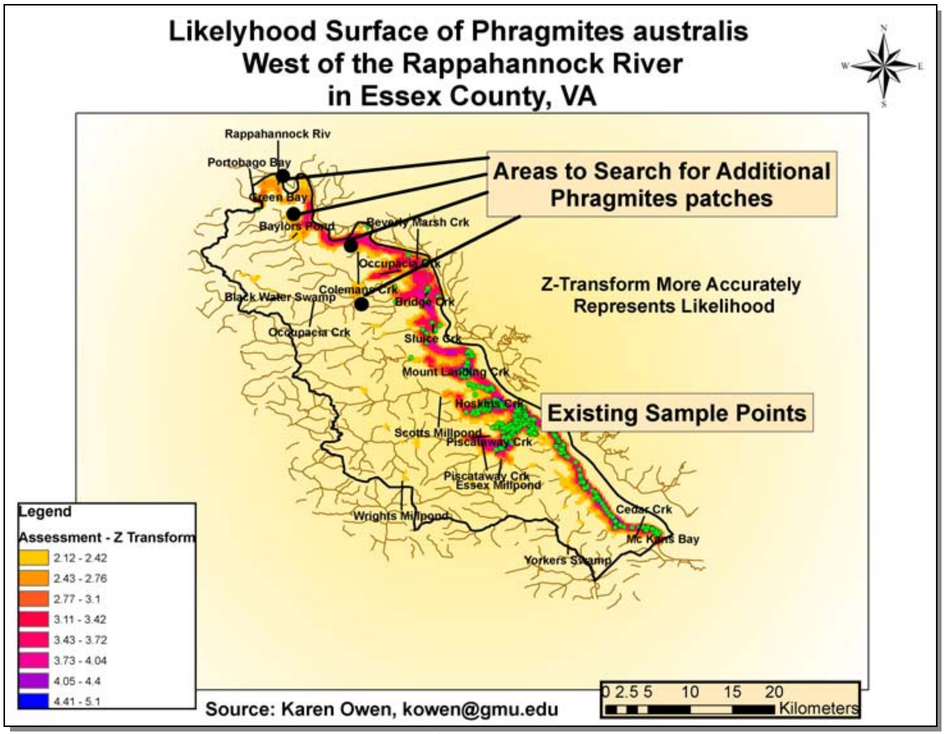


Figure 6. Top 10% of cells from model outcome.

The Signature Analyst™ model's geospatial signature reveals the possibility of *Phragmites* in the northern part of the county near Baylor's Pond and Green Bay as well as an expanded region along Occupacia Creek. Approximately 5-7km west of the Rappahannock River, Cheatwood Millpond, Sturgeon Swamp and Wrights Millpond are additional areas that share similar characteristics as the sample points, and are identified in Figure 6. Although no certainty exists that these areas have *Phragmites,* the factors near them are statistically similar to the factors at sample points. When the model factors are normalized using the Z-Transform method, the top ten percent of likely cells emerge more clearly pointing to the northwest region of the county in an area that was not detected in the original sampling effort. Figure 7 maps the region and draws attention to the northwest part of the study area where field work should follow. The legend units are simply relative likelihood values and do not represent exact probabilities. Areas with zero likelihood are masked out from the map. These are areas of no statistical significance in comparison to the sample points.



Source: Karen Owen, kowen@gmu.edu

Figure 7.

Given the large investment in regional and local biological control for invasive species, predicting where additional populations may be found in a study area can help avoid expensive aerial sampling and help to limit ground-based measurements by focusing resources where they are needed most.

FUTURE RESEARCH

The next phase of the research will involve field work to test the predictive accuracy of the model. After field work confirms or recants the suspected existence of the invader in previously unrecorded areas, follow-on efforts will incorporate hyperspectral remote sensing into the analysis. Reflectance values of the species in nearby regions could be measured radiometrically on the ground, to provide support for ensuing work to capture similar signatures in hyperspectral imagery (HSI) and enhance more rigorous scientific inquiry into spectral analysis of this species in wetland areas. The goal would be to identify, with reasonable accuracy through geospatial signature analysis, those areas likely to contain *Phragmites*, and then confirm this with HSI over those same areas. The ability to locate the species in previously unsampled areas with only a training data set and publicly available geospatial factor data is a valuable step toward regional control.

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