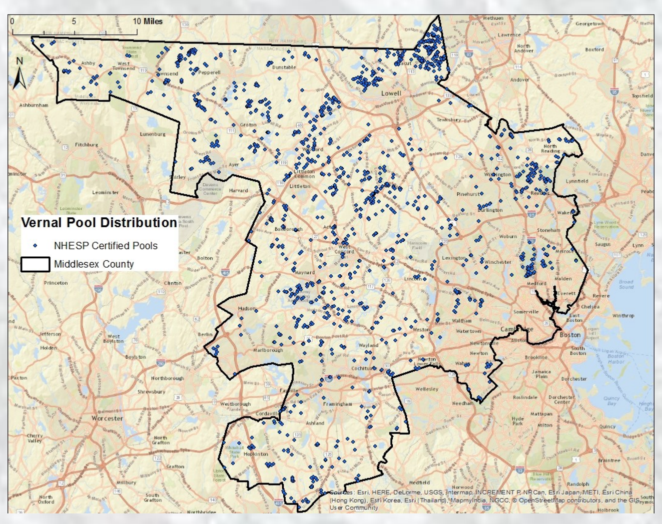
Reducing Road Deicing Salt for Vernal Pool Protection:

Fuzzy and Non-Fuzzy Methods in Middlesex County, MA

Introduction



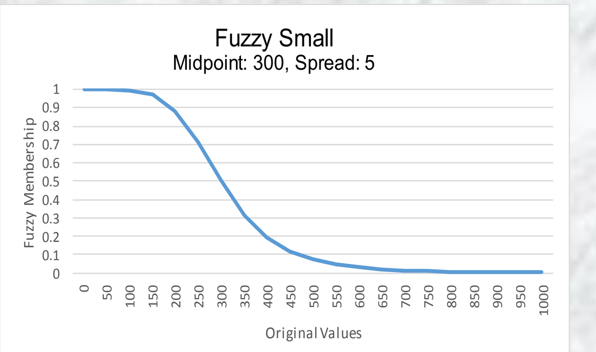
Vernal pools (ephemeral pools, autumnal pools, temporary woodland ponds), are "critical habitats" for many amphibian species as well as invertebrates and reptiles. Identification can be difficult because of the temporal variance in pool presence, but once a pool has been found it can be certified by the Natural Heritage and Endangered Species Program based on characteristics such as the presence of obligate species, mainly pool-breeding amphibians. For many species, the key factor is the absence of fish in the pools due to seasonal drying, isolation, and low dissolved oxygen levels[1]. Since the pools are not wet throughout the year they are not technically wetlands by Massachusetts law, though they do receive protections from certain aspects of the Wetland Protection Act and other state and local legislation[1]. The amount of forest currently protected around certified pools is 100 ft (about 30 m), a size which research increasingly finds to be insufficient upland habitat to support viable populations of the species which use vernal pools for breeding[2,3]. This is compounded by runoff from a variety of human activities which can affect larval survival and reproductive success and rates within pools. This project will focus on deicing salt runoff given that Massachusetts is one of the worst offenders for deicing salt application (yearly average of 28 metric tons per lane km) and that studies have measured salt travel distances of up to 172 m[4]. Reduced egg mass density and larval survival have been associated with increased salt levels and salt can persist in terrestrial and aquatic ecosystems for extended periods of time, so decreasing the use of deicing salt around pools could aid in protecting this critical habitat[4,5,6]. Middlesex County was chosen for this analysis because of its relatively high density of both certified vernal pools and roads.

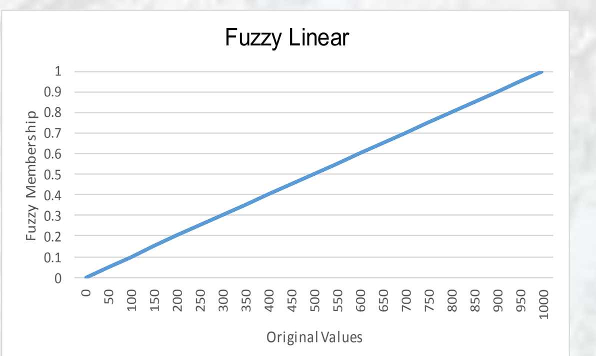
Research Questions:
1. Which roads in Middlesex County should receive less deicing salt in the context of vernal pool conservation?
2. How can fuzzy methods assist in this analysis?

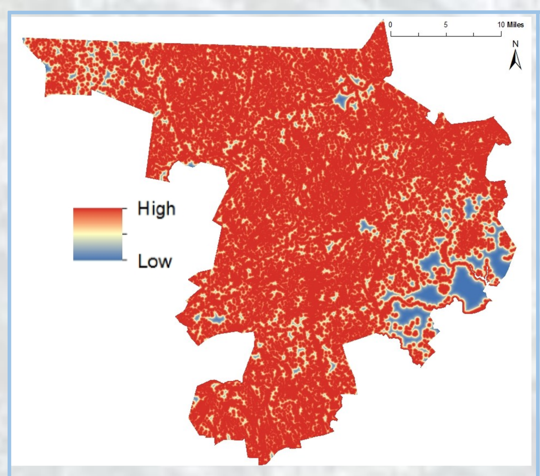
Methodology

Seven variables were selected from the MassGIS data repository (some of which were already in the Tufts M Drive) to be used as criteria in this risk analysis because of their impact on vernal pool habitat quality and deicing salt deposition and/or transport. Each layer was rasterized and then processed using fuzzy membership, which assigns cell values based on the possibility of it belonging to the "favorable" set. In this case "favorable" meant suitable for reducing salt application because of the variable's relationship to vernal pools. Using fuzzy membership allows for less distinct categorization of data, instead focusing on the range of favorability within a dataset. Most of the variables were fuzzified with fuzzy small, which assigns highest membership to the smallest values. The midpoint is assigned a membership of 0.5 and the spread determines how steep the curve is; increasing spread creates a steeper membership curve. Fuzzy linear was more appropriate for two variables, pool density and land use. In the fuzzy variable maps, "high" signifies high risk posed by deicing salt. In other words, high suitability for reducing salt application.

MassGIS Data	Layer Type	Pre-Fuzzy Raster Processing
NHESP Certified Pools (2005)	Points	1. Point Density 2. Euclidean Distance
Elevation (2005)	DEM	Calculate Slope, Reclass slope & elevation, Raster Calculator
Land Use (2005)	Polygons	Classify categories (python), Polygon to Raster
Wetlands (2006)	Polygons	Euclidean Distance
Wetland Loss (1998-2009)	Polygons	Euclidean Distance
Roads	Lines	Buffer around pools, Intersect

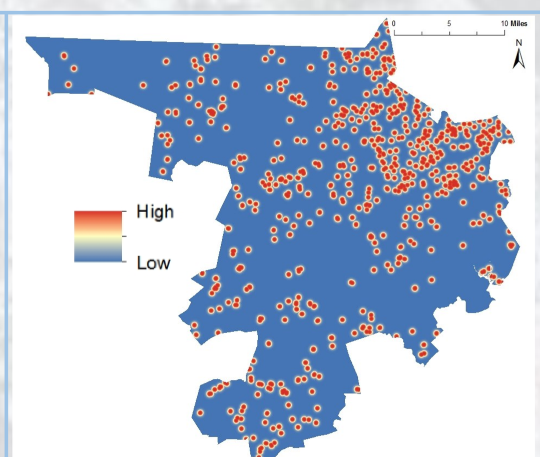






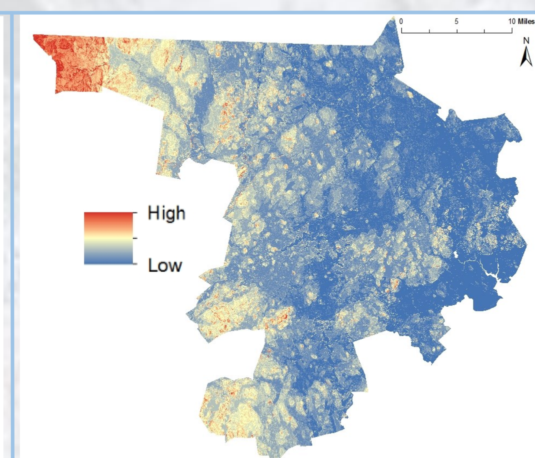
Fuzzy Wetlands

Risk of deicing salt application as distance from wetlands prioritizing distances under 400 meters. Fuzzy type: Small



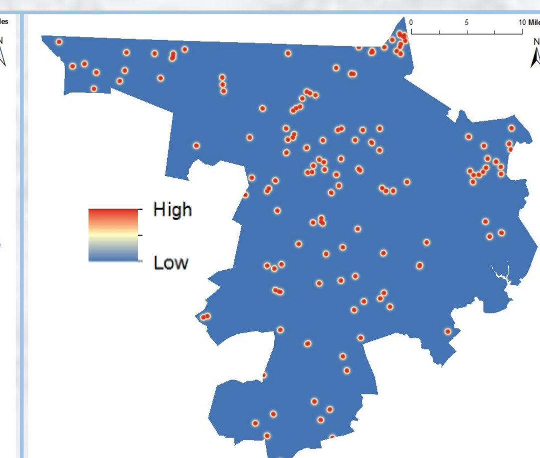
Fuzzy Converted Wetlands

Risk of deicing salt due to proximity to former wetland area developed within the past ten years. Fuzzy type: Small



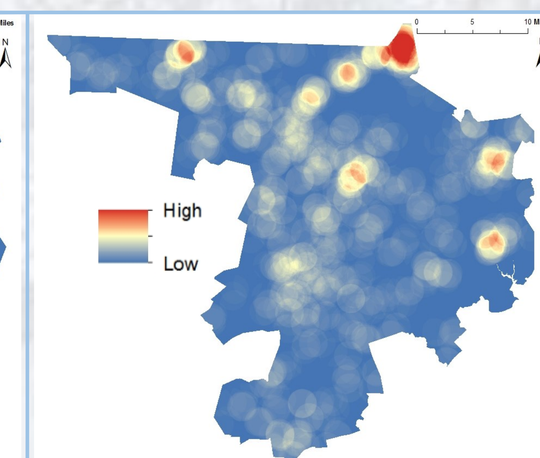
Fuzzy Slope and Elevation

Combined slope and elevation data. Highest values belong to areas of high slope and high elevation. Fuzzy type: Linear



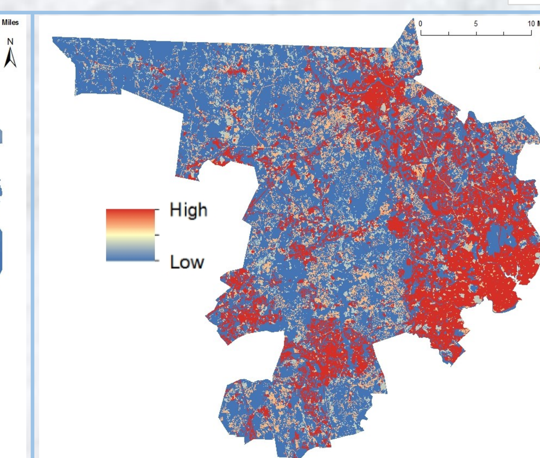
Fuzzy Roads in Buffers

Distance from road segments that intersect the current 30 m protected areas around vernal pools. Fuzzy type: Small



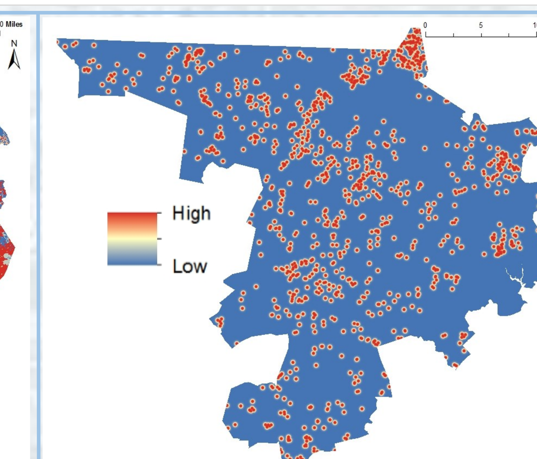
Fuzzy Pool Density

Areas with high pool density were prioritized for salt reduction to protect clusters of pools. Fuzzy type: Linear



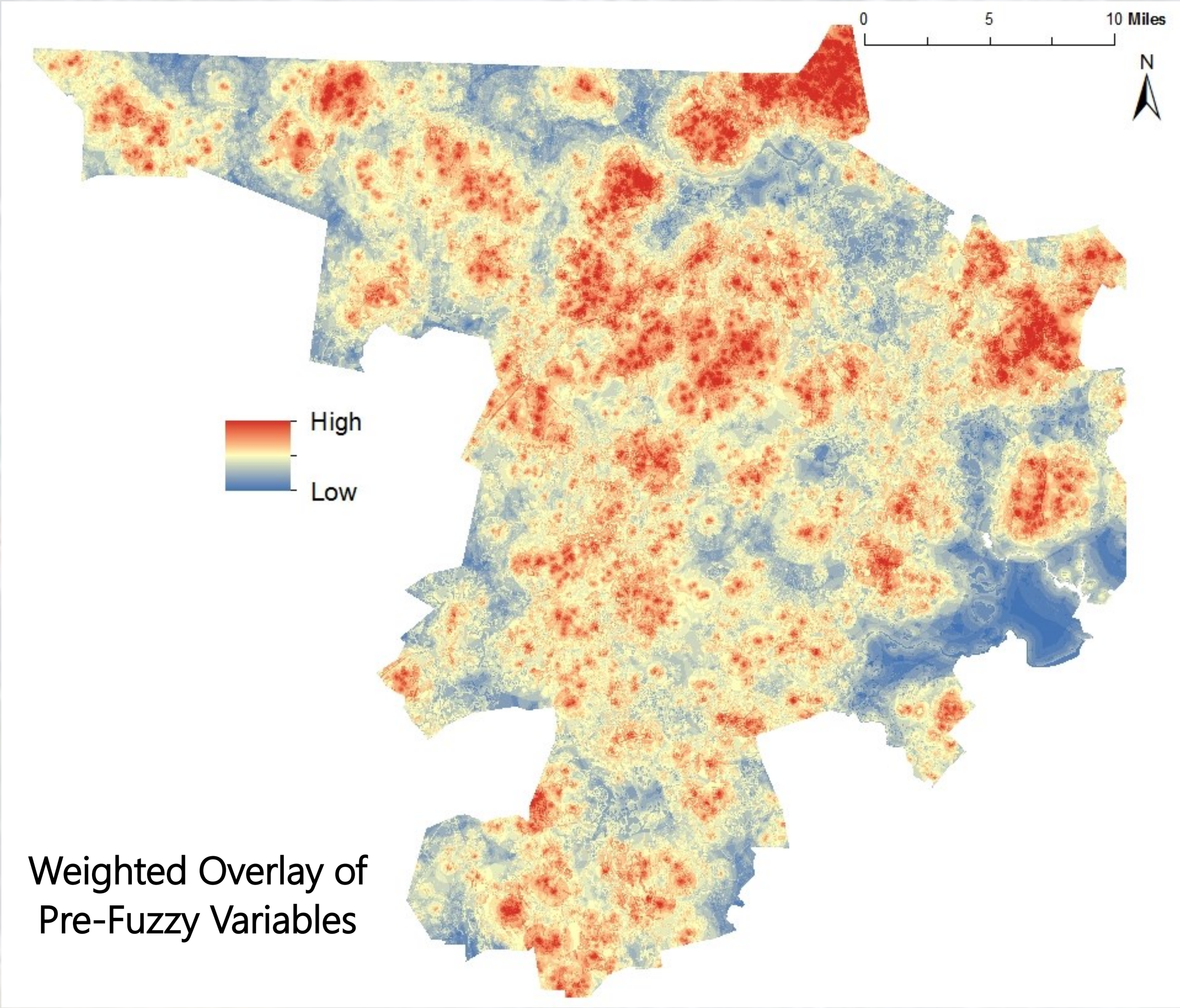
Fuzzy Land Use

Condensed groups, highest impact given to more human development and impervious surfaces. Fuzzy type: Linear

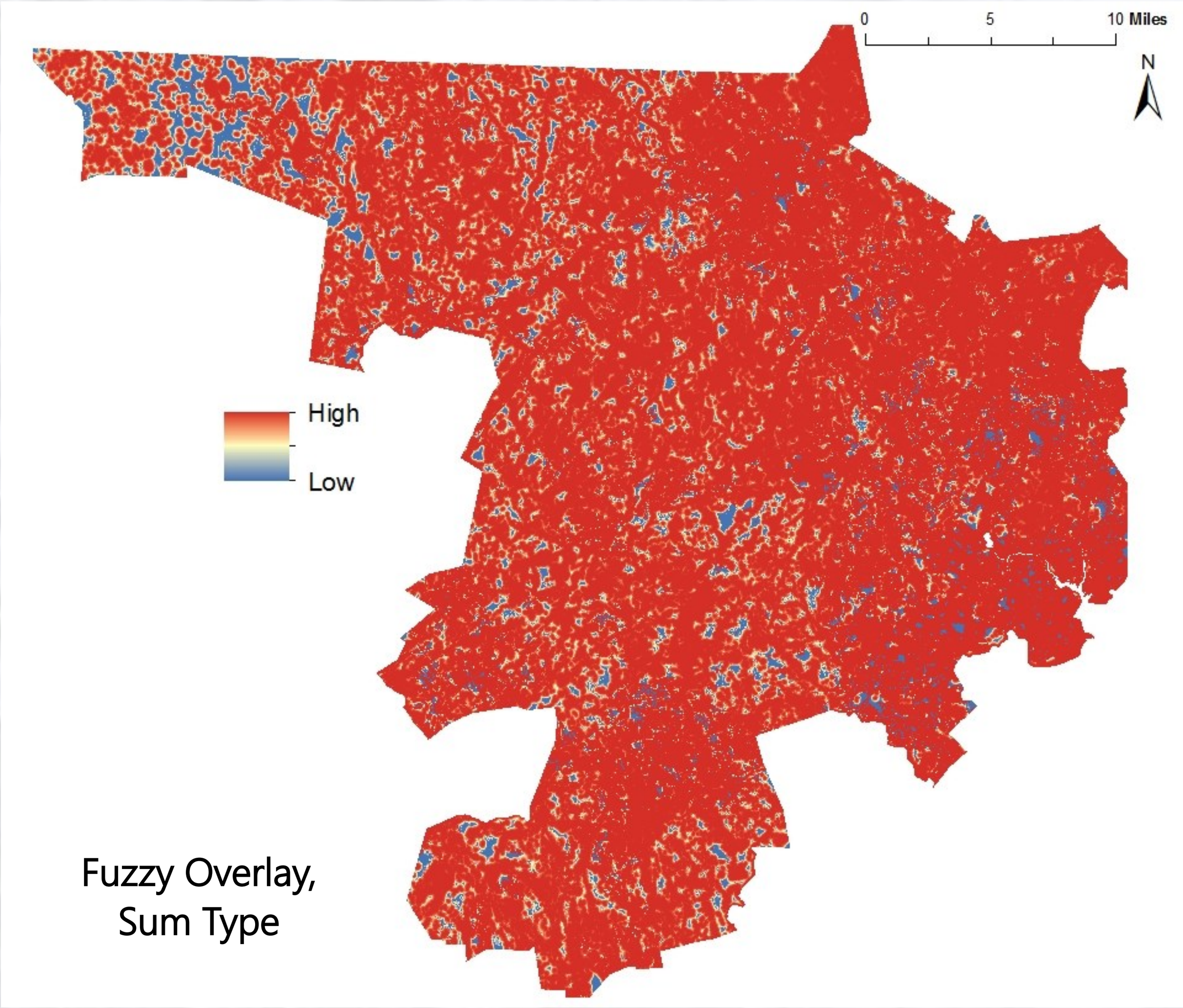


Fuzzy Distance from Pools

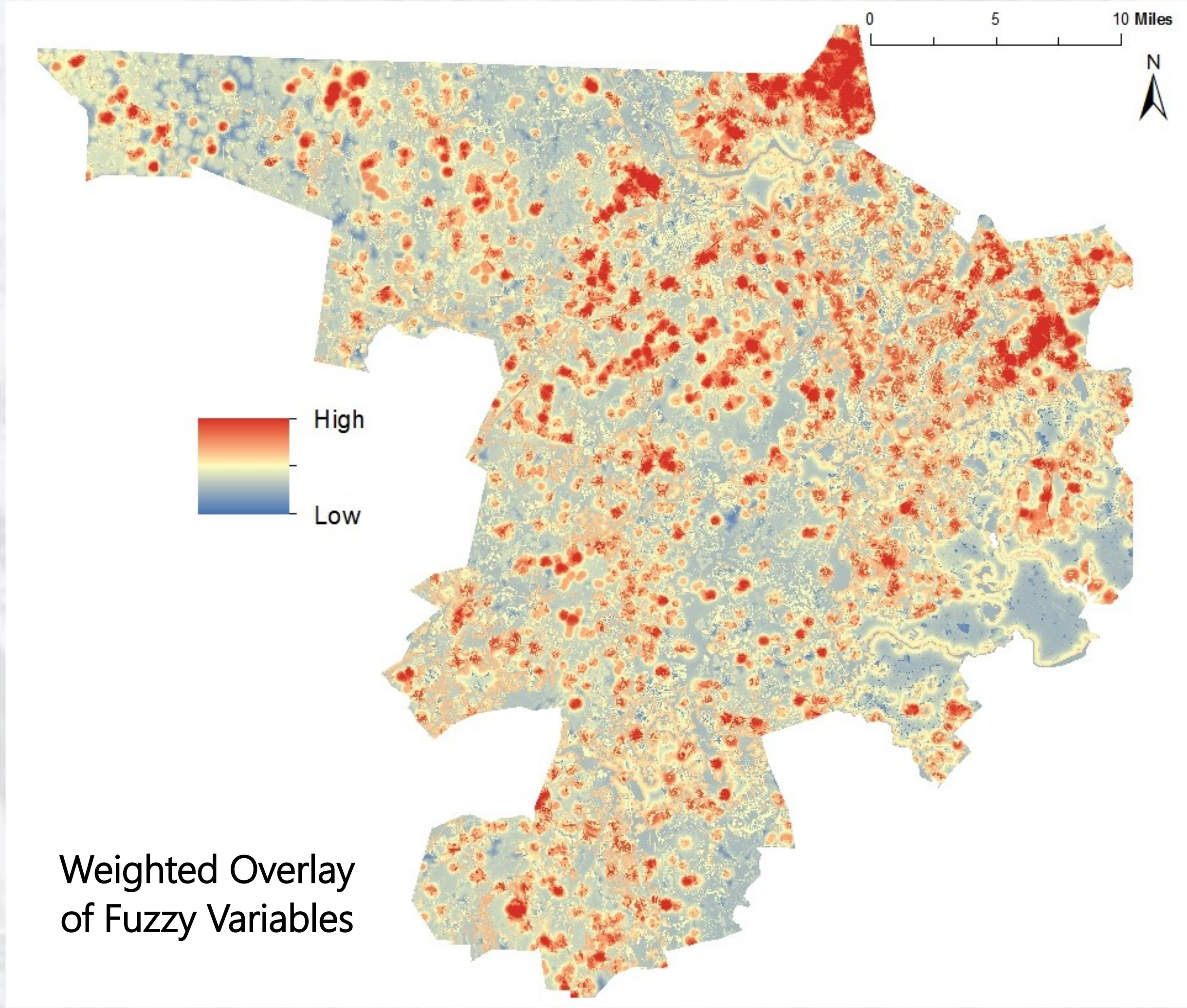
Distance from vernal pools, prioritizing distances that salt can travel based on field research. Fuzzy type: Small



Weighted Overlay of Pre-Fuzzy Variables



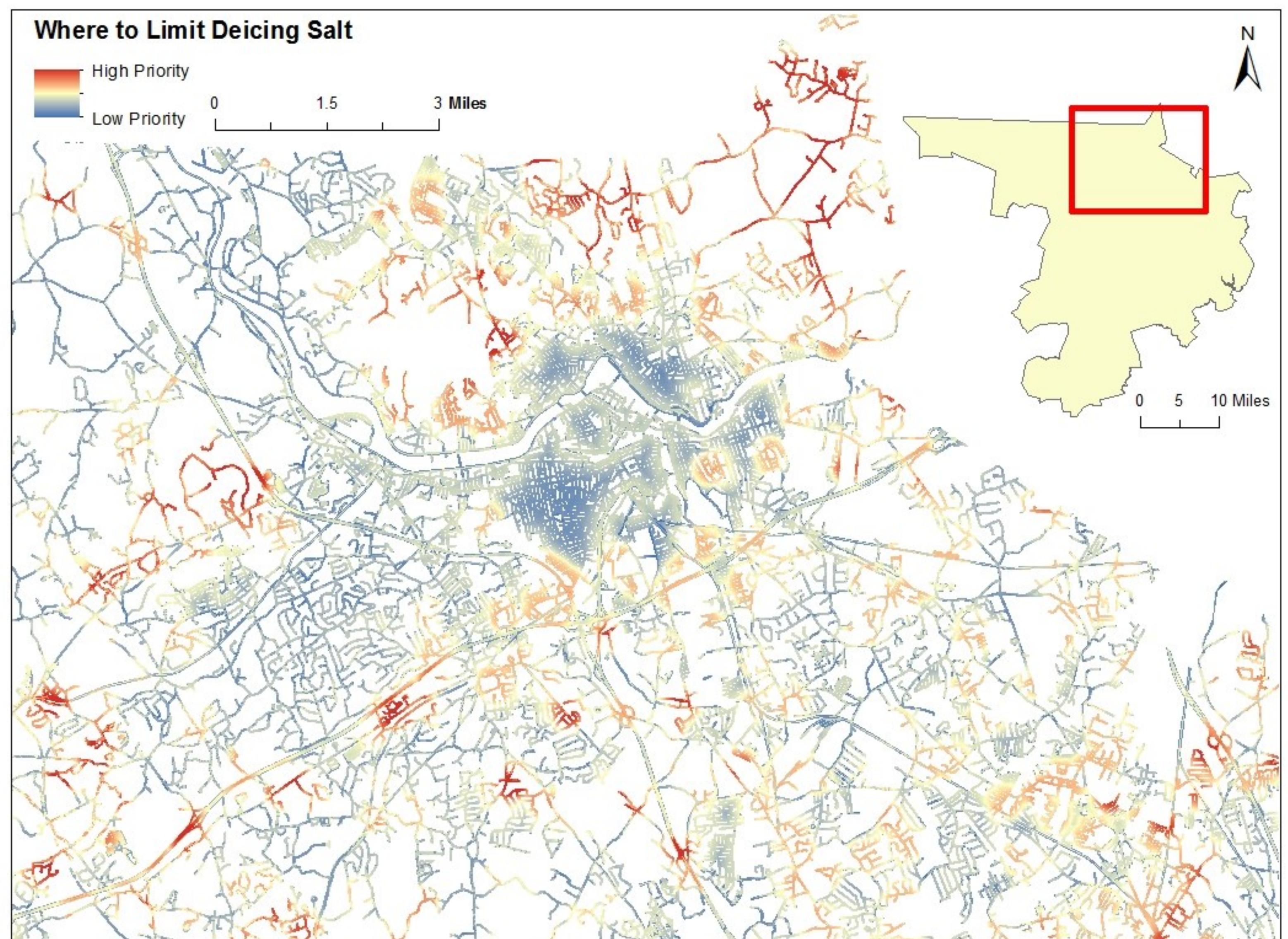
Fuzzy Overlay, Sum Type



Weighted Overlay of Fuzzy Variables

Methodology (Continued)

To compare differences between fuzzy and non-fuzzy methods, the seven variables were combined using three different overlay techniques: a weighted overlay of the pre-fuzzy rasters (left), a weighted overlay of the fuzzy rasters (right), and a fuzzy overlay of the fuzzy variables using the sum type (center). In the two weighted overlays, each variable was given equal influence (14%) except distance from pools, which received 16%. This was performed with a simple raster calculator expression multiplying each variable's values by its assigned weight and adding them together. The fuzzy overlay works similarly but no weights are assigned to the variables and the results are not normalized. This method of fuzzy overlay is recommended when the combination of variables is more important than any one variable as opposed to Fuzzy And or Fuzzy Or, which detect cells with high membership across all variables or at least one variable, respectively. Clearly, the fuzzy overlay produces very different results than the weighted methods and identifies the majority of the county for reduction. The weighted overlay of fuzzy values was chosen to extract onto a roads layer to show the specific segments of roads where the application of deicing salt should be reduced. The area shown illustrates the precise nature of the weighted overlay.



Images:
- Vernal pool image: https://vernalpoolsnewfield.wordpress.com/. Accessed May 8, 2017
- Background image: By Edwin Herrera aka Joswin. http://joswin.com/. Accessed May 8, 2017.

Data Sources:
MassGIS (mass.gov), Tufts M Drive

Cited Sources:
1 http://www.mass.gov/eea/docs/dfg/nhesp/vernal-pools/vpcert.pdf
2 Harper, EB., Rittenhouse, TA, Semlitsch, RD. 2008. Demographic consequences of terrestrial habitat loss for pool-breeding amphibians: predicting extinction risks associated with inadequate size of buffer zones. Conservation Biology 22(5).
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4 Karraker, N., Gibbs, J., & Vonesh, J. (2008). Impacts of road deicing salt on the demography of vernal pool-breeding amphibians. Ecological Applications, 18(3).
6 Findlay, S. & Kelly, V. (2011). Emerging indirect and long-term road salt effects on ecosystems. The Year in Ecology and Conservation Biology, 1223.
5 Sanzo, D. & Hecnar, S.J. (2005). Effects of road de-icing salt (NaCl) on larval wood frogs (Rana sylvatica). Environmental Pollution, 140(2).
7 Zehetner, F., Rosenfellner, U., Mentler, A., Gerzabek, M. (2009). Distribution of road salt residues, heavy metals, and polycyclic aromatic hydrocarbons across a highway-forest interface. Water, Air, and Soil Pollution, 198(1).
8 Rosenberry, D.O., Bukaveckas, P.A., Buso, D.C., Likens, G.E., Shapiro, A.M., Winter, T.C. (1999). Movement of road salt to a small New Hampshire lake. Water, Air, & Soil Pollution, 109(1).

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Projection: Lambert Conformal Conical
Coordinate System: NAD 1983 Stateplane Massachusetts Mainland

Conclusions

While the two weighted overlays identify the same general areas for salt reduction, the overlay using fuzzy values produced much more localized regions. The three overlay maps highlight the usefulness of fuzzy membership; when the problem is analyzed from a perspective which looks for possibility rather than strict categorization, each dataset maintains its variance and range of suitability. When this is combined in the final step, the end result can produce more specific recommendations. This precision seems more practical in terms of applicability; policymakers probably wouldn't be too keen on restricting deicing salt on nearly every road in the county. Until there are less environmentally hazardous methods of ice removal which are also cost effective, small-scale reductions are more feasible[6]. However, the benefits of decreased application would be widespread, since salt runoff affects plants and animals alike as it travels away from roads. Increased chloride concentrations in groundwater as well as heavy metal and polycyclic aromatic hydrocarbon transport have negative effects on organism and ecosystem health as well as human infrastructure [6,7,8]. One limitation of this study is that many relevant variables were not included, such as soil type, hydrology, and road type. Additionally, it is difficult to tell whether the final fuzzy sum is so different from the other results because of the nature of fuzzy overlay itself or whether it is the product of decisions made in earlier steps.