2010

DISTRIBUTION OF EASTERN HEMLOCK, TSUGA CANADENSIS, IN EASTERN KENTUCKY AND THE SUSCEPTIBILITY TO INVASION BY THE HEMLOCK WOOLLY ADELGID, ADELGES TSUGAE

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ABSTRACT OF THESIS

DISTRIBUTION OF EASTERN HEMLOCK, TSUGA CANADENSIS, IN EASTERN KENTUCKY AND THE SUSCEPTIBILITY TO INVASION BY THE HEMLOCK WOOLLY ADELGID, ADELGES TSUGAE

The hemlock woolly adelgid, an invasive non-native insect, is threatening eastern hemlock in Kentucky. This study examined three techniques to map the distribution of eastern hemlock using decision trees, remote sensing, and species distribution modeling. Accuracy assessments showed that eastern hemlock was best modeled using a decision tree without incorporating satellite radiance. Using the distribution from the optimal model, risk maps for susceptibility to hemlock woolly adelgid infestation were created using two species distribution models. Environmental variables related to dispersal were used to build the models and their contributions to the models assessed. The models showed similar spatial distributions of eastern hemlock at high risk of infestation.

KEYWORDS: *Tsuga canadensis*, *Adelges tsugae*, Landsat 7 ETM+, MaxEnt, Mahalanobis Distance

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29 June 2010

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THESIS

Joshua Taylor Clark

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2010

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture at the University of Kentucky

By

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Lexington, Kentucky

2010

ACKNOWLEDGEMENTS

First, I would like to thank the members of my committee who provided guidance and aided my research and graduate career. Songlin Fei, Lynne Rieske-Kinney, and John Obrycki gave me advice and showed immense patience which was invaluable to me. I would also like to thank Nicole Kong for her time and effort in instructing and assisting me with geospatial techniques.

I am grateful for my forestry GIS and forest entomology lab mates who were supportive companions as well as sources of inspiration, new ideas, and humor. I appreciate the staff of the Kentucky Office of the State Entomologist, especially J.D. Loan, Carl Harper, and Joe Collins, who provided indispensable field data. I would like to thank Melanie Antonik and Tom Kuhlman for their technical assistance.

I would like to thank the Tracy Farmer Institute for Sustainability and the Environment for selecting me as a recipient of the Karri Casner Environmental Sciences Fellowship. Those funds were crucial to completing this research.

Finally, I would like to thank my family for their endless love and support. My beautiful wife, Amanda, has always been encouraging, motivating, and patiently endured the long hours I have spent in front of a computer. My parents, Terry and Sharlyn, have been comforting and tremendously supportive, and I am blessed to have them. I am very grateful for my close friends who have kept me in good spirits.

This material is based upon work supported by the Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture, under Agreement No. 2006-34408-17021. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

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CHAPTER ONE

BACKGROUND AND LITERATURE REVIEW

The hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand, Hemiptera: Adelgidae) is a non-native invasive pest that has recently spread into southeastern Kentucky (Kentucky Forest Health Task Force, 2006). HWA is a small (0.8-1.4mm) species that attacks hemlock (*Tsuga* spp.) forests of eastern North America. The common name alludes to the white, cotton-like, ovisac of adults. Using piercing mouthparts, HWA pierce the leaf cushion and feed on parenchyma cells within the xylem (Young *et al.*, 1995). Hemlock woolly adelgids have a complex life cycle, with a primary host of spruce trees and secondary hosts in the same family Pinaceae, including larch, Douglas fir, pine, hemlock, and fir trees (Annand, 1928). In its native range, HWA feeds on several species of hemlock and spruce and five generations are produced (Havill & Foottit, 2007). In North America, no suitable spruce host exists so the sexual generation dies as first instar nymphs (McClure, 1989), resulting in exclusive parthenogenesis with two generations.

Hemlock woolly adelgids are native to parts of China, Japan, and India (Montgomery *et al.*, 1999). They are also found in western North America (Annand, 1928), and recent molecular analyses demonstrates that it is native to the Pacific northwest (Havill *et al.*, 2007). HWA became established in eastern North America in Richmond, Virginia in the early 1950s, most likely dispersing from infested eastern hemlock (*T. canadensis* Carrière) nursery stock (Havill *et al.*, 2006). The geographic distribution of HWA was restricted to Virginia for nearly three decades until reports in the 1980s confirmed that infestations had expanded northward along the east coast. In 1985 Hurricane Gloria apparently dispersed populations northward, contributing to the dispersal of HWA to New England (McClure, 1990). In the northeast United States, eastern hemlock grows in large contiguous tracts which promoted the ensuing dispersal of HWA northward and westward. However, in the southern Appalachian mountains, suitable eastern hemlock habitat is typically confined to moist coves, higher elevations and north-facing slopes (Godman & Lancaster, 1990). This patchy distribution of host trees has not stopped the invasion of HWA, but merely slowed the encroachment into the southern Appalachians. Eastern Kentucky is part of this region and the hemlock woolly adelgid was first discovered on the south side of Pine Mountain in Harlan County in March 2006 (Kentucky Forest Health Task Force, 2006). Since then, infestations have been reported in 12 counties, mostly in southeastern Kentucky.

Hemlock woolly adelgids exploit at least eight species of *Tsuga* (Pinaceae, subfamily, Abietoideae) (Del Tredici & Kitajima, 2004). Of these, four are nearctic, including eastern, Carolina (*T. carolinana*), mountain (*T. mertensiana*), and western (*T. heterophylla*) hemlocks. While HWA feeds on mountain and western hemlock, it does not reach pest status in western North America. However, both eastern and Carolina hemlocks are highly susceptible to HWA (Del Tredici & Kitajima, 2004).

Eastern hemlock is an exceptionally shade tolerant (Quimby, 1996), late-successional species. It is long-lived (≥800 yrs), reaching a height of 40m and a diameter of 2m (Little, 1971), with shallow roots, intolerance of high winds, drought, or floods

(Quimby, 1996). The native range of eastern hemlock lies from Canada to Alabama (latitudes 34° to 49° N) and from Nova Scotia to Minnesota (longitudes 59° to 94° W) (Little, 1971). In Kentucky, hemlocks are found in two of Braun's forest regions: mixed mesophytic and Western mesophytic (Braun, 1950; Delcourt & Delcourt, 2000). Hemlock grows in Kentucky in isolated pockets on north to east facing slopes in moist riparian zones, between 610 to 1520m, in neutral to acidic soils, and in cool, humid climates (Farjon, 1990; Godman & Lancaster, 1990; Quimby, 1996).

Eastern hemlock is vital in maintaining stream quality by regulating air and soil temperatures, soil moisture, hydrologic discharge, and amplitude of stream flow (Ford & Vose, 2007). Disruption of these processes can lead to loss of aquatic invertebrate and vertebrate biodiversity (Snyder *et al.*, 2002; Ross *et al.*, 2003). Several species of fish, including darters (Percidae), shiners (Cyprinidae), and lampreys (Petromyzontidae), are endangered or threatened in some of Kentucky's eastern upland headwater streams (Kentucky Department of Fish & Wildlife Resources, 2002). These areas are also vital habitat for the endangered Wehrle's salamander (*Plethodon wehrlei*) and the eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*), a species of special concern in the state (Kentucky Department of Fish & Wildlife Resources, 2002). Numerous Ephemeroptera, Diptera, Trichoptera, and Plecoptera are strongly associated with eastern hemlock (Snyder *et al.*, 2002).

Eastern hemlock forests provide seasonal habitat for grouse, turkey, deer, and other wildlife (Snyder *et al.*, 2002). Several avian species are dependent on hemlock, including Acadian flycatchers (*Empidonax virescens*), black-throated blue warblers

(*Dendroica caerulescens*), blue-head vireos (*Vireo solitaries*), northern parulas (*Parula americana*), dark-eyed juncos (*Junco hyemalis*), Canada warblers (*Wilsonia Canadensis*), and blackburnian warblers (*Dendroica fusca*) (Shriner, 2001; Keller, 2004; Ross *et al.*, 2004). In Kentucky, both the dark-eyed junco and Canada warbler are species of special concern and the blackburnian warbler is threatened (Kentucky Department of Fish & Wildlife Resources, 2002). Eastern hemlock mortality has negative consequences for these hemlock-dependent birds (Keller, 2004; Ross *et al.*, 2004).

Because of the importance of eastern hemlock as a foundation species, adelgid-induced hemlock mortality will have far-reaching consequences. For example, as hemlock die, light penetration to the forest floor increases. This leads to a larger percent of ground cover by vascular plants, including potentially harmful non-natives, and thus changes vegetation composition and structure. Tree species such as red maple (*Acer rubrum*) and black birch (*Betula lenta*) benefit from increased sun exposure and it is expected that these species will replace eastern hemlock (Catovsky & Bazzaz, 2000; Yorks *et al.*, 2003; Spaulding & Rieske, 2010).

The continued spread of HWA through Kentucky's hemlock forests is imminent, but data concerning how that spread will develop is lacking, due in part to a poor understanding of the distribution of eastern hemlock. In order to evaluate the extent to which HWA is affecting our hemlock resources and to manage its expanding populations, accurate eastern hemlock maps and knowledge of the areas most vulnerable to infestation are needed. Presently there are a few available data sets of the distribution of eastern hemlock in Kentucky: the 2001 National Land Cover Dataset

(NLCD) Anderson level III (Kentucky Division of Geographic Information, 2004), the 2002 Kentucky Gap Analysis Land Cover Map (Mid America Remote Sensing Center at Murray State University, 2002), and the 2001-2005 NLCD Change Detection Anderson level II (Kentucky Division of Geographic Information, 2007). These maps depict vegetation grouped into several classifications. In Kentucky, eastern hemlock is a relatively minor component, so the areas with hemlock-inclusive classes are permitted to have lower accuracy in order to increase overall accuracy of the map. Consequently, in spite of extensive hemlock forests in the southeast portion of the state, these maps depict only sparse and intermittent distribution of this critically important component of our forests. In order to protect this important resource, an accurate map of eastern hemlock is needed.

In addition to a map of eastern hemlock distribution, predictive models estimating the spread of HWA would be a powerful tool in combating this invasive insect. Predictive models use environmental, geographical, and/or biological community data to produce a statistical output that describes some parameter(s) of the distribution or niche of one or more species. The predictions that can be made depend on the type of model used (Guisan & Zimmermann, 2000); a chief concern in the selection of predictive models is the availability of the occurrence or absence data of individuals to be modeled (Elith *et al.*, 2006; Pearce & Boyce, 2006). Since HWA is small and cryptic, detection can be very difficult. Therefore, absence data cannot be considered truly reliable. This is a common problem in wildlife modeling and several methods have been developed to deal with this setback (Elith *et al.*, 2006). One option is to use a model that only uses presence-only data in the analyses; these models may be less accurate than presence-absence models, but are useful with a small sample of records (Elith *et al.*, 2006; Pearce & Boyce, 2006). Other presence-only models require only input of presence-only data, but then generate background samples, either environmental or pseudo-absences, to use in the analyses (Pearson, 2007). The complexity and difficulty of interpretation of some of these models are often offset by higher performance (Elith *et al.*, 2006; Pearce & Boyce, 2006). Choice of models also depends on type of input variables, parameters, and transparency of variable interactions calculated by the model (Pearson, 2007).

My first objective, the focus of chapter two, is to generate maps of eastern hemlock distribution in eastern Kentucky. Environmental and satellite spectral variables were analyzed using three different modeling techniques; results were evaluated to determine capability of models as decision support tools for land managers. In chapter three I examine my second objective, which is to determine areas of eastern hemlock that are highly susceptible to HWA infestation. Presence-only species distribution models were constructed and assessed with model performance measures.

CHAPTER TWO

COMPARISON OF CLASSIFICATION TECHNIQUES IN EASTERN HEMLOCK, *Tsuga canadensis*, MAPPING

INTRODUCTION

Hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand, Hemiptera: Adelgidae) is a non-native invasive insect causing extensive mortality of eastern hemlock (*Tsuga canadensis* Carrière) in the eastern United States (Mcclure *et al.*, 2001). Since the 1980s, infestations have expanded along the east coast, moving northward and westward from the initial infestation in Virginia (Havill *et al.*, 2006), exploiting the large contiguous tracts of hemlock forest common in the northeast. More recently HWA has expanded its geographic range southward through the southern Appalachians (Ward *et al.*, 2004). HWA was first discovered in Kentucky in March 2006 (Kentucky Forest Health Task Force, 2006), and since then, infestations have been steadily expanding. The continued spread of HWA through the region's hemlock forests is imminent, but data concerning how that spread will develop is lacking, due in part to a poor understanding of the distribution of eastern hemlock.

Eastern hemlock is critically important ecologically. Eastern hemlock is vital for maintaining stream quality by regulating air and soil temperatures, soil moisture, hydrologic discharge, and amplitude of stream flow (Ford & Vose, 2007). Disruption of these processes can lead to loss of aquatic invertebrate and vertebrate biodiversity (Snyder *et al.*, 2002; Ross *et al.*, 2003). Loss of eastern hemlock will also cause changes in vegetation composition and structure. For example, increased light penetration creates suitable habitat for less shade-tolerant tree species such as red maple (*Acer rubrum*) and black birch (*Betula lenta*) (Catovsky & Bazzaz, 2000; Yorks *et al.*, 2003; Spaulding & Rieske, 2010). The consequences of widespread hemlock mortality for hemlock-associated and hemlock-dependent aquatic and terrestrial wildlife will be devastating.

In spite of the ecological importance of eastern hemlock, little is known about its fine-scale distribution in Kentucky and the central/southern Appalachians, and resource managers have only a limited understanding of the scope of its spatial distribution. No hemlock-specific maps exist for Kentucky, in part because in this region hemlock is unimportant economically, is not dominant in terms of abundance or basal area, and its distribution is confined to the eastern portion of the state (Little, 1971 and Figure 2.1). In order to understand the extent of our eastern hemlock resources and the extent to which the invasive HWA will affect these resources, maps must be produced showing accurate areas of hemlock cover.

Ground mapping the patchy distribution of eastern hemlock is impractical, so alternative techniques are needed. Remote sensing has been used to map eastern hemlock in the Daniel Boone National Forest in Kentucky, but with low classification accuracies (Maingi & Luhn, 2005). Remotely sensed data have also been successfully used in other regions to map eastern hemlock and to assess HWA-induced eastern hemlock decline, though on a relatively small (<2,000 km^2) landscape scale (Royle & Lathrop, 1997; Bonneau *et al.*, 1999; Royle & Lathrop, 2002; Koch *et al.*, 2005).

While these studies have mapped eastern hemlock using satellite imagery, I investigated alternative approaches because satellite image pre-processing such as georectification and topographic normalization is time intensive and a source of errors. In this study, I investigated the feasibility and accuracy of three different approaches to map eastern hemlock. In my first approach (designated TREE-ETM+), I performed a decision tree analysis using remotely-sensed spectral data and environmental variables. For the second technique (designated TREE-OMIT), I repeated the decision tree analysis but omitted the spectral data, using only environmental data. Decision trees require at least two classes of dependent variables, necessitating collection of both presence and absence points. In a large study area, this may be problematic and exceedingly time-consuming to produce distribution maps needed for immediate decision-making. For that reason, the third method (MaxEnt) I used was maximum entropy species distribution modeling, which requires only presence data (Phillips *et al.*, 2006).

The objective of my study was to determine the optimal mapping procedure to create a reliable regional map of eastern hemlock. Processing complexity, time to completion, and accuracy of the three approaches were compared to reveal which is the most advantageous procedure, depending on the priorities set forth by the end users.

METHODS

Study area

The study area covered 27,006 km^2 of eastern Kentucky (38.29-36.58°N, 81.96-84.83°W) and was partitioned into two Eastern Coal Field physiographic regions: upper eastern Coal Field (hereafter, Coal Field) and Pine Mountain (Figure 2.2). This mountainous area is composed of sandstone, shale, and siltstone and ranges in elevation from 154 to 1259m (McDowell, 1986). Average monthly temperature ranges from 1.1 ^{o}C in January to 23.9 ^{o}C in July and average monthly precipitation ranges from 8.1 cm in October to 13.1 cm in May (Jackson Carroll AP, 1971-2000 data; National Oceanic and Atmospheric Administration, 2002). The dominant forest type is mixed mesophytic consisting primarily of oak-hickory and oak-pine forests (Braun, 1950; Turner *et al.*, 2008).

GPS data

A total of 2,801 GPS points were collected within the study area and compiled into a database representing hemlock or non-hemlock categories. The data points were split by physiographic region (Coal Field vs Pine Mountain) then one-fourth of the points were randomly selected and set aside to be used as test data for accuracy assessments. The remaining training data sets were used in the decision tree classifications and distribution models.

Environmental data

In all three modeling approaches, eleven environmental layers were used as independent variables representing topographic and climatic characteristics (Table 2.1). A data layer of geologic formations, units of rocks with unique characteristics and position, were also included in the analyses. To conform to the spatial resolution of the satellite images and maintain consistency across all models, each variable was converted to a raster layer with cell size of 30 x 30m using tools in ArcGIS 9.3 (ESRI, Redlands, CA, U.S.). A 10m digital elevation model (DEM) raster was re-sampled to a cell size of 30 x 30m using bilinear interpolation.

Image processing

To ensure complete coverage I took advantage of the large scenes offered by the mid-resolution Landsat 7 ETM+ satellite imagery. Three Landsat 7 ETM+ satellite images (Table 2.2) covering three geographic sections of eastern Kentucky (Figure 2.2) were obtained (USGS Earth Resources Observation and Science Center, http://eros.usgs.gov). Spectral bands 1-5 and 7 were included in the decision tree analyses. Images were first re-projected to Kentucky State Plane Single Zone (FIPS 1600) and then geometrically corrected with ground control points selected from 2000-2001 leaf-off digital orthophoto quarter quads (DOQQs). Images were georectified to root mean square errors of less than 0.5 pixel (pixel size = 30 x 30m) with a third-order polynomial and re-sampled using nearest neighbor assignment. Images were masked by the Kentucky state boundary, and converted from digital numbers into at-satellite radiance (Landsat Project Science Office, 2009).

Remote sensing analysis in mountainous terrain such as eastern Kentucky is made difficult by the altered brightness values caused by inconsistent reflectance angles of solar radiation, which causes identical objects in different topographic areas to have different brightness values. To correct for this a topographic normalization was applied. After images were clipped by physiographic regions to reduce the variance of incidence angles, topographic normalizations were performed using the C-correction method (Teillet *et al.*, 1982). Clouds were removed using a maximum likelihood classification.

Decision tree analysis

I chose a decision tree classification model because it is non-parametric, robust to noisy or missing data, easy to interpret, and can utilize both continuous and categorical data (Huang *et al.*, 2003; Nelson *et al.*, 2003; Koch *et al.*, 2005). Similar methods have produced accurate maps for eastern hemlock at a landscape scale (Koch *et al.*, 2005) and for other evergreen trees on a much larger regional scale (Landenburger *et al.*, 2008; McDermid & Smith, 2008). Using PASW Statistics software (SPSS Inc., Chicago, IL, U.S.) decision tree analyses were employed to classify areas with presence or absence of eastern hemlock. For each decision tree a Chi-squared Automatic Interaction Detection (CHAID) growing method was applied with a Pearson chi-square statistic, maximum tree depth set to ten levels, and a significance level of 0.1 for splitting nodes. The CHAID method was used in order to take advantage of multiple splitting pathways for each node, as opposed to the binary splitting of a classification and regression tree (CART) algorithm. This multi-way splitting allows variables to be partitioned in a more biologically meaningful way. The significance level was set at 0.1 in order to further divide nodes to minimize overestimation or underestimation of hemlock classification. Node response was used as the threshold to assign the area represented by that node to either the presence or absence class.

Two variations of the decision trees were produced, one including Landsat ETM+ satellite imagery (TREE-ETM+) and one excluding satellite imagery (TREE-OMIT). In the former, models were generated for each satellite image separately, and then merged into a single map layer for accuracy calculations. Images were not standardized before running the decision tree analyzes. Where images overlapped, the image covering the most geographic area was given priority when merging model results.

MaxEnt models

Maximum entropy models were constructed separately for each physiographic region using the MaxEnt program, version 3.2.19 (Phillips *et al.*, 2006). Maximum entropy algorithm predicts the probability distribution of species occurrence based on the environmental constraints estimated from known occurrence locations. The resulting distribution has maximized entropy within those bounding constraints. The MaxEnt model was run with the maximum number of iterations and convergence threshold parameters set to 1000 and 0.00001, respectively. All layers were indicated as continuous variables except geologic formations and soil types, which were specified as categorical. All hemlock presence points (N = 844) were used to build the model, except one-fourth that were randomly selected by the program to use in model validation procedures. The model was executed for 10 iterations with different random partitions of training and validation data. I chose the best model to use based on highest area under the curve (AUC) value (Boubli & de Lima, 2009). The jackknife option was used to evaluate the importance of each environmental variable in the model. The output of the model was a continuous probability map with values between 0 and 1; therefore, a threshold value must be assigned in order to reclassify the output into nominal classes representing either suitable or unsuitable areas of hemlock distribution. The threshold was established using the maximum cumulative frequencies difference method

(Browning *et al.*, 2005; Thompson *et al.*, 2006; Fei *et al.*, 2007) to simulate a lack of absence data.

Accuracy assessments

Accuracy assessments were completed for each modeling method, consisting of error matrices and Kappa statistics. A thirty meter buffer of test points was used in the accuracy calculations to account for georectification and GPS errors.

RESULTS

The model approaches varied the distribution of eastern hemlock in the study area (Figure 2.3). Of the three models, the TREE-ETM+ model classified the most area as eastern hemlock (Figure 2.6) with the distribution spread generally throughout the study area, but more so in the eastern and southern parts of the study area. TREE-OMIT showed a distribution of eastern hemlock predominantly localized in the western and central parts of the study area. The MaxEnt model also showed considerable hemlock coverage in the western part of the study area, but the distribution was much more substantial in the eastern portion of the study area than the TREE-OMIT model. All three models showed abundant eastern hemlock located near Pine and Cumberland mountains in the Pine Mountain physiographic region.

In the Coal Field physiographic region, the decision trees outperformed the MaxEnt models (Figure 2.4). However, in the Pine Mountain region, the TREE-ETM+ decision tree performed very poorly which led to the lowest accuracy. Overall accuracies in the Coal Field were highest with the TREE-ETM+ decision tree (using remotely-sensed spectral data and environmental variables); however, in the Pine Mountain region, the omission of satellite data (TREE-OMIT) greatly increased overall accuracy. These trends were also apparent in the Kappa statistics (Figure 2.5). Both the TREE-ETM+ and MaxEnt models had similar overall accuracies when averaged across physiographic regions (79% vs 80%, respectively) which were much lower than the TREE-OMIT model at 85.4%. Furthermore, the TREE-OMIT model predicted the least amount of hemlock cover of the three models (Figure 2.6). The most frequent predictor variables used by the decision trees were proximity to nearest stream, moisture index, and band 5 for the TREE-ETM+ classifier (Table 2.3.A), and proximity to nearest stream, minimum temperature, and geologic formation for the TREE-OMIT classifier (Table 2.3.B).

MaxEnt models resulted in test AUC values that suggest high model performance (Figure 2.7). The threshold values determined using cumulative frequencies difference yielded maps with the lowest overall accuracies (Figure 2.4) and Kappa statistics (Figure 2.5). The predictor variables with the highest percent contributions were proximity to nearest stream, soil type, and geologic formation, but the rank of those variables depended on physiographic region (Table 2.4). At the estimated thresholds, 19.9% of the total area was classified as hemlock.

The overlap area (Figure 2.3), which denotes the areas in which all three models predicted presence of eastern hemlock, indicate that 90% of hemlock coverage is located less than 278 m from streams and between 234 and 477m in elevation. A majority of the eastern hemlock area is situated on northeast to southeast facing slopes and on geologic formations composed of shale, sandstone, or alluvium. The most abundant soils in the predicted hemlock areas are well drained, loamy, acidic ultisols and inceptisols including shelocta, helechawa, or grigsby complexes.

DISCUSSION

All three methods produced maps of eastern hemlock distribution with overall accuracy values ranging from 69% to 89%. The producer's accuracy calculated from the error matrix suggests that the TREE-ETM+ model slightly underestimated the amount of hemlock cover in the Coal Field region based on the true distribution of the hemlock reference points. In the Pine Mountain region, low overall, producer's, and user's accuracies indicate that the TREE-ETM+ model produced a weak classification. The accuracy assessments also showed that the TREE-OMIT model moderately underestimated eastern hemlock distribution in both physiographic regions while the low accuracy and kappa statistic produced by the MaxEnt model was a result of a severe overestimation of eastern hemlock.

The accuracy of our results are similar to previous studies in which remotely sensed data have been used to successfully map eastern hemlock and to assess small scale HWA-induced eastern hemlock decline (Royle & Lathrop, 1997; Bonneau *et al.*, 1999; Royle & Lathrop, 2002; Koch *et al.*, 2005). Bonneau et al. (1999) created an eastern hemlock map using supervised classification of six Landsat TM bands with an overall accuracy of 85.9% and a Kappa statistic of 0.843. Koch et al. (2005) used satellite imagery from Landsat ETM+ and ASTER radiometers to discriminate areas of eastern hemlock from other evergreen species using a 3-split tree-based classification along with environmental, land use, fire history, and spectral-ratio variables resulting in a map with an accuracy of 85.3% and a Kappa statistic of 0.767. Eastern hemlock has been mapped along with other conifer species, including white (*Pinus strobus)* , shortleaf (*P. echinata)*, and Virginia pines (*P.* virginiana), in the Daniel Boone National Forest, which lies within my study area (Maingi & Luhn, 2005). Landsat TM imagery and ancillary data were modeled using a decision tree to delineate three classes of conifers (Maingi & Luhn, 2005). However, producer's and user's accuracies of the eastern hemlock classification were relatively low (58.7% and 68.3%, respectively) compared to the pine species. Although these studies were completed using a variety of methods, each was implemented on a much smaller landscape scale (< 2,000 km^2). Previous work on whitebark pine (*P. albicaulis*) has shown that using Landsat ETM+ and ancillary data in a decision tree analysis is a practical approach to generating highly accurate maps on a larger regional scale (Landenburger *et al.*, 2008). My study supports that methodology and further shows that it is possible to reduce analysis efforts by excluding satellite data with minimal effects on accuracy.

The models confirm previous descriptions of eastern hemlock habitat in the southern Appalachian Mountains that found that hemlock grows on north to east facing slopes in moist riparian zones, on sandstone rock beds, and in neutral to acidic soils (Godman & Lancaster, 1990; Quimby, 1996; Hart & Shankman, 2005). Eastern hemlock has been described as occurring at 610 to 1520m in this region (Godman & Lancaster, 1990), much higher than predicted by my study, but was located at even lower elevations (<125m) in Alabama (Hart & Shankman, 2005).

Analysis of the TREE-ETM+ decision tree showed that Landsat 7 ETM+ radiance bands 5 and 4 provided more information to the model than the remaining bands (Table 2.3.A). This is not unexpected since these bands are related to vegetation water content and vegetative foliar structures, respectively (Rock *et al.*, 1994). Integrating satellite data into the model increased accuracy in the Coal Field by four percent, and diminished overall accuracy in the Pine Mountain region by nearly 20 percent. A decrease in accuracy in the Pine Mountain region was not unexpected considering the impact that extreme topography has on satellite imagery, despite the normalization process. A likely explanation for this is the higher variability of slope angles in the Pine Mountain area than in the Coal Field due to the rugged, mountainous terrain. The extreme angles of solar incidence in this region have a shadowing effect apparent in the raw Landsat ETM+ images, which may lead to less accurate classifications (Meyer *et al.*, 1993; Twele & Erasmi, 2005). The detrimental effect of the shadowing may be reflected in the lower overall accuracy for Pine Mountain.

Even though the MaxEnt technique was given a computational advantage by selecting the best model from ten separate iterations, the omission of absence data had a negative effect on the classifications compared to the decision trees (Figure 2.4). In both regions, the MaxEnt model over-fit the predicted eastern hemlock data; approximately one-quarter of the non-hemlock ground-truthed reference points were incorrectly classified as eastern hemlock.

The difficulty and time required to complete each model varied considerably. The image processing required of the satellite images added a substantial amount of time to the model completion, especially the topographic normalization. Because of that, the TREE-ETM+ model was the most difficult and time consuming. Without the satellite image processing, the TREE-OMIT decision tree was much faster to model. Since both decision tree methods required final maps to be built in GIS using the node-splitting conditions, the decision trees were significantly more time-intensive than the MaxEnt models. The MaxEnt program was straightforward, due in part to the simple user interface, and while estimation of the thresholds added to the time committed, it was the least complicated and quickest model to execute. However, the MaxEnt model was not as accurate as the TREE-OMIT model.

The results indicate that the most advantageous procedure for mapping conifer resources in the central Appalachian mountain range depends on the priorities set forth by the end user. This study demonstrates that an accurate map can be produced without the extra time required to acquire and process mid-resolution satellite imagery. In situations where absence data is unreliable or unavailable, a presence-only species distribution model like MaxEnt may be the only option, but still a reliable one. However, if absence data has been collected and resource managers need to know the most likely areas to find isolated or unknown populations, the TREE-OMIT decision tree classifier is the best option. This model produced the highest average overall accuracy with the least amount of predicted hemlock cover which suggests a very precise method for mapping eastern hemlock at the edge of its habitat range.

As non-native invaders such as the hemlock woolly adelgid continue to invade our ecosystems and threaten valued resources, land managers must utilize diverse approaches to develop increasingly aggressive tools for invasive species management. My results demonstrate that decision tree classification is a feasible means of determining high-risk areas of invasion and could aid in combating this and other exotic invaders.

Table 2.1

Environmental variables used in the classification and regression tree analysis to delineate eastern hemlock from other evergreen species.

Environmental Layer	Description	Source
Elevation	Digital elevation model (DEM)	USGS
Slope	Slope derived from DEM	Calculated using ArcGIS slope tool
Aspect	Aspect derived from DEM	Calculated using ArcGIS aspect tool
Soil type	Soil Survey Geographic (SSURGO) data	USDA Geospatial Data Gateway
Moisture index	Topographic relative moisture index (modified)	TRMIM.aml script downloaded from http://earth.gis.usu.edu/swgap/landform.html
Stream distance	Euclidean distance from nearest stream	Calculated using ArcGIS Euclidean distance tool
Topographic position	Topographic position index	Calculated using TPI extension (Jenness, 2006) for ArcView (ESRI, Redlands, CA, U.S.)
Curvature	Curvature of the terrain derived from DEM	Calculated using ArcGIS curvature tool
Minimum temperature	Average minimum temperature	The Geospatial Data Gateway http://datagateway.nrcs.usda.gov/GatewayHome.html
Maximum temperature	Average maximum temperature	The Geospatial Data Gateway http://datagateway.nrcs.usda.gov/GatewayHome.html
Geologic formation	Geologic formations of Kentucky	Kentucky Geological Survey

Table 2.2

Characteristics of the Landsat 7 ETM+ scenes used in eastern hemlock classifications.

Season	WRS Path	WRS Row	ID	Acquisition Date	Solar Azimuth	Solar Elevation
Summer	18	34	L71018034_03420000601	1 Jun 2000	122.5244383	65.5350559
Summer	19	34	L71019034_03420000608	8 Jun 2000	120.6754585	65.8272615
Summer	19	35	L71019035_03520000608	8 Jun 2000	117.3767641	66.2986124

Table 2.3

Results of decision tree analyses showing variable rankings and the frequencies of each variable used as a splitting condition at each tree growth level.

2.3.A. TREE-ETM+. Decision trees were generated for each satellite coverage area in each physiographic region, resulting in six total decision trees. Number of nodes and tree level frequencies represent totals of all six decision trees.

Rank	Variable	# of Nodes	Level of Tree					
			1	2	3	4	5	6
1	Streams	8	3	1	2	1	1	
2	Moisture index	6		1	2	3		
3	Band 5	6		2	2	2		
4	Geo form	5	1	1	1	1	1	
5	Maximum temperature	5	2		1	1		1
6	Band 4	5		3		2		
7	TPI	4		1	1		2	
8	Aspect	3		2		1		
9	Band 2	3			2		1	
10	Elevation	2	2		1	1		1
11	Soil type	2				1		1
12	Band 1	2				2		
13	Minimum temperature	1			1			
14	Curvature	1		1				
15	Slope	1			1			
16	Band 7	1		1				
17	Band 3	0						

2.3.B. TREE-OMIT. Decision trees were generated for each physiographic region separately; number of nodes and tree level frequencies represent totals from both decision trees.

Rank	Variable	# of Nodes	Level of Tree						
			1	2	3	4	5	6	7
1	Streams	5	2			2	1		
2	Minimum temperature	3		2		1			
3	Geo form	3		1	1				1
4	Moisture index	3		1		1		1	
5	Aspect	3			2	1			
6	Curvature	3			2	1			
7	TPI	3				1	1	1	
8	Slope	2		1		1			
9	Elevation	2		1			1		
10	Maximum temperature	2			2				
11	Soil type	0							

Table 2.4

Percent contribution of variables to MaxEnt models in each physiographic region.

Region	Variable	Percent contribution
Coal Field	Streams	41.0
	Soil type	37.1
	Geo form	12.0
	Elevation	2.4
	TPI	2.0
	Aspect	1.6
	Minimum temperature	1.5
	Slope	1.0
	Moisture index	0.5
	Curvature	0.5
	Maximum temperature	0.4
Pine Mountain	Soil type	43.8
	Geo form	21.2
	Streams	21.1
	Minimum temperature	3.1
	Curvature	2.3
	Elevation	2.3
	TPI	1.8
	Slope	1.6
	Aspect	1.2
	Moisture index	1.1
	Maximum temperature	0.5

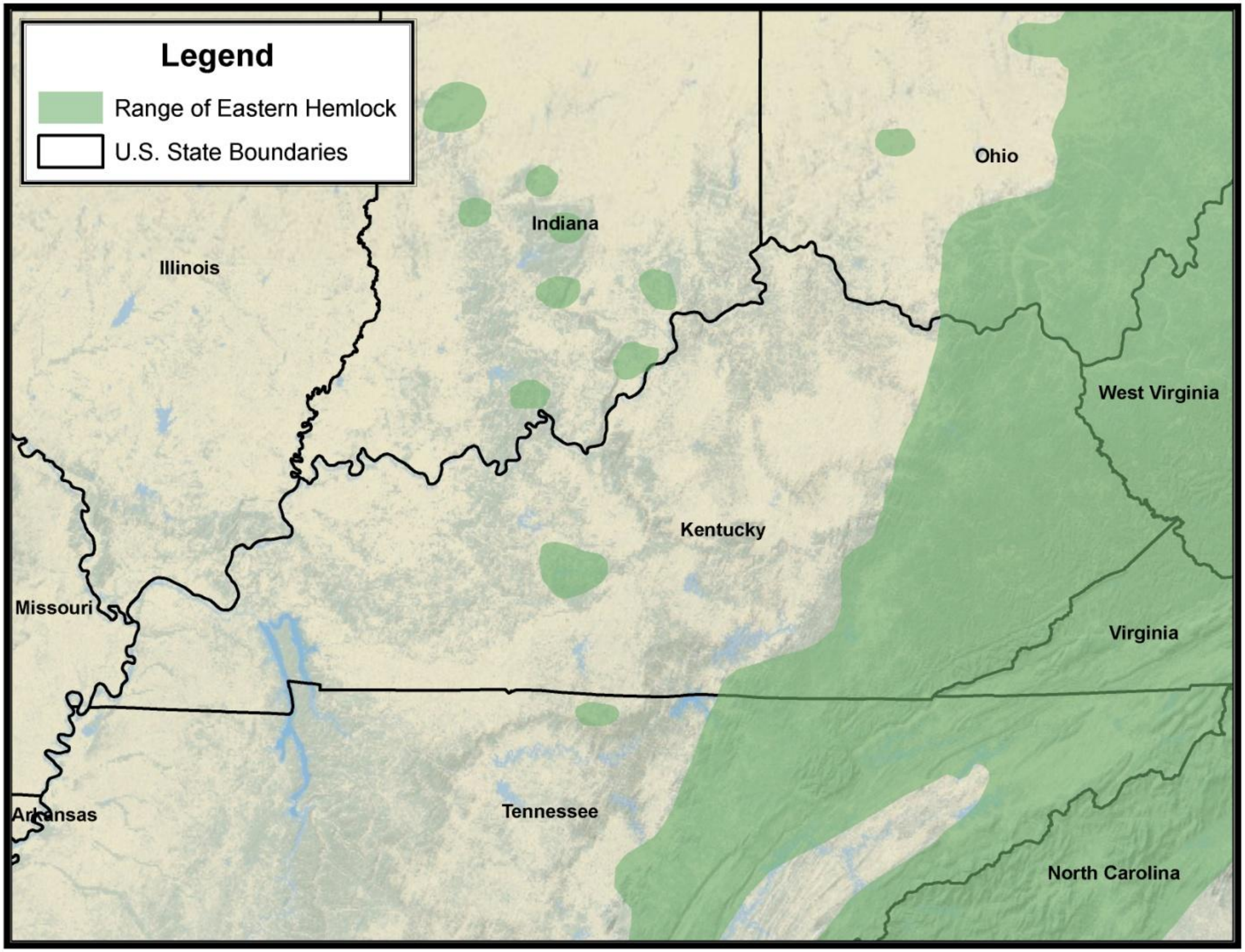

Legend
Range of Eastern Hemlock
U.S. State Boundaries
Ohio
Indiana
Illinois
West Virginia
Kentucky
Missouri
Virginia
Arkansas
Tennessee
North Carolina

FIGURE 2.1.

Geographic distribution of eastern hemlock in Kentucky based on a GIS representation of Little (1971).

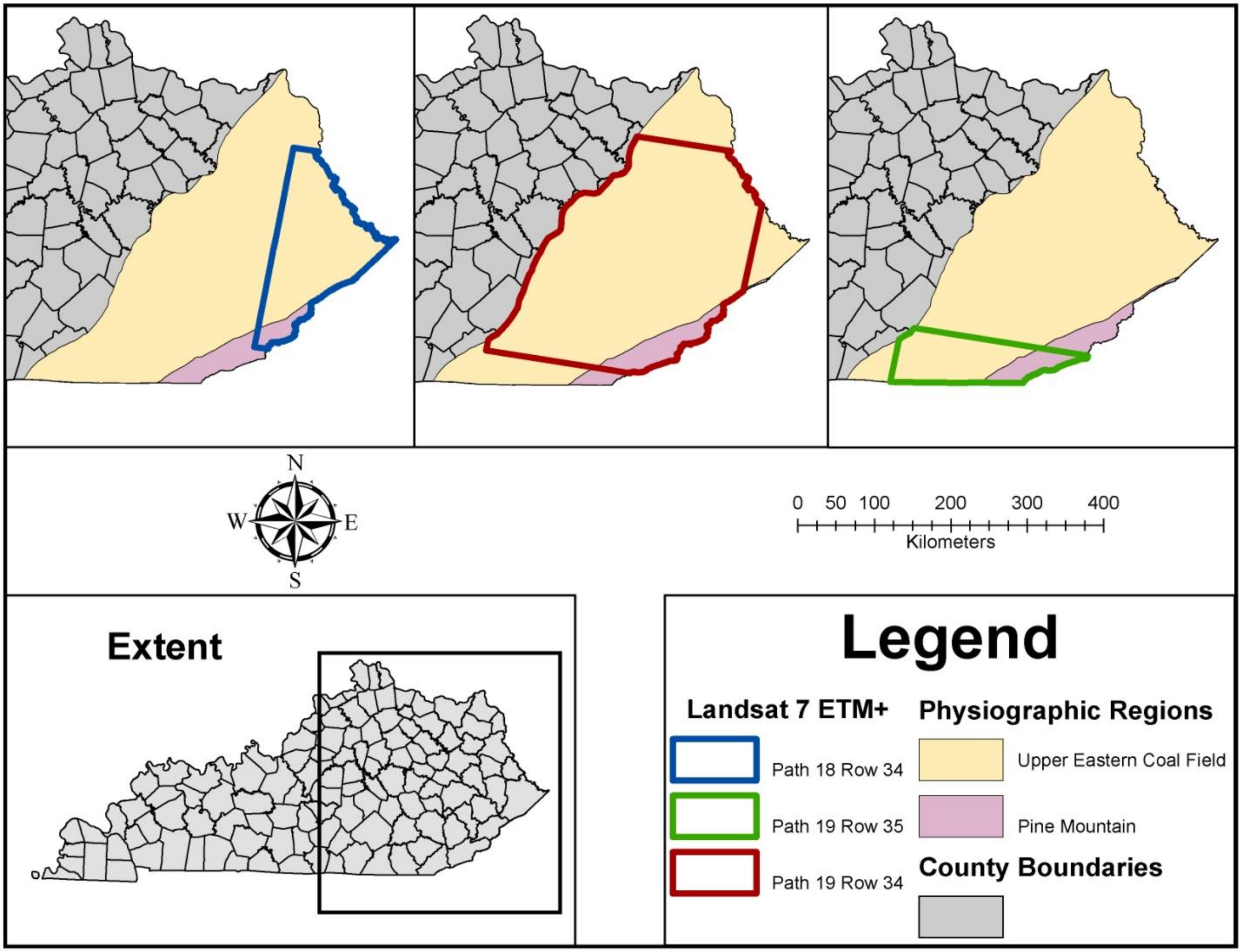

N
S
W
E
0 50 100 200 300 400
Kilometers
Extent
Legend
Landsat 7 ETM+
Path 18 Row 34
Path 19 Row 35
Path 19 Row 34
Physiographic Regions
Upper Eastern Coal Field
Pine Mountain
County Boundaries

FIGURE 2.2.

Study area (approximately 27,000 km^2) in eastern Kentucky.

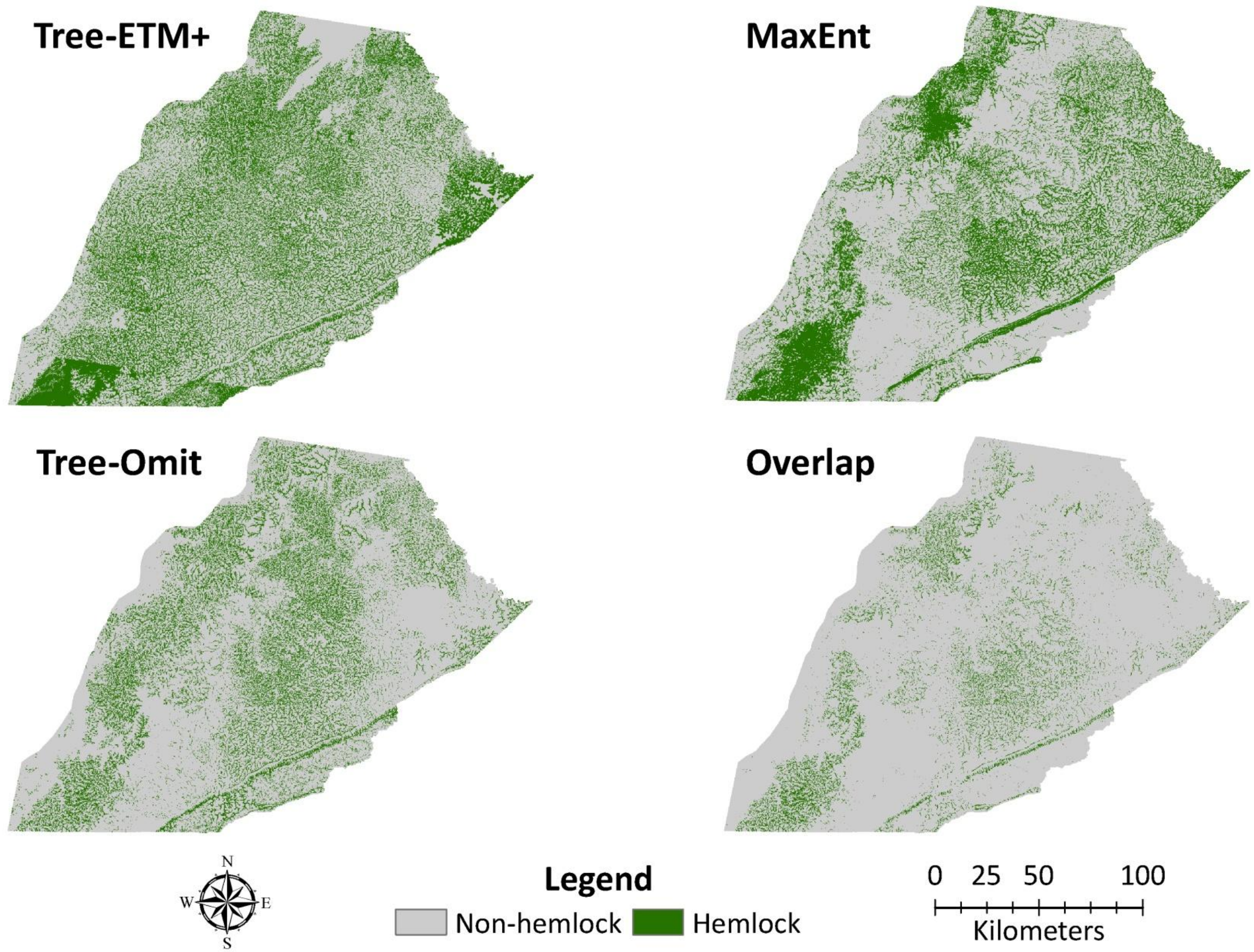
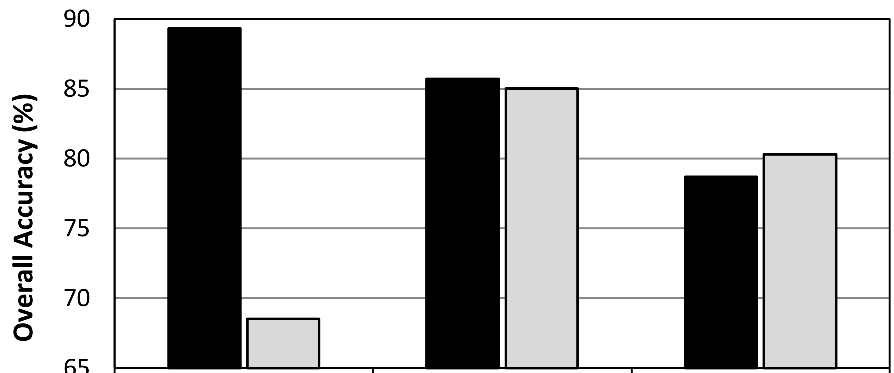

Tree-ETM+
MaxEnt
Tree-Omit
Overlap
N
W
E
S
Legend
Non-hemlock
Hemlock
0 25 50 100
Kilometers

FIGURE 2.3.

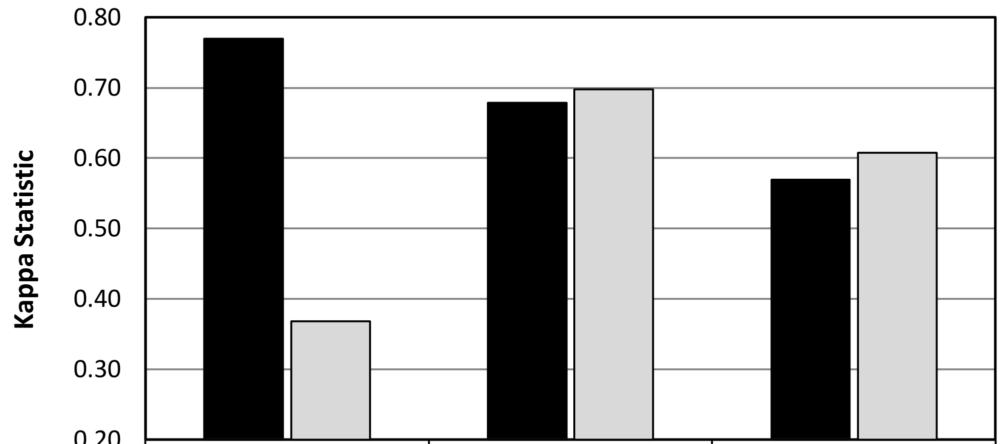
Distribution of eastern hemlock resulting from three modeling approaches, a decision tree using variables that included satellite spectral data (TREE-ETM+), a decision tree that excluded the spectral data (TREE-OMIT), and a maximum entropy species distribution model (MaxEnt). The overlap area (Overlap) denotes the areas in which all three models predicted presence of eastern hemlock.



	Tree-ETM+	Tree-Omit	MaxEnt
■ Coal Field	89.3	85.7	78.7
□ Pine Mountain	68.5	85.0	80.3

FIGURE 2.4.

Overall accuracies of hemlock maps in two physiographic regions that resulted from three different models: a decision tree that included Landsat 7 ETM+ imagery (Tree-ETM+), a decision tree that excluded Landsat imagery (Tree-Omit), and a MaxEnt distribution model (MaxEnt). A 30-meter buffer was used in the calculations to account for georectification and GPS errors.



	Tree-ETM+	Tree-Omit	MaxEnt
■ Coal Field	0.770	0.679	0.569
□ Pine Mountain	0.368	0.698	0.608

FIGURE 2.5.

Kappa statistics of hemlock maps in two physiographic regions that resulted from three difference models: a decision tree that included Landsat 7 ETM+ imagery (Tree-ETM+), a decision tree that excluded Landsat imagery (TREE-OMIT), and a MaxEnt distribution model (MaxEnt).

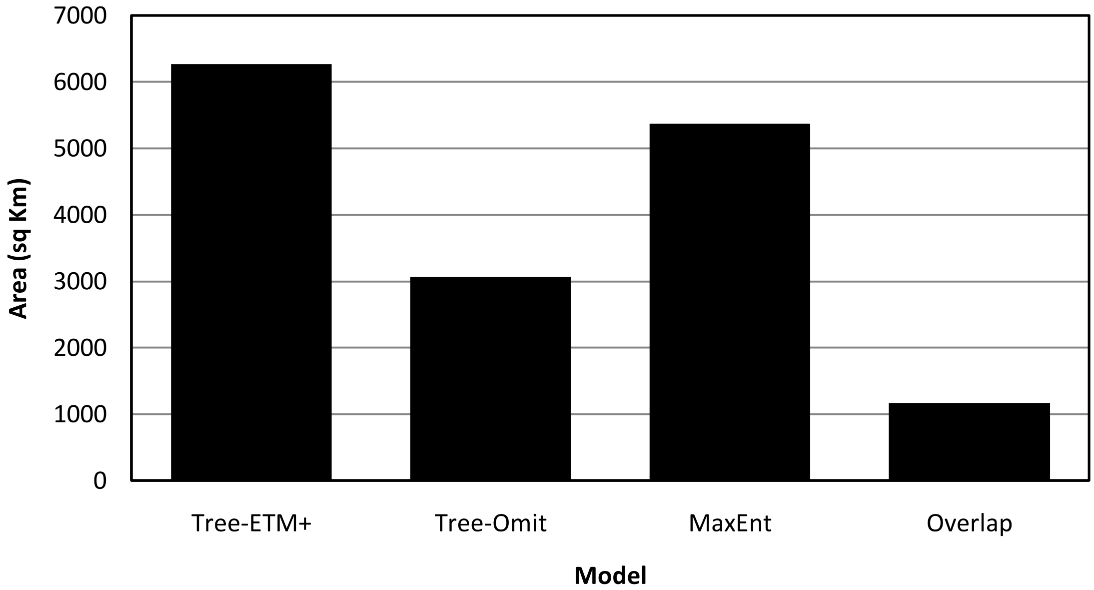


FIGURE 2.6.

Area, in square kilometers, predicted as eastern hemlock by each modeling approach. Overlap denotes the areas in which all three models predicted presence of eastern hemlock.

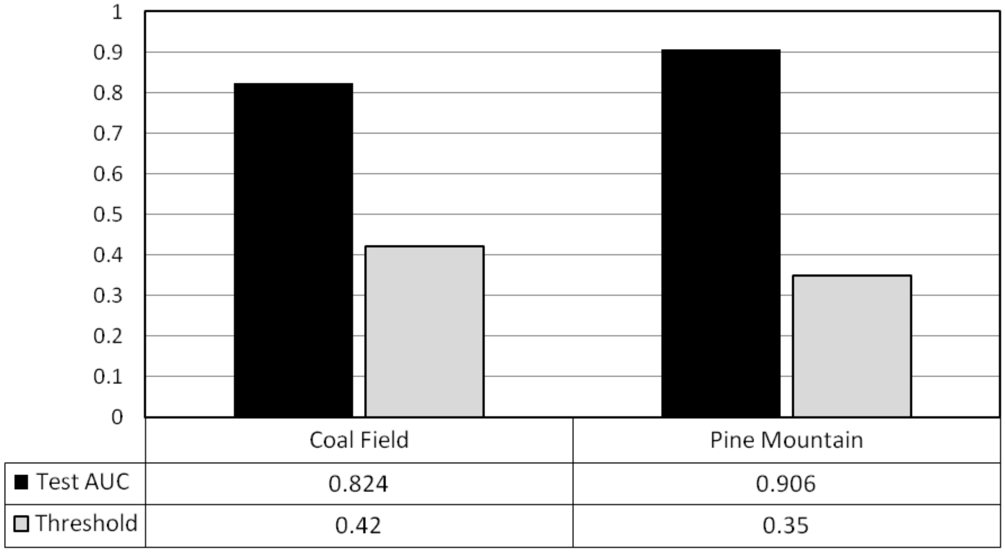


FIGURE 2.7.

Area under the curve (AUC) and threshold of hemlock distribution models in two physiographic regions generated using MaxEnt.

CHAPTER THREE

PREDICTING EASTERN HEMLOCK, *Tsuga canadensis*, SUSCEPTIBILITY TO HEMLOCK WOOLLY ADELGID, *Adelges tsugae*, USING SPECIES DISTRIBUTION MODELS

INTRODUCTION

The hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand, Hemiptera: Adelgidae) is a small (0.8-1.4mm) exotic invasive herbivore in hemlock (*Tsuga* spp.) forests of eastern North America. On eastern hemlock (*T. canadensis* Carrière), HWA causes high rates of mortality, especially in the southern portion of hemlock's distribution range, killing trees in just a few years (Mcclure *et al.*, 2001; Ward *et al.*, 2004). Native to parts of China, Japan, and India (Montgomery *et al.*, 1999), the first report of HWA in eastern North America occurred in 1951 in Richmond, Virginia on eastern hemlock probably transported on infested nursery stock from southern Japan (Havill *et al.*, 2006). Following its initial establishment in Virginia there was a lag time of almost 30 years, during which the population did not expand. However, in the 1980s infestations expanded northward along the east coast, and since then HWA has moved northward and westward, exploiting the large contiguous tracts of hemlock forest common in the northeast. More recently HWA has expanded its geographic range southward through the southern Appalachians where eastern hemlock is more confined to moist coves, higher elevations and north-facing slopes (Godman & Lancaster, 1990; Ward *et al.*, 2004). HWA was first reported in March 2006 in southeast Kentucky, and by spring 2009 infestations had been recorded in 12 counties (Kentucky Forest Health Task Force, 2006).

Eastern hemlock is critically important ecologically: it is vital in maintaining stream quality, provides habitat for hemlock-dependent birds, and provides seasonal habitat for grouse, turkey, moose, deer, and other wildlife (Shriner, 2001; Snyder *et al.*, 2002; Keller, 2004; Ross *et al.*, 2004; Ford & Vose, 2007). Loss of eastern hemlock will cause changes in vegetation composition and structure; as hemlock die, light penetration to the forest floor increases, leading to a larger percent of ground cover by vascular plants, including potentially harmful non-natives. Increased light penetration also creates suitable habitat for less shade-tolerant tree species such as black birch (*Betula lenta*) and red maple (*Acer rubrum*) (Catovsky & Bazzaz, 2000; Yorks *et al.*, 2003; Spaulding & Rieske, 2010). The consequences of widespread hemlock mortality for hemlock-associated and hemlock-dependent aquatic and terrestrial wildlife will be devastating. Because of the importance of eastern hemlock as a foundation species, adelgid-induced hemlock mortality will have far-reaching consequences. The western border of eastern hemlock's natural distribution range lies within the eastern portion of Kentucky (Little, 1971), where it grows in isolated clusters usually confined to moist coves, higher elevations and north-facing slopes (Godman & Lancaster, 1990). Peripheral populations may be important in conservation of a threatened species (Channell & Lomolino, 2000; Van Rossum *et al.*, 2003); consequently, Kentucky may play a crucial role in the preservation of eastern hemlock.

Predictive models for the spread of HWA would be a powerful tool in the battle to combat this invasive insect. Since HWA is small, highly mobile, and cryptic, detection can be very difficult. Therefore, absence data cannot be considered truly reliable. This is a common problem in wildlife modeling and several methods have been developed to deal with this setback (Elith *et al.*, 2006). One option is to use a model that only uses presence-only data in the analyses; these models may be less accurate than presence-absence models, but are useful even with a small sample of records (Elith *et al.*, 2006; Pearce & Boyce, 2006). Maximum entropy and Mahalanobis distance are two presence-only models that have been shown to perform better than some alternatives (Farber & Kadmon, 2003; Elith *et al.*, 2006; Phillips *et al.*, 2006; Tsoar *et al.*, 2007). These two models have been used to successfully model the habitat suitability of a wide range of taxa, including geckos, snakes, bats, birds, rats, sloths, snails, and caribou (Browning *et al.*, 2005; Johnson & Gillingham, 2005; Phillips *et al.*, 2006; Watrous *et al.*, 2006; Dudik *et al.*, 2007; Pearson *et al.*, 2007; Tsoar *et al.*, 2007)

The maximum entropy species distribution model (MaxEnt; Phillips *et al.*, 2006) uses presence data to produce a continuous probability of relative habitat suitability. The name refers to the fact that the resulting estimation of the probability distribution is that which is most uniform—in other words, has maximum entropy (Pearson *et al.*, 2007). This program generates randomly selected background environmental samples from the study area. MaxEnt is similar to generalized linear models (GLMs) and generalized additive models (GAMs), two common techniques which require absence data or background samples that represent true absences. However, MaxEnt does not interpret background samples as absence data (Phillips *et al.*, 2006).

Mahalanobis distance (MD; Jenness, 2009) is a multivariate statistic based on the ecological niche concept (Hutchinson, 1957) that can be used to map the probability of use or probability of occupancy of an organism by determining the similarity of habitats (Rotenberry *et al.*, 2002; Tsoar *et al.*, 2007). A hyper-elliptical envelope of variables is calculated using the mean vectors and inverse of the covariance matrix of the variables, the center representing the optimal habitat of the species based on calibration (training) data. The distance from the center of the hyper-ellipsoid to a point representing a geographic location with a particular set of habitat conditions is known as the Mahalanobis distance; the shorter the distance, the more likely the location will be suitable for the species (Watrous *et al.*, 2006). MD differs from MaxEnt in that it does not generate background environmental samples to use in the analysis.

Use of these models to create maps showing areas with high susceptibility of HWA infestation would be a valuable asset in managing infestations and reducing its spread. This information could be used to prioritize conservation measures, e.g., where to survey for new infestations or to help determine optimal locations for management efforts. The objective of my study was to create potential distribution maps for the invading hemlock woolly adelgid in eastern Kentucky using presence-only modeling techniques.

METHODS

The study area covered approximately 27,006km^2 of eastern Kentucky (38.29-36.58^{o}N, 81.96-84.83^{o}W; Figure 3.1), of which 3,064km^2 were predicted as eastern hemlock habitat by a decision tree classification (see Chapter Two). This region is comprised of the Eastern Coal Field physiographic region which is part of the Cumberland Plateau. This mountainous area is composed of sandstone, shale, and siltstone (McDowell, 1986) and ranges in elevation from 154 to 1259m. Average monthly temperature ranges from 1.1^{o}C in January to 23.9^{o}C in July and average monthly precipitation ranges from 8.1cm in October to 13.1cm in May (Jackson Carroll AP, 1971-2000 data; National Oceanic and Atmospheric Administration, 2002). The dominant forest type is mixed mesophytic consisting primarily of pine-oak forests (Braun, 1950; Turner *et al.*, 2008).

Hemlock woolly adelgid infested sites were recorded using global positioning system (GPS) receivers. The infestation sites (N=62) that fell within an eastern hemlock coverage area (see Chapter Two) were used in the model analyses (Figure 3.1). HWA infestation points were randomly divided into sub-sets of training (n=42) and test (n=20) data. The data were split into sub-sets 10 separate times so that each distribution model could be run for 10 iterations. The test data points were withheld from model calibration to be used as evaluation data. Ten environmental layers that have potential association with HWA spread were constructed and masked by the eastern hemlock coverage area for use as predictor variables in the model (Table 3.1). Correlations between these layers show no or moderation association except the strong positive correlation between active railroads and electric transmission lines (r=0.76). All layers were converted to rasters with a cell-size of 30m and the projection set to Kentucky Single Zone State Plane. Wind maps were created from three data layers representing wind power at three heights, 30, 50, and 70 meters. These layers were combined into a single layer of the mean of the wind power values of all three heights, then re-sampled from a cell-size of 200m to 30m using bilinear interpolation. Slope and aspect were calculated from a 30m digital elevation model (DEM). For use in MaxEnt, all rasters were then converted to ASCII files. The maximum entropy program used to model the spatial distribution was MaxEnt version 3.3.1 (Phillips *et al.*, 2006). The MaxEnt model was run with the maximum number of iterations and convergence threshold parameters set to 1000 and 0.00001, respectively. The MD model was generated using the Mahalanobis distance extension (Jenness, 2009) for ArcGIS 9.x (ESRI, Redlands, CA, U.S.), and the MD surface was created using raster cell values at the training points.

Each training data set was used to build a MaxEnt and MD model, resulting in ten iterations of each model type. The corresponding test data set was used to estimate an area under the curve (AUC) value (the area between the plot of a receiver operator characteristic curve and the x-axis) for each model using the trapezoid method (Phillips *et al.*, 2006). For AUC calculations, MD surface grids were converted to p-values by fitting raw MD values to a chi-square distribution with 9 degrees of freedom using the Mahalanobis distances tool (Jenness, 2003) for ArcView 3.3 (ESRI, Redlands, CA, U.S.). Following Boubli (2009), the MaxEnt and MD models with the highest AUC value was used to assess further model performance.

A threshold value was assigned in order to reclassify the outputs into nominal classes representing areas of high or low susceptibility to potential infestation. The threshold was established using maximum cumulative frequencies difference method (Browning *et al.*, 2005; Thompson *et al.*, 2006; Fei *et al.*, 2007) to account for a lack of absence data. To determine the threshold value, training data and an equal number of random locations were used to create plots of cumulative frequency versus habitat suitability; the point of maximum difference between these two curves represents the threshold.

The models were evaluated using a one-tailed binomial test, receiver operating characteristic (ROC) analysis, and Kappa statistics. One-tailed binomial tests were used to assess the sensitivity of the models, which indicates how each model predicted areas of high susceptibility compared to a random model. Statistical significance of model sensitivity was determined using the proportion of HWA test samples that lie within the predicted distribution area and the proportion of the area predicted to be suitable by the model. Comparison of the models is not suitable using a one-tailed binomial test because it is threshold dependent, relying on proportions of the study area. Therefore, ROC analysis was used to reduce model performance to a single AUC value which is independent of threshold value, enabling me to compare model performance. HWA training data and 10,000 random points were used to calculate the ROC curves. The Kappa statistic was used to determine how well the maps agree with each other.

RESULTS

The HWA risk maps that resulted from MaxEnt and MD have similar spatial patterns but with different coverage (Figure 3.4). The models agreed most in the southern and eastern portions of the study area (areas D and C, Figure 3.5). As expected, both models estimate hemlocks along Pine Mountain to be highly susceptible, where HWA infestations are the most concentrated (area D, Figure 3.5). However, the MaxEnt model showed a higher distribution of vulnerable trees in this area than the MD model. This was also true for the south-central portion of the study area (area B, Figure 3.5) where a large cluster of at risk hemlocks was identified by MaxEnt but conspicuously unacknowledged by the MD model. In the western and eastern portions of the study area (areas A and C, Figure 3.5), the MD model showed a greater distribution of susceptible hemlocks than MaxEnt.

The maximum cumulative frequencies difference method resulted in thresholds at the logistic MaxEnt value of 0.45 and Mahalanobis distance of 16. After applying thresholds, 70% of the MaxEnt test points and 85% of the Mahalanobis test points fell within areas of high susceptibility; the proportion of the study area predicted as high susceptibility by the MaxEnt model was about half that of the MD model (Table 3.2).

The one-tailed binomial tests showed that both models had significant sensitivity, suggesting that each model performed better than chance (Table 3.2). ROC plots (Figure 3.2) produced AUC values of 0.915 and 0.855 for the MaxEnt and MD models, respectively. Comparison of susceptibility maps yielded a low kappa statistic of 0.299, but high overall agreement (79.5%).

MaxEnt model training gain (Figure 3.3) shows how much information each variable contributed to the model. First, training gain is determined for a model constructed using one isolated variable then again for a model constructed using all remaining variables, leaving the variable of interest omitted. Variables with high training gain when isolated and also decreases training gain when removed contribute a substantial amount of information; therefore these variables are more important. The variables have been ranked based on the inverse of the difference of the omitted and isolated model gains. This method suggests that the most important variables for building the MaxEnt model was proximity to nearest trail followed by proximity to nearest active railroad then proximity to populated places. Susceptibility to infestation was inversely proportional to distance to the nearest trail, and approximately 84% of the region estimated as highly susceptible by the MaxEnt model was within 9km of a trail. For the active railroads and populated places variables, susceptibility peaked at 0.9km and 0.2km, respectively, and decreased with distance from these optimal distances. Most, approximately 84%, of the high susceptibility region was positioned within 10km of an active railroad and 0.7km of a populated place. The variables with the least contribution to the MaxEnt model were aspect, distance to nearest stream, and distance to nearest road. Means and standard errors of the means for all variables are shown in Table 3.3 for the entire study area, known HWA infestations, the MaxEnt model, and the Mahalanobis distance model. The means of both distribution models were lower than the full study area for all variables except slope, which may be a consequence of the large number of HWA infestations located on the steep slopes of

Pine Mountain. The MD high susceptibility region showed means that were greater than MaxEnt means for all variables except electric transmission lines, roads, and slope. This reflects the greater distribution of the MD high susceptibility area compared to the more restricted high susceptibility distribution predicted by the MaxEnt model.

DISCUSSION

I tested two models to predict the spread of the highly invasive HWA through the eastern hemlock forests of eastern Kentucky. The invasion of HWA in Kentucky can potentially occupy the entire study area, which consists exclusively of predicted eastern hemlock habitat. Consequently, the predictions of the distribution models cannot be interpreted as habitat suitability because all eastern hemlock in the state is vulnerable to attack. However, trees that have already succumbed to HWA must be associated with a dispersal pathway. Therefore, the models reveal areas of eastern hemlock highly susceptible to invasion based on similarity of dispersal conditions to known infestations. Aside from slope, aspect, and wind power, the environmental variables represent corridors that animals or humans might use when inadvertently spreading HWA from one tree to another.

Recreational trails, the variable that contributed the most information to the MaxEnt model, serves as a one of those corridors used by humans, deer, and flyways for birds. Distance to active railroads and populated places were also high ranking variables which may indicate that HWA is being dispersed more by animals than by wind. In fact, susceptibility decreased with increased wind power. Wind has been found to be a significant mode of dispersal in the northeast United States (McClure, 1990), but the contradiction here is a reasonable assertion considering the patchy distribution of eastern hemlock in the southern Appalachian region. Therefore, it is likely that in eastern Kentucky wind is in fact dispersing HWA, but there is not a nearby hemlock tree when the eggs, crawlers, or adults land and they soon die.

The high AUC values indicate that the models performed better than chance and to such a degree as to be valuable (Elith *et al.*, 2006). A high percentage of the sample points were located on Pine Mountain in the extreme southern part of the study area (Figure 3.1). This would lead to a spatial autocorrelated test data set which may have boosted the AUC value (Veloz, 2009). This spatial autocorrelation would be reduced by further sampling throughout the study area. The MaxEnt model had a higher AUC value, implying that it performed better than the Mahalanobis distance model. However, the latter correctly predicted more test points in the high susceptibility class. One explanation for this could be that the Mahalanobis distance model overestimated the area of high susceptibility; nearly one-quarter of the study area was classified as high susceptibility. This may be a consequence of using a small data set and only presence data. Availability of true absence data would constrain a distribution model and has been shown to increase accuracy (Vaclavik & Meentemeyer, 2009). Unfortunately, absence data cannot be considered reliable in this situation.

The low kappa statistic value, along with the relatively high overall agreement, suggests that the maps agree on the general location of areas of high susceptibility, but differ markedly on the quantity of that area. The overall pattern of areas acutely suitable for HWA infestation is very similar in both models. However, the high risk area of the Mahalanobis distance model is generally more voluminous than the MaxEnt model. The spatial references of the models (Figure 3.4) show that both models predict eastern hemlock along the southeastern border of the study area to be highly susceptible to HWA infestations. In fact HWA infestations have been found in this area (Figure 3.1) which encompasses Pine and Cumberland mountains, where the first infestations were found. Extending north from this region is a stretch of highly susceptible eastern hemlock where, as of spring 2010, no HWA has been reported. Both models also show patches of vulnerable eastern hemlock along the western border of the study area. Apparent in either model are areas of dispersal corridors or bottlenecks. These areas will be particularly important from a management standpoint in the efforts to mitigate the expansion of HWA.

Model sensitivity, the percentage of correctly classified test points, and high AUC values imply that both models performed well. Both models predict similar geographic areas of eastern hemlock are at high risk of HWA invasion. The corridors and bottlenecks of the most susceptible eastern hemlock have implications in planning HWA mitigation. Identification of these dispersal corridors and bottlenecks will allow managers to impede the expansion of HWA with fewer resources. My results demonstrate that species distribution modeling of a non-native forest pest can generate an effective decision management tool.

Table 3.1

Environmental layers used as predictor variables in the species distribution models.

Environmental Layer	Description	Source
Abandoned railroads	Euclidean distance from nearest abandoned railroad	Kentucky Geography Network
Active railroads	Euclidean distance from nearest active railroad	Kentucky Geography Network
Aspect	Aspect derived from DEM	Calculated using ArcGIS aspect tool
Electric transmission lines	Euclidean distance from nearest electric transmission line	Kentucky Public Service Commission
Populated places	Euclidean distance from nearest feature listed in the USGS Geographic Names Information System (GNIS)	Kentucky Geography Network
Roads	Euclidean distance from nearest road	Kentucky Geography Network
Slope	Slope derived from DEM	Calculated using ArcGIS slope tool
Streams	Euclidean distance from nearest stream	Kentucky Geography Network
Trails	Euclidean distance from nearest recreational trail	Kentucky Geography Network
Wind power	Average of wind power (W/m^2) densities at hub heights of 30, 50, and 70 m	Kentucky Geography Network

Table 3.2

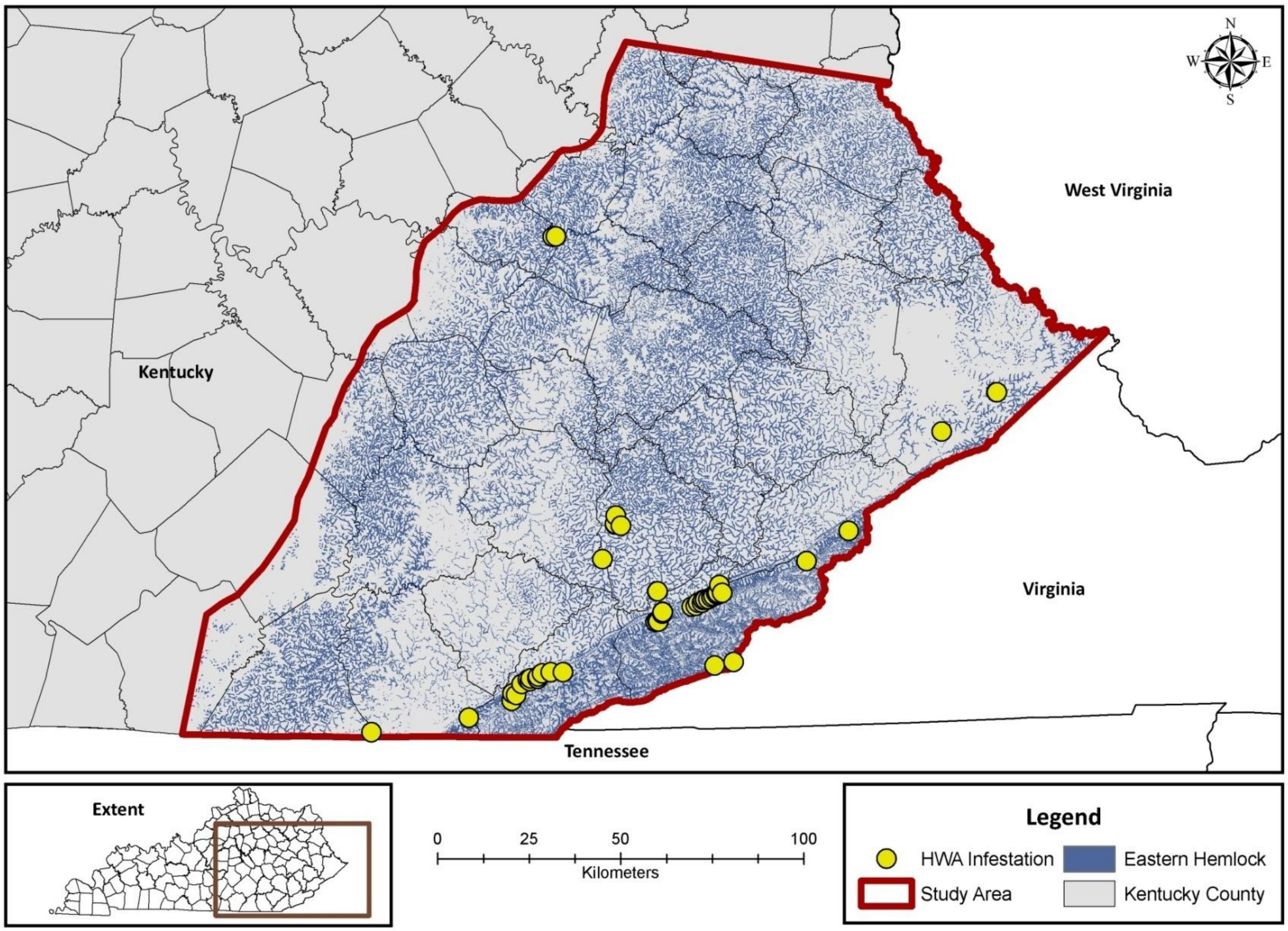
One-tailed binomial test of significance of model sensitivity (1-omission rate). Known locations of HWA infestations were categorized based on high or low susceptibility classes. Predicted area is the proportion of study area classified by the model as high susceptibility.

Model	Prediction Category	N	Proportion of study area	Significance
MaxEnt	Present	14	.115	<0.001
	Absent	6		
Mahalanobis Distance	Present	17	.230	<0.001
	Absent	3		

Table 3.3

Mean and standard error of the mean (se) of each variable used in MaxEnt and Mahalanobis distance (MD) models. Statistics for each variable was calculated for each pixel of the entire study area (N=3404478), HWA infestations (N=62), or areas classified as high susceptibility in the MaxEnt (N=393175) and MD (N=783009) models. Aspect and slope are in units of degrees, wind power in watts per meter-squared, and the remaining variables are in kilometers.

Variable	Study Area	HWA Infestations	MaxEnt	MD
Abandoned railroads	8.23 (3.47x10^{-3})	5.86 (0.88)	6.07 (1.25 x10^{-2})	6.74 (6.16 x10^{-3})
Active railroads	12.22 (6.50x10^{-3})	6.21 (0.87)	4.97 (8.57 x10^{-3})	6.35 (5.81 x10^{-3})
Aspect	159.7 (5.58 x10^{-2})	141 (11.66)	135.3 (1.46 x10^{-1})	142.2 (1.03 x10^{-1})
Electric transmission lines	3.54 (1.60 x10^{-3})	2.43 (0.31)	2.36 (3.99 x10^{-3})	2.32 (2.10 x10^{-3})
Populated places	0.8 (2.79 x10^{-4})	0.52 (0.05)	0.45 (4.44 x10^{-4})	0.56 (3.72 x10^{-4})
Roads	0.42 (2.62 x10^{-4})	0.37 (0.05)	0.32 (6.34 x10^{-4})	0.3 (3.40 x10^{-4})
Slope	17.9 (4.21 x10^{-3})	18.8 (1.04)	19.7 (1.37 x10^{-2})	18 (8.56 x10^{-3})
Streams	0.05 (3.28 x10^{-5})	0.04 (0.01)	0.04 (9.50 x10^{-5})	0.04 (3.61 x10^{-5})
Trails	9.69 (4.18 x10^{-3})	5.55 (0.47)	5.33 (5.74 x10^{-3})	6.23 (4.48 x10^{-3})
Wind power	57.9 (1.12 x10^{-2})	48.7 (3.02)	43.5 (3.53 x10^{-2})	49 (1.87 x10^{-2})



West Virginia
Kentucky
Virginia
Tennessee
N
S
E
W
Extent
0
25
50
100
Kilometers
Legend
HWA Infestation
Eastern Hemlock
Study Area
Kentucky County

FIGURE 3.1.

Study area in eastern Kentucky, approximately 27,500 km^2. Geographic extent is 38.43^o N – 36.58^o N, 81.96^o W -84.83^o W.

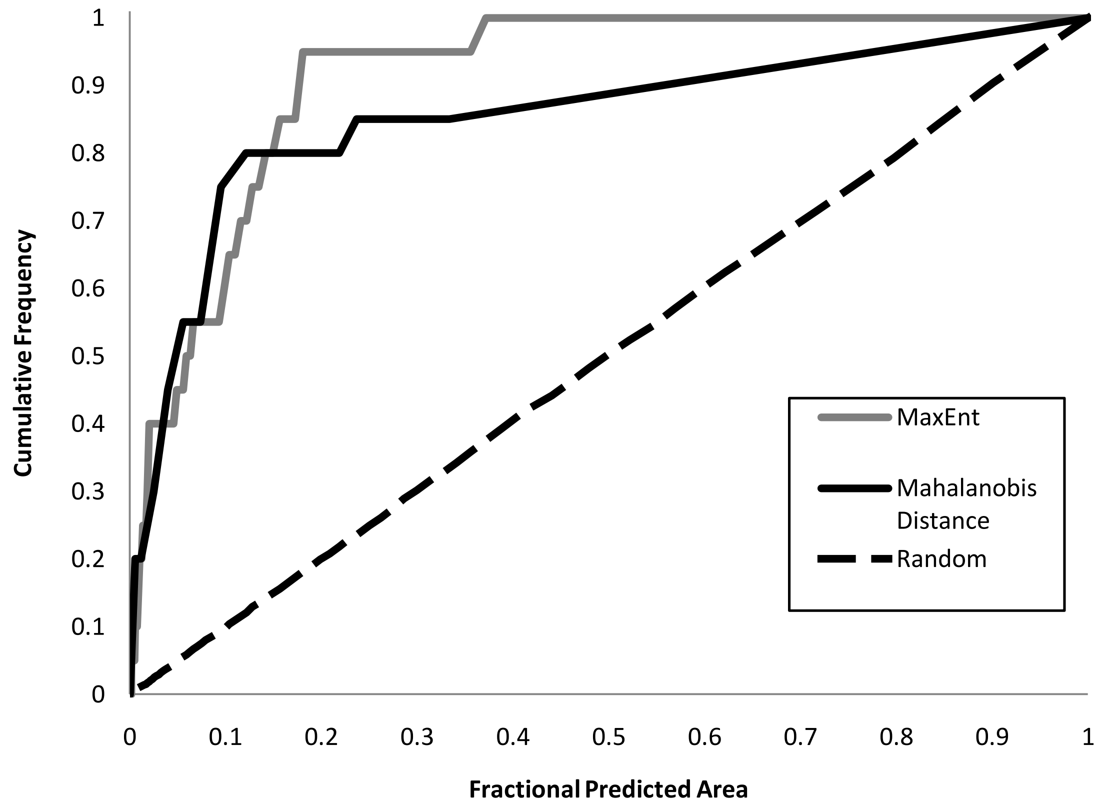


FIGURE 3.2.

Receiver operating characteristic (ROC) curves for MaxEnt and MD models plotted using HWA test points and 10,000 random locations. These curves represent how well the models predict the test data compared to a random model. The ROC curves were used to generate area under the curve (AUC) values which is the area between the ROC curve and the x-axis. Models with higher AUC values are better fit to test HWA infestation locations.

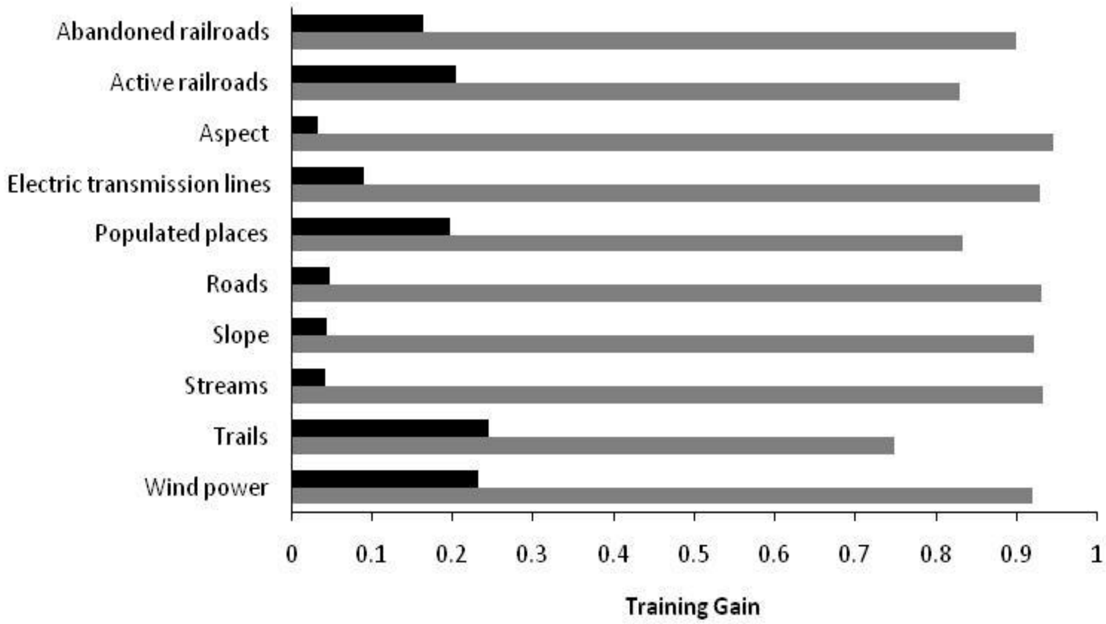


FIGURE 3.3.

Jackknife test of MaxEnt model training gain for environmental variables. Dark bars refer to training gain for models that were constructed using only the corresponding variable and light bars represent training gain when each variable is removed from the model. Variables with the highest isolated-variable trainging gain (dark bars) and lowest omitted-variable training gain (light bars) are contributing more information in building the model than other variables.

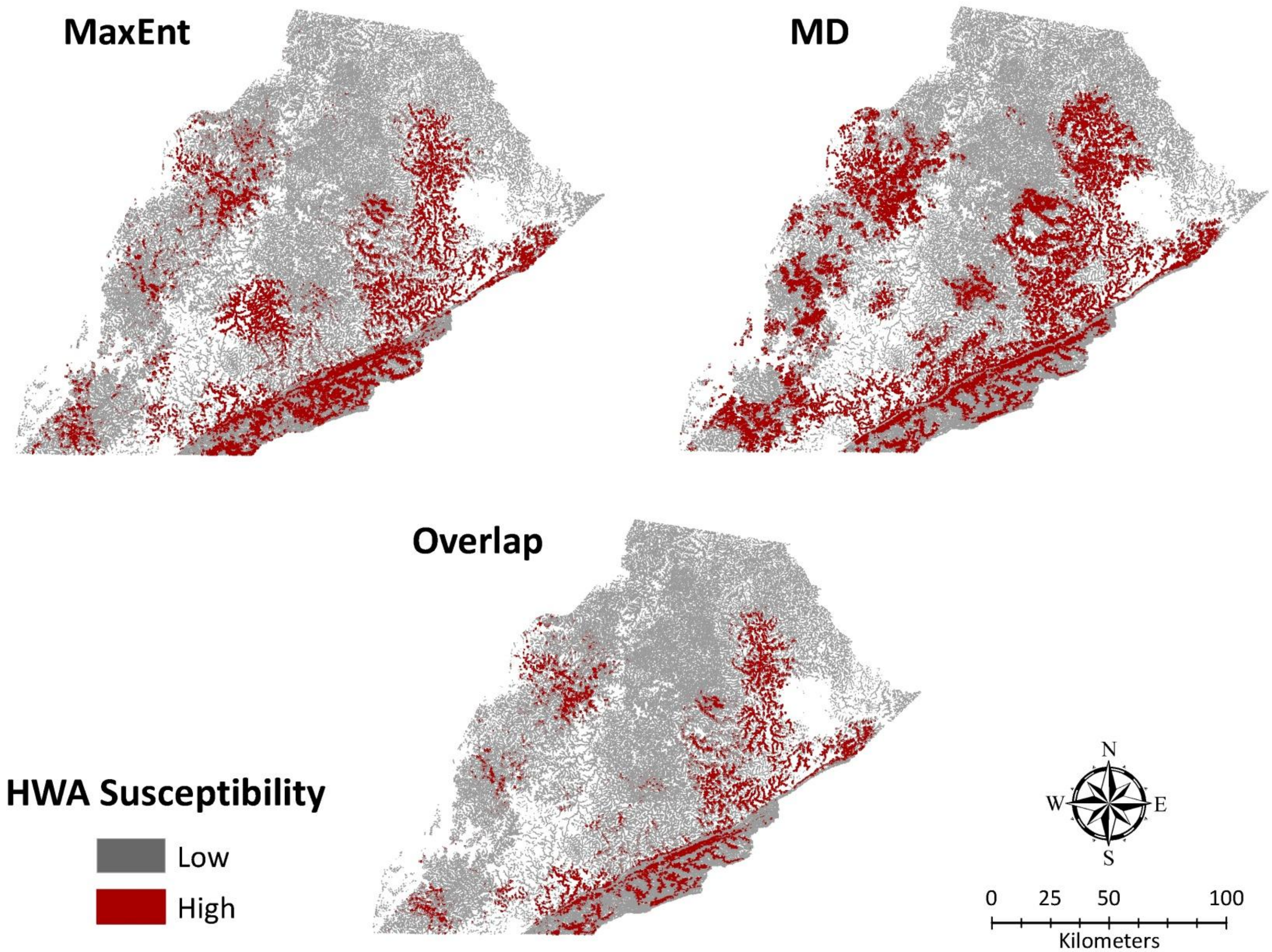

MaxEnt
MD
Overlap
HWA Susceptibility
Low
High
N
W
E
S
0
25
50
100
Kilometers

FIGURE 3.4.

Spatial references of MaxEnt and Mahalanobis distance distribution models showing areas of eastern hemlock highly susceptible to hemlock woolly adelgid infestation.

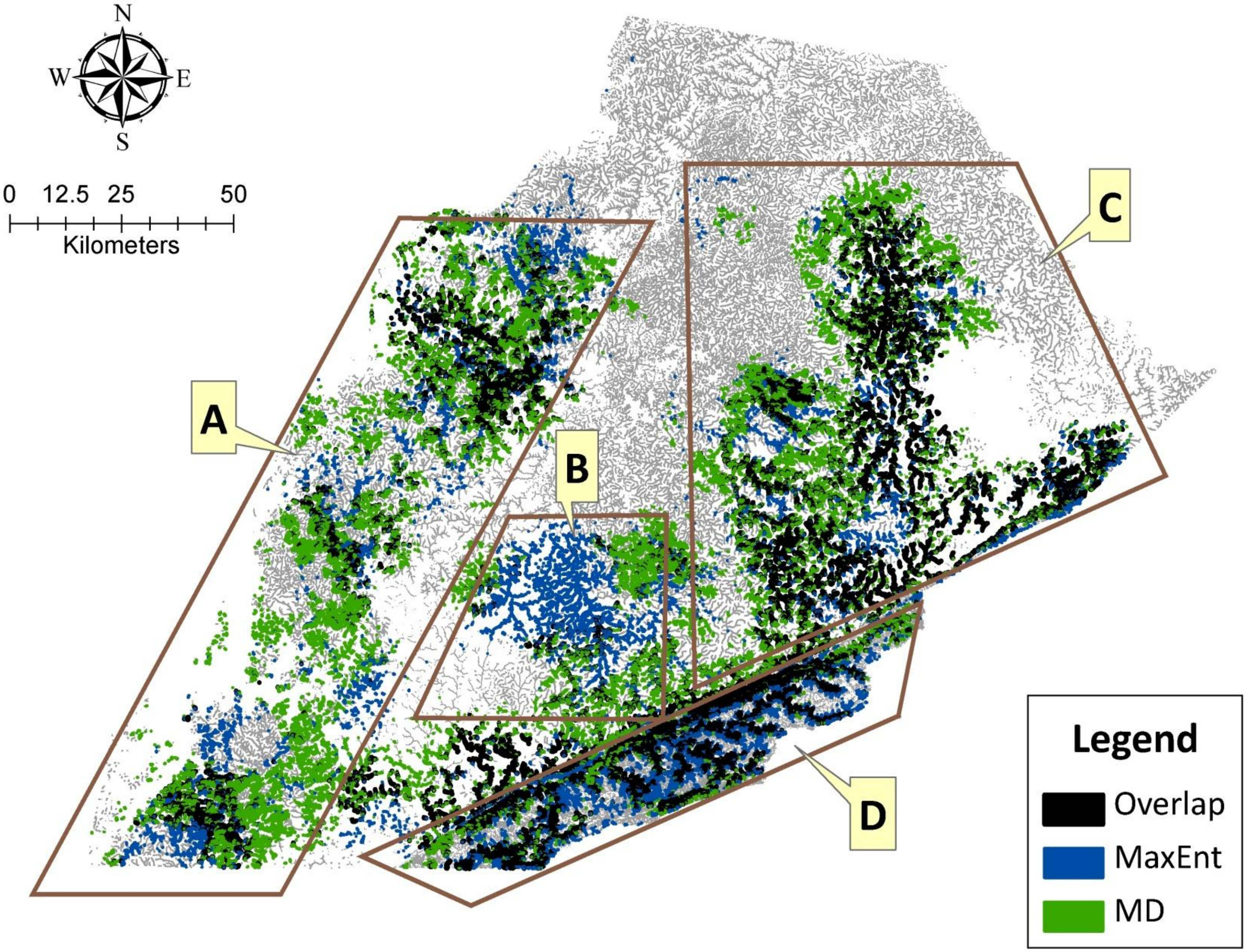

N
W
E
S
0 12.5 25 50
Kilometers
A
B
C
D
Legend
Overlap
MaxEnt
MD

FIGURE 3.5.

Spatial contrast of MaxEnt and Mahalanobis distance (MD) distribution models. Areas in which both models predict high susceptibility to HWA are represented as Overlap. Letters A through D refer to geographic regions discussed in the results section of chapter three.

APPENDICES

Appendix 1. Data points used in the hemlock classification analyses. Lon and lat represent longitude and latitude, respectively, which are reported in the North American Datum 1983 geographic coordinate system. Data points obtained from the U.S. Forest Service Forest Inventory and Analysis program have been excluded from this table.

LON	LAT	CLASS TYPE
-83.9120	36.5891	non-hemlock
-83.8575	36.6729	non-hemlock
-83.8534	36.6371	non-hemlock
-83.8449	36.5894	non-hemlock
-83.8228	36.6932	non-hemlock
-83.7938	36.7156	non-hemlock
-83.7831	36.7215	non-hemlock
-83.7790	36.7271	non-hemlock
-83.7686	36.7206	non-hemlock
-83.7408	36.7368	non-hemlock
-83.7384	36.7425	non-hemlock
-83.7341	36.6177	non-hemlock
-83.7275	36.7325	non-hemlock
-83.7196	36.6293	non-hemlock
-83.7058	36.7627	non-hemlock
-83.7054	36.7416	non-hemlock
-83.6917	36.7410	non-hemlock
-83.6889	36.6669	non-hemlock
-83.6835	36.6613	non-hemlock
-83.6686	36.7589	non-hemlock
-83.6666	36.6342	non-hemlock
-83.6652	36.6363	non-hemlock
-83.6411	36.6505	non-hemlock
-83.6357	36.6485	non-hemlock
-83.6320	36.7728	non-hemlock
-83.6306	36.6467	non-hemlock
-83.6272	36.7671	non-hemlock
-83.6108	36.6534	non-hemlock
-83.6097	36.7827	non-hemlock
-83.6095	36.6606	non-hemlock
-83.6008	36.6620	non-hemlock
-83.5822	36.6499	non-hemlock
-83.5806	36.7805	non-hemlock
-83.5803	36.6534	non-hemlock
-83.5799	36.6502	non-hemlock
-83.5782	36.6477	non-hemlock
-83.5740	36.6522	non-hemlock
-83.5627	36.7284	non-hemlock
-83.5602	36.7259	non-hemlock
-83.5579	36.7848	non-hemlock
-83.5541	36.6916	non-hemlock
-83.5510	36.6862	non-hemlock
-83.5394	36.6692	non-hemlock
-83.5359	36.6688	non-hemlock
-83.5354	36.8084	non-hemlock
-83.5338	36.6702	non-hemlock

LON	LAT	CLASS TYPE
-83.5330	36.6670	non-hemlock
-83.5323	36.8015	non-hemlock
-83.5272	36.8197	non-hemlock
-83.5104	36.8256	non-hemlock
-83.4902	36.8261	non-hemlock
-83.4806	36.7742	non-hemlock
-83.4793	36.7482	non-hemlock
-83.4765	36.7588	non-hemlock
-83.4450	36.8344	non-hemlock
-83.4185	36.8281	non-hemlock
-83.4155	36.8588	non-hemlock
-83.4101	36.8719	non-hemlock
-83.4073	36.8452	non-hemlock
-83.4037	36.7838	non-hemlock
-83.3998	36.7247	non-hemlock
-83.3973	36.7970	non-hemlock
-83.3966	36.8850	non-hemlock
-83.3934	36.7802	non-hemlock
-83.3560	36.8875	non-hemlock
-83.3500	36.7730	non-hemlock
-83.3469	36.8383	non-hemlock
-83.3451	36.7927	non-hemlock
-83.3447	36.8944	non-hemlock
-83.3442	36.8142	non-hemlock
-83.3436	36.8093	non-hemlock
-83.3434	36.7985	non-hemlock
-83.3430	36.7106	non-hemlock
-83.3414	36.7993	non-hemlock
-83.3394	36.8348	non-hemlock
-83.3331	36.7080	non-hemlock
-83.3278	36.8969	non-hemlock
-83.3184	36.8822	non-hemlock
-83.3139	36.8606	non-hemlock
-83.3025	36.8907	non-hemlock
-83.2808	36.8944	non-hemlock
-83.2743	36.7320	non-hemlock
-83.2723	36.9047	non-hemlock
-83.2720	36.7306	non-hemlock
-83.2659	36.8986	non-hemlock
-83.2610	36.9059	non-hemlock
-83.2568	36.8940	non-hemlock
-83.2498	36.9030	non-hemlock
-83.2432	36.7320	non-hemlock
-83.2342	36.9074	non-hemlock
-83.2269	36.9157	non-hemlock
-83.2253	36.7455	non-hemlock

LON	LAT	CLASS TYPE
-83.2199	36.7472	non-hemlock
-83.2193	36.9411	non-hemlock
-83.2174	36.9131	non-hemlock
-83.2030	36.9250	non-hemlock
-83.2023	36.9198	non-hemlock
-83.2021	36.9406	non-hemlock
-83.1906	36.9247	non-hemlock
-83.1889	36.9495	non-hemlock
-83.1883	36.9195	non-hemlock
-83.1874	36.9362	non-hemlock
-83.1861	36.9204	non-hemlock
-83.1838	36.9360	non-hemlock
-83.1807	36.9276	non-hemlock
-83.1803	36.9524	non-hemlock
-83.1746	36.9294	non-hemlock
-83.1713	36.9447	non-hemlock
-83.1700	36.7637	non-hemlock
-83.1662	36.9476	non-hemlock
-83.1657	36.9403	non-hemlock
-83.1648	36.7723	non-hemlock
-83.1599	36.9360	non-hemlock
-83.1595	36.9416	non-hemlock
-83.1576	36.9492	non-hemlock
-83.1516	36.9529	non-hemlock
-83.1445	36.9637	non-hemlock
-83.1261	36.9596	non-hemlock
-83.1167	36.9620	non-hemlock
-83.0981	36.9789	non-hemlock
-83.0971	36.9684	non-hemlock
-83.0944	36.9748	non-hemlock
-83.0745	36.9748	non-hemlock
-83.0696	36.9712	non-hemlock
-83.0554	36.9728	non-hemlock
-83.0538	36.9880	non-hemlock
-83.0536	36.9798	non-hemlock
-83.0507	36.9728	non-hemlock
-83.0404	36.9765	non-hemlock
-83.0370	36.9585	non-hemlock
-83.0209	36.9667	non-hemlock
-83.0202	36.9684	non-hemlock
-82.9965	36.9676	non-hemlock
-82.9938	36.9692	non-hemlock
-82.9707	36.9507	non-hemlock
-82.9561	36.9408	non-hemlock
-82.9539	36.8700	non-hemlock
-82.9466	36.9040	non-hemlock

LON	LAT	CLASS TYPE
-82.9149	36.8792	non-hemlock
-82.9130	36.8803	non-hemlock
-82.9077	36.8941	non-hemlock
-82.9011	36.9393	non-hemlock
-82.8974	36.9414	non-hemlock
-82.8822	37.0421	non-hemlock
-82.8755	37.0248	non-hemlock
-82.8748	37.0287	non-hemlock
-82.8733	37.0384	non-hemlock
-82.8722	37.0201	non-hemlock
-82.8608	36.9382	non-hemlock
-82.8554	37.0517	non-hemlock
-82.8514	37.0607	non-hemlock
-82.8499	37.0035	non-hemlock
-82.8410	37.0626	non-hemlock
-82.8389	37.0586	non-hemlock
-82.8291	37.0665	non-hemlock
-82.8192	37.0206	non-hemlock
-82.8176	37.0720	non-hemlock
-82.8110	37.0106	non-hemlock
-82.7960	37.0783	non-hemlock
-82.7893	37.0188	non-hemlock
-82.7818	37.0095	non-hemlock
-82.7749	37.0723	non-hemlock
-82.7735	37.0784	non-hemlock
-82.7732	37.0703	non-hemlock
-82.7710	37.0805	non-hemlock
-82.7702	37.0743	non-hemlock
-82.7683	37.0784	non-hemlock
-82.7437	37.0526	non-hemlock
-82.7368	37.0557	non-hemlock
-82.7285	37.1003	non-hemlock
-82.7282	37.0868	non-hemlock
-82.7228	37.0832	non-hemlock
-82.6755	37.1409	non-hemlock
-82.6599	37.1445	non-hemlock
-82.6572	37.1465	non-hemlock
-82.6565	37.1512	non-hemlock
-82.6452	37.1519	non-hemlock
-82.6405	37.1650	non-hemlock
-82.6342	37.1609	non-hemlock
-82.6130	37.1718	non-hemlock
-82.6083	37.1796	non-hemlock
-82.6077	37.1735	non-hemlock
-82.6008	37.1911	non-hemlock
-82.5879	37.1890	non-hemlock

LON	LAT	CLASS TYPE
-82.5776	37.1996	non-hemlock
-82.5739	37.1912	non-hemlock
-82.5732	37.2044	non-hemlock
-82.5480	37.2053	non-hemlock
-82.5334	37.2102	non-hemlock
-82.5282	37.2238	non-hemlock
-82.5067	37.2320	non-hemlock
-82.4989	37.2358	non-hemlock
-82.4640	37.2372	non-hemlock
-82.4421	37.2458	non-hemlock
-82.4322	37.2559	non-hemlock
-82.4172	37.2568	non-hemlock
-82.3969	37.2575	non-hemlock
-82.3864	37.2600	non-hemlock
-82.3662	37.2653	non-hemlock
-82.3343	37.2837	non-hemlock
-83.6603	37.8189	evergreen
-83.6548	37.8077	evergreen
-83.6511	37.8203	hemlock
-83.6464	37.8096	evergreen
-83.6447	37.8176	hemlock
-83.6432	37.8087	evergreen
-83.6403	37.8162	hemlock
-83.6396	37.8171	hemlock
-83.6396	37.8164	hemlock
-83.6374	37.8053	evergreen
-83.6350	37.8107	evergreen
-83.6344	37.8086	evergreen
-83.6329	37.8003	hemlock
-83.6276	37.8001	evergreen
-83.6274	37.8002	evergreen
-83.6026	37.8455	evergreen
-83.5997	37.8499	hemlock
-83.5970	37.8059	hemlock
-83.5968	37.8511	hemlock
-83.5966	37.8059	hemlock
-83.5963	37.8509	hemlock
-83.5957	37.8058	hemlock
-83.5914	37.7903	evergreen
-83.5913	37.7903	evergreen
-83.5913	37.7904	evergreen
-83.5910	37.7903	evergreen
-83.5910	37.7904	evergreen
-83.5529	37.1074	evergreen
-83.5529	37.1075	evergreen
-83.5488	37.0987	hemlock

LON	LAT	CLASS TYPE
-83.5483	37.0991	hemlock
-83.5460	37.0994	hemlock
-83.5242	37.1058	evergreen
-83.5242	37.1059	evergreen
-83.5200	37.1062	hemlock
-83.4774	37.1277	evergreen
-83.4773	37.1276	evergreen
-83.4736	37.1108	evergreen
-83.1726	37.5820	hemlock
-83.1725	37.5822	hemlock
-83.1622	37.6346	evergreen
-83.1621	37.6131	evergreen
-83.1620	37.6130	evergreen
-83.1618	37.6130	evergreen
-83.1617	37.6130	evergreen
-83.1616	37.6349	evergreen
-83.1588	37.6316	evergreen
-83.1587	37.6315	evergreen
-83.1587	37.6316	evergreen
-83.1523	37.6315	evergreen
-83.1490	37.5904	hemlock
-83.1488	37.5908	hemlock
-83.1482	37.6236	evergreen
-83.1481	37.6239	evergreen
-83.1451	37.6208	evergreen
-83.1402	37.6157	evergreen
-83.1399	37.6154	evergreen
-83.0008	37.9366	evergreen
-83.0007	37.9368	evergreen
-83.0005	37.9366	evergreen
-83.0002	37.9315	evergreen
-82.9995	37.9347	evergreen
-82.9965	37.9382	evergreen
-82.9963	37.9382	evergreen
-82.9963	37.9383	evergreen
-82.9960	37.9382	evergreen
-82.9956	37.9309	evergreen
-82.9946	37.9270	evergreen
-82.9633	37.8757	hemlock
-82.9630	37.8751	hemlock
-82.9629	37.8763	hemlock
-82.9626	37.8750	hemlock
-82.9624	37.8763	hemlock
-82.9599	37.8731	evergreen
-82.9087	37.8647	evergreen
-82.9086	37.8644	evergreen

LON	LAT	CLASS TYPE
-82.9083	37.8654	hemlock
-82.8801	37.8388	hemlock
-82.8754	37.8390	evergreen
-82.8725	37.8361	evergreen
-82.8725	37.8363	evergreen
-82.8718	37.8381	hemlock
-82.8716	37.8361	hemlock
-82.8715	37.8380	hemlock
-82.8714	37.8377	hemlock
-82.7425	37.7259	evergreen
-82.7396	37.7039	evergreen
-82.7389	37.7034	evergreen
-82.7389	37.7038	evergreen
-82.7284	37.7174	evergreen
-82.7252	37.6954	hemlock
-82.3595	37.4311	hemlock
-82.3595	37.4310	hemlock
-82.3587	37.4313	hemlock
-82.3585	37.4313	hemlock
-82.3584	37.4313	hemlock
-82.3584	37.4312	hemlock
-82.3555	37.4314	hemlock
-82.3554	37.4314	hemlock
-82.3553	37.4315	hemlock
-82.3551	37.4315	hemlock
-82.3551	37.4314	hemlock
-82.3160	37.3989	hemlock
-82.3151	37.3985	hemlock
-82.3106	37.4012	hemlock
-82.3103	37.4013	hemlock
-82.3095	37.4013	hemlock
-84.7720	36.8165	non-hemlock
-84.7386	36.9040	non-hemlock
-84.7313	36.8265	non-hemlock
-84.6291	36.9528	non-hemlock
-84.6221	36.9281	non-hemlock
-84.6053	36.9245	non-hemlock
-84.5976	36.9786	non-hemlock
-84.5942	36.8379	non-hemlock
-84.5924	36.9016	non-hemlock
-84.5912	36.9539	non-hemlock
-84.5709	36.9810	non-hemlock
-84.5618	36.9467	non-hemlock
-84.5610	36.8443	non-hemlock
-84.5605	37.0341	non-hemlock
-84.5601	36.9019	non-hemlock

LON	LAT	CLASS TYPE
-84.5599	36.9266	non-hemlock
-84.5381	36.6776	non-hemlock
-84.5344	36.9457	non-hemlock
-84.5319	36.9729	non-hemlock
-84.5315	37.0107	non-hemlock
-84.5287	36.8410	non-hemlock
-84.5285	37.0554	non-hemlock
-84.5277	36.7620	non-hemlock
-84.5244	36.9278	non-hemlock
-84.5239	37.0253	non-hemlock
-84.5095	36.6332	non-hemlock
-84.5011	36.7546	non-hemlock
-84.5002	36.9198	non-hemlock
-84.4981	36.8374	non-hemlock
-84.4962	36.6547	non-hemlock
-84.4948	36.8749	non-hemlock
-84.4930	36.8125	non-hemlock
-84.4927	36.8968	non-hemlock
-84.4752	36.7560	non-hemlock
-84.4713	36.7919	non-hemlock
-84.4710	36.7369	non-hemlock
-84.4703	36.6302	non-hemlock
-84.4696	36.8374	non-hemlock
-84.4682	36.9733	non-hemlock
-84.4675	36.8061	non-hemlock
-84.4674	36.6546	non-hemlock
-84.4671	36.6833	non-hemlock
-84.4654	36.7044	non-hemlock
-84.4623	36.9557	non-hemlock
-84.4546	36.9179	non-hemlock
-84.4435	36.6722	non-hemlock
-84.4393	36.7100	non-hemlock
-84.4362	36.8327	non-hemlock
-84.4357	36.7276	non-hemlock
-84.4351	36.6249	non-hemlock
-84.4343	36.6562	non-hemlock
-84.4300	36.9215	non-hemlock
-84.4279	36.9430	non-hemlock
-84.4235	36.8670	non-hemlock
-84.4128	36.6239	non-hemlock
-84.4084	36.6519	non-hemlock
-84.4079	36.6759	non-hemlock
-84.4064	36.8386	non-hemlock
-84.4064	36.7284	non-hemlock
-84.4051	36.8149	non-hemlock
-84.3982	36.7071	non-hemlock

LON	LAT	CLASS TYPE
-84.3963	36.7875	non-hemlock
-84.3942	36.8591	non-hemlock
-82.5046	37.8300	non-hemlock
-82.5044	37.8158	non-hemlock
-82.5026	37.7400	non-hemlock
-82.5007	37.6528	non-hemlock
-82.5007	37.5947	non-hemlock
-82.4999	37.6904	non-hemlock
-82.4988	37.6099	non-hemlock
-82.4980	37.7046	non-hemlock
-82.4975	37.7231	non-hemlock
-82.4967	37.5126	non-hemlock
-82.4967	37.4145	non-hemlock
-82.4950	37.6716	non-hemlock
-82.4949	37.3658	non-hemlock
-82.4948	37.7595	non-hemlock
-82.4943	37.8026	non-hemlock
-82.4935	37.3995	non-hemlock
-82.4933	37.3498	non-hemlock
-82.4932	37.4326	non-hemlock
-82.4919	37.4912	non-hemlock
-82.4907	37.2947	non-hemlock
-82.4900	37.5759	non-hemlock
-82.4900	37.2513	non-hemlock
-82.4899	37.3858	non-hemlock
-82.4884	37.3262	non-hemlock
-82.4883	37.4762	non-hemlock
-82.4875	37.5281	non-hemlock
-82.4871	37.2438	non-hemlock
-82.4852	37.5617	non-hemlock
-82.4850	37.6896	non-hemlock
-82.4842	37.2709	non-hemlock
-82.4837	37.4497	non-hemlock
-82.4836	37.3098	hemlock
-82.4820	37.7658	non-hemlock
-82.4812	37.8326	non-hemlock
-82.4774	37.7403	non-hemlock
-82.4771	37.5810	non-hemlock
-82.4753	37.9060	non-hemlock
-82.4752	37.6661	non-hemlock
-82.4745	37.8584	non-hemlock
-82.4743	37.4522	non-hemlock
-82.4741	37.4745	non-hemlock
-82.4741	37.3461	hemlock
-82.4735	37.3832	non-hemlock
-82.4729	37.6506	non-hemlock

LON	LAT	CLASS TYPE
-82.4727	37.8697	non-hemlock
-82.4726	37.3614	non-hemlock
-82.4722	37.5270	non-hemlock
-82.4709	37.8806	non-hemlock
-82.4708	37.4351	non-hemlock
-82.4707	37.7759	non-hemlock
-82.4704	37.2918	non-hemlock
-82.4702	37.7978	non-hemlock
-82.4699	37.5122	non-hemlock
-82.4685	37.5407	non-hemlock
-82.4682	37.3135	non-hemlock
-82.4681	37.8151	non-hemlock
-82.4677	37.5594	non-hemlock
-82.4674	37.7198	non-hemlock
-82.4669	37.6331	non-hemlock
-82.4669	37.4895	non-hemlock
-82.4666	37.7071	non-hemlock
-82.4661	37.3324	non-hemlock
-82.4650	37.2681	hemlock
-82.4649	37.6203	non-hemlock
-82.4648	37.4210	non-hemlock
-82.4627	37.2587	non-hemlock
-82.4615	37.8476	non-hemlock
-82.4603	37.8303	non-hemlock
-82.4602	37.6342	non-hemlock
-82.4597	37.8145	non-hemlock
-82.4565	37.6528	non-hemlock
-82.4553	37.8817	non-hemlock
-82.4543	37.7816	non-hemlock
-82.4539	37.6666	non-hemlock
-82.4537	37.9074	non-hemlock
-82.4533	37.7985	non-hemlock
-82.4527	37.4705	non-hemlock
-82.4513	37.4146	non-hemlock
-82.4507	37.8728	non-hemlock
-82.4499	37.5307	non-hemlock
-82.4498	37.6992	non-hemlock
-82.4495	37.4549	non-hemlock
-82.4487	37.4350	non-hemlock
-82.4484	37.5752	non-hemlock
-82.4482	37.5122	non-hemlock
-82.4469	37.5645	non-hemlock
-82.4467	37.7425	non-hemlock
-82.4465	37.6116	non-hemlock
-82.4458	37.2753	non-hemlock
-82.4457	37.7598	non-hemlock

LON	LAT	CLASS TYPE
-82.4456	37.6001	non-hemlock
-82.4455	37.3562	non-hemlock
-82.4445	37.5447	non-hemlock
-82.4438	37.8675	non-hemlock
-82.4438	37.6861	non-hemlock
-82.4425	37.7617	non-hemlock
-82.4424	37.7233	non-hemlock
-82.4421	37.3294	non-hemlock
-82.4416	37.3836	non-hemlock
-82.4414	37.3525	non-hemlock
-82.4409	37.4932	non-hemlock
-82.4396	37.3122	non-hemlock
-82.4390	37.8513	non-hemlock
-82.4386	37.2909	non-hemlock
-82.4381	37.6920	non-hemlock
-82.4352	37.7195	non-hemlock
-82.4339	37.6523	non-hemlock
-82.4339	37.5502	non-hemlock
-82.4322	37.8388	non-hemlock
-82.4314	37.8889	non-hemlock
-82.4298	37.7067	non-hemlock
-82.4290	37.7972	non-hemlock
-82.4282	37.3236	hemlock
-82.4271	37.8107	non-hemlock
-82.4269	37.5210	non-hemlock
-82.4268	37.4518	non-hemlock
-82.4268	37.4352	non-hemlock
-82.4268	37.3809	non-hemlock
-82.4266	37.2573	non-hemlock
-82.4265	37.6037	non-hemlock
-82.4263	37.7427	non-hemlock
-82.4263	37.4864	non-hemlock
-82.4262	37.5115	non-hemlock
-82.4245	37.4757	non-hemlock
-82.4243	37.5752	non-hemlock
-82.4242	37.6717	non-hemlock
-82.4241	37.7798	non-hemlock
-82.4239	37.4152	non-hemlock
-82.4223	37.6351	non-hemlock
-82.4217	37.3446	non-hemlock
-82.4216	37.4009	non-hemlock
-82.4208	37.6165	non-hemlock
-82.4204	37.5607	non-hemlock
-82.4200	37.2718	non-hemlock
-82.4169	37.7838	non-hemlock
-82.4169	37.7668	non-hemlock

LON	LAT	CLASS TYPE
-82.4142	37.7963	non-hemlock
-82.4135	37.6662	non-hemlock
-82.4116	37.6125	non-hemlock
-82.4089	37.8352	non-hemlock
-82.4084	37.4729	non-hemlock
-82.4075	37.7418	non-hemlock
-82.4071	37.7006	non-hemlock
-82.4071	37.6906	non-hemlock
-82.4063	37.3642	non-hemlock
-82.4061	37.6074	non-hemlock
-82.4060	37.6400	non-hemlock
-82.4056	37.7228	non-hemlock
-82.4053	37.5598	non-hemlock
-82.4042	37.5827	non-hemlock
-82.4039	37.5117	non-hemlock
-82.4030	37.4574	non-hemlock
-82.4025	37.4048	non-hemlock
-82.4024	37.4112	non-hemlock
-82.4016	37.8166	non-hemlock
-82.4012	37.6567	non-hemlock
-82.3999	37.5461	non-hemlock
-82.3992	37.4409	non-hemlock
-82.3984	37.2760	non-hemlock
-82.3943	37.3422	non-hemlock
-82.3930	37.3116	non-hemlock
-82.3926	37.5283	non-hemlock
-82.3888	37.7750	non-hemlock
-82.3870	37.7442	non-hemlock
-82.3870	37.6523	non-hemlock
-82.3866	37.7613	non-hemlock
-82.3863	37.7988	non-hemlock
-82.3854	37.5306	non-hemlock
-82.3841	37.8150	non-hemlock
-82.3834	37.5759	non-hemlock
-82.3815	37.5711	non-hemlock
-82.3810	37.4670	non-hemlock
-82.3808	37.7080	non-hemlock
-82.3805	37.5962	non-hemlock
-82.3804	37.4088	non-hemlock
-82.3794	37.6856	non-hemlock
-82.3790	37.5131	hemlock
-82.3789	37.4390	non-hemlock
-82.3786	37.6723	non-hemlock
-82.3781	37.6326	non-hemlock
-82.3781	37.2765	non-hemlock
-82.3769	37.6171	non-hemlock

LON	LAT	CLASS TYPE
-82.3748	37.4517	non-hemlock
-82.3746	37.3422	non-hemlock
-82.3743	37.7232	non-hemlock
-82.3711	37.3654	non-hemlock
-82.3691	37.3320	non-hemlock
-82.3675	37.6654	non-hemlock
-82.3667	37.7795	non-hemlock
-82.3657	37.7620	non-hemlock
-82.3647	37.6505	non-hemlock
-82.3635	37.7049	non-hemlock
-82.3630	37.5290	hemlock
-82.3615	37.6895	non-hemlock
-82.3609	37.4396	non-hemlock
-82.3594	37.7421	non-hemlock
-82.3592	37.7228	non-hemlock
-82.3588	37.5112	non-hemlock
-82.3569	37.3730	non-hemlock
-82.3562	37.6357	non-hemlock
-82.3560	37.5649	non-hemlock
-82.3555	37.2972	non-hemlock
-82.3549	37.4559	non-hemlock
-82.3545	37.3480	non-hemlock
-82.3540	37.5939	non-hemlock
-82.3530	37.3143	non-hemlock
-82.3522	37.6178	non-hemlock
-82.3519	37.5441	non-hemlock
-82.3513	37.5793	non-hemlock
-82.3511	37.4944	non-hemlock
-82.3473	37.6667	non-hemlock
-82.3454	37.7102	non-hemlock
-82.3433	37.6536	non-hemlock
-82.3430	37.7280	non-hemlock
-82.3414	37.5044	non-hemlock
-82.3404	37.7775	non-hemlock
-82.3394	37.4399	non-hemlock
-82.3375	37.3649	non-hemlock
-82.3371	37.5828	non-hemlock
-82.3359	37.3098	non-hemlock
-82.3358	37.4936	non-hemlock
-82.3355	37.6027	non-hemlock
-82.3354	37.5677	non-hemlock
-82.3343	37.7640	non-hemlock
-82.3341	37.7398	non-hemlock
-82.3338	37.5278	non-hemlock
-82.3321	37.6117	non-hemlock
-82.3320	37.5370	non-hemlock
-82.3315	37.2949	non-hemlock
-82.3306	37.6394	non-hemlock
-82.3295	37.3261	non-hemlock
-82.3239	37.3816	non-hemlock
-82.3210	37.7578	non-hemlock
-82.3189	37.3306	non-hemlock
-82.3180	37.6143	non-hemlock
-82.3179	37.5844	non-hemlock
-82.3179	37.4938	non-hemlock
-82.3177	37.5372	non-hemlock
-82.3156	37.6360	non-hemlock
-82.3146	37.3620	non-hemlock
-82.3141	37.6711	non-hemlock
-82.3139	37.4520	non-hemlock
-82.3135	37.5683	non-hemlock
-82.3127	37.6890	non-hemlock
-82.3093	37.7089	non-hemlock
-82.3093	37.3467	non-hemlock
-82.3092	37.4036	non-hemlock
-82.3091	37.3848	non-hemlock
-82.3083	37.5070	non-hemlock
-82.3080	37.4390	non-hemlock
-82.3074	37.3086	non-hemlock
-82.3073	37.6028	non-hemlock
-82.3069	37.6524	non-hemlock
-82.3034	37.4265	non-hemlock
-82.3012	37.6524	non-hemlock
-82.2941	37.5307	non-hemlock
-82.2937	37.3620	non-hemlock
-82.2934	37.5981	non-hemlock
-82.2933	37.6389	non-hemlock
-82.2932	37.6161	non-hemlock
-82.2912	37.5447	non-hemlock
-82.2912	37.5054	non-hemlock
-82.2911	37.3838	non-hemlock
-82.2898	37.4538	non-hemlock
-82.2895	37.4853	non-hemlock
-82.2891	37.3281	non-hemlock
-82.2873	37.3972	non-hemlock
-82.2871	37.5631	non-hemlock
-82.2857	37.4306	non-hemlock
-82.2841	37.4759	non-hemlock
-82.2817	37.5800	non-hemlock
-82.2742	37.6414	non-hemlock
-82.2741	37.6025	non-hemlock
-82.2741	37.5065	non-hemlock

LON	LAT	CLASS TYPE
-82.2700	37.5794	non-hemlock
-82.2698	37.4239	non-hemlock
-82.2692	37.6183	non-hemlock
-82.2688	37.6523	non-hemlock
-82.2686	37.4873	non-hemlock
-82.2682	37.4687	non-hemlock
-82.2677	37.4368	non-hemlock
-82.2666	37.4517	non-hemlock
-82.2649	37.3508	hemlock
-82.2646	37.4051	non-hemlock
-82.2637	37.5646	non-hemlock
-82.2625	37.3805	non-hemlock
-82.2596	37.3653	non-hemlock
-82.2534	37.6365	non-hemlock
-82.2506	37.5263	non-hemlock
-82.2495	37.6578	non-hemlock
-82.2493	37.5827	non-hemlock
-82.2478	37.5972	non-hemlock
-82.2474	37.3822	non-hemlock
-82.2465	37.3507	non-hemlock
-82.2455	37.3690	non-hemlock
-82.2453	37.4017	non-hemlock
-82.2443	37.5141	non-hemlock
-82.2438	37.4287	non-hemlock
-82.2426	37.6179	non-hemlock
-82.2424	37.5647	non-hemlock
-82.2424	37.4369	non-hemlock
-82.2405	37.4911	non-hemlock
-82.2400	37.4717	non-hemlock
-82.2395	37.4525	non-hemlock
-82.2317	37.5600	non-hemlock
-82.2265	37.4693	non-hemlock
-82.2242	37.4013	non-hemlock
-82.2229	37.5824	non-hemlock
-82.2229	37.3706	non-hemlock
-82.2227	37.4567	non-hemlock
-82.2217	37.4862	non-hemlock
-82.2197	37.6395	non-hemlock
-82.2188	37.5244	non-hemlock
-82.2180	37.6041	non-hemlock
-82.2178	37.3795	hemlock
-82.2168	37.5450	non-hemlock
-82.2166	37.6179	non-hemlock
-82.2166	37.5083	non-hemlock
-82.2145	37.4179	non-hemlock
-82.2070	37.6213	non-hemlock

LON	LAT	CLASS TYPE
-82.2048	37.5982	non-hemlock
-82.2024	37.4197	non-hemlock
-82.2015	37.4748	non-hemlock
-82.2015	37.4032	non-hemlock
-82.2003	37.5660	non-hemlock
-82.2002	37.5506	non-hemlock
-82.1970	37.5860	non-hemlock
-82.1967	37.5288	non-hemlock
-82.1965	37.5189	non-hemlock
-82.1954	37.4966	non-hemlock
-82.1938	37.3867	non-hemlock
-82.1937	37.4420	non-hemlock
-82.1912	37.4527	non-hemlock
-82.1851	37.4765	non-hemlock
-82.1831	37.5380	non-hemlock
-82.1813	37.4255	non-hemlock
-82.1801	37.5807	non-hemlock
-82.1797	37.4414	non-hemlock
-82.1784	37.6180	non-hemlock
-82.1778	37.6059	non-hemlock
-82.1774	37.6378	non-hemlock
-82.1740	37.5032	non-hemlock
-82.1736	37.4083	non-hemlock
-82.1729	37.4518	non-hemlock
-82.1712	37.5681	non-hemlock
-82.1687	37.5437	non-hemlock
-82.1584	37.5467	non-hemlock
-82.1574	37.5291	non-hemlock
-82.1554	37.5874	non-hemlock
-82.1553	37.5689	non-hemlock
-82.1530	37.5148	non-hemlock
-82.1523	37.4573	non-hemlock
-82.1487	37.4913	non-hemlock
-82.1482	37.4345	non-hemlock
-82.1467	37.4190	non-hemlock
-82.1355	37.5075	non-hemlock
-82.1347	37.4598	non-hemlock
-82.1313	37.5290	non-hemlock
-82.1309	37.4708	non-hemlock
-82.1306	37.5516	non-hemlock
-82.1283	37.4444	non-hemlock
-82.1262	37.5799	non-hemlock
-82.1106	37.4387	non-hemlock
-82.1088	37.4884	non-hemlock
-82.1065	37.5309	non-hemlock
-82.1048	37.5112	non-hemlock

LON	LAT	CLASS TYPE
-82.1033	37.5478	non-hemlock
-82.1005	37.4741	non-hemlock
-82.0889	37.5234	non-hemlock
-82.0883	37.5550	non-hemlock
-82.0878	37.4967	non-hemlock
-82.0816	37.4746	non-hemlock
-82.0642	37.4723	hemlock
-82.0632	37.5063	non-hemlock
-82.0630	37.4982	non-hemlock
-82.0594	37.5343	non-hemlock
-82.0436	37.5284	non-hemlock
-82.0431	37.4932	non-hemlock
-82.0424	37.5456	non-hemlock
-82.0372	37.5150	non-hemlock
-82.0228	37.5310	non-hemlock
-82.0168	37.5176	non-hemlock
-81.9974	37.5245	non-hemlock
-83.8171	37.0137	hemlock
-83.7868	36.9728	hemlock
-83.7490	36.9967	hemlock
-83.6805	36.9074	hemlock
-83.6406	36.9228	hemlock
-83.5695	37.1200	hemlock
-83.5427	37.7267	hemlock
-83.5421	36.9362	hemlock
-83.5386	37.0192	hemlock
-83.5384	37.1346	hemlock
-83.5381	37.0686	hemlock
-83.5223	37.0563	hemlock
-83.5197	37.1054	hemlock
-83.5133	37.1425	hemlock
-83.4959	37.0470	hemlock
-83.4954	37.0135	hemlock
-83.4926	37.1076	hemlock
-83.4905	37.2224	hemlock
-83.4892	37.0431	hemlock
-83.4766	37.1125	hemlock
-83.4625	37.1309	hemlock
-83.4592	37.0741	hemlock
-83.4510	37.2209	hemlock
-83.4489	36.9501	hemlock
-83.4383	36.9256	hemlock
-83.4221	37.0879	hemlock
-83.4217	37.1021	hemlock
-83.4176	37.2458	hemlock
-83.4144	37.2343	hemlock

LON	LAT	CLASS TYPE
-83.4136	37.2577	hemlock
-83.4129	36.9504	hemlock
-83.4087	37.2846	hemlock
-83.4056	37.0445	hemlock
-83.4014	37.2828	hemlock
-83.3992	37.2619	hemlock
-83.3890	37.1014	hemlock
-83.3846	37.3151	hemlock
-83.3812	37.1277	hemlock
-83.3798	37.2002	hemlock
-83.3712	36.9368	hemlock
-83.3618	37.2529	hemlock
-83.3614	37.1235	hemlock
-83.3596	37.2160	hemlock
-83.3466	37.2497	hemlock
-83.3321	37.0962	hemlock
-83.3290	37.3079	hemlock
-83.3261	37.2507	hemlock
-83.3069	37.2087	hemlock
-83.3016	37.3664	hemlock
-83.2946	37.2635	hemlock
-83.2945	37.3120	hemlock
-83.2944	37.3019	hemlock
-83.2918	37.1898	hemlock
-83.2912	37.2697	hemlock
-83.2828	37.3358	hemlock
-83.2740	37.2266	hemlock
-83.2733	37.3186	hemlock
-83.2723	37.2866	hemlock
-83.2648	37.1777	hemlock
-83.2460	37.1818	hemlock
-83.2389	37.2485	hemlock
-83.2380	37.3605	hemlock
-83.2369	37.2269	hemlock
-83.2365	37.3690	hemlock
-83.2353	37.6063	hemlock
-83.2273	37.1761	hemlock
-83.2236	37.3477	hemlock
-83.2185	37.3384	hemlock
-83.2166	37.0765	hemlock
-83.2095	37.1969	hemlock
-83.1914	37.0980	hemlock
-83.1867	37.1210	hemlock
-83.1854	37.5558	hemlock
-83.1764	37.1683	hemlock
-83.1610	37.3489	hemlock

LON	LAT	CLASS TYPE
-83.1513	37.3630	hemlock
-83.1511	37.2693	hemlock
-83.1500	37.7808	hemlock
-83.1410	37.2019	hemlock
-83.1309	37.0469	hemlock
-83.1243	37.3434	hemlock
-83.1231	37.3789	hemlock
-83.1209	37.1311	hemlock
-83.1165	37.5669	hemlock
-83.1109	37.3433	hemlock
-83.0944	37.3769	hemlock
-83.0926	37.1028	hemlock
-83.0880	37.3879	hemlock
-83.0713	37.2729	hemlock
-83.0679	37.3709	hemlock
-83.0667	37.4198	hemlock
-83.0560	37.4326	hemlock
-83.0502	37.4071	hemlock
-83.0468	37.4068	hemlock
-83.0391	37.4574	hemlock
-83.0235	37.3345	hemlock
-83.0055	37.3972	hemlock
-83.0015	37.4469	hemlock
-82.9987	37.1639	hemlock
-82.9966	37.3057	hemlock
-82.9936	37.3694	hemlock
-82.9888	37.4220	hemlock
-82.9879	37.1478	hemlock
-82.9787	37.3945	hemlock
-82.9777	37.3248	hemlock
-82.9774	37.3893	hemlock
-82.9733	37.3056	hemlock
-82.9650	37.4579	hemlock
-82.9580	37.4573	hemlock
-82.9563	37.3573	hemlock
-82.9406	37.3743	hemlock
-82.9311	37.4662	hemlock
-82.9271	37.4076	hemlock
-82.9256	37.7331	hemlock
-82.9218	37.6957	hemlock
-82.9190	37.5324	hemlock
-82.9099	37.6676	hemlock
-82.9073	37.5236	hemlock
-82.8970	37.7981	hemlock
-82.8921	37.3912	hemlock
-82.8918	37.4190	hemlock

LON	LAT	CLASS TYPE
-82.8901	37.1948	hemlock
-82.8883	37.3809	hemlock
-82.8879	37.4679	hemlock
-82.8766	37.5568	hemlock
-82.8712	37.7773	hemlock
-82.8629	37.3529	hemlock
-82.8613	37.2829	hemlock
-82.8484	37.2747	hemlock
-82.8329	37.9674	hemlock
-82.8111	37.8945	hemlock
-82.7870	37.3849	hemlock
-82.7422	37.2419	hemlock
-82.7402	37.3873	hemlock
-82.7379	37.3794	hemlock
-82.7347	37.4299	hemlock
-82.7338	37.6857	hemlock
-82.7275	37.6025	hemlock
-82.7265	37.3927	hemlock
-82.7098	37.9893	hemlock
-82.7086	38.0404	hemlock
-82.6790	37.1942	hemlock
-82.6700	37.2805	hemlock
-82.6631	37.2935	hemlock
-82.6606	37.4593	hemlock
-82.6538	37.4582	hemlock
-82.6496	37.8555	hemlock
-82.6466	37.6671	hemlock
-82.6443	37.3379	hemlock
-82.6421	38.0732	hemlock
-82.6407	37.3367	hemlock
-82.6225	37.8100	hemlock
-82.6217	37.3182	hemlock
-82.6215	37.6925	hemlock
-82.6070	37.7758	hemlock
-82.6065	37.3570	hemlock
-82.5858	37.3746	hemlock
-82.5853	37.9307	hemlock
-82.5739	37.8743	hemlock
-82.5499	37.4559	hemlock
-82.5379	37.4045	hemlock
-82.5197	37.3283	hemlock
-82.5091	37.6916	hemlock
-82.5010	37.5765	hemlock
-82.5003	37.7199	hemlock
-82.4731	37.8989	hemlock
-82.4705	37.7982	hemlock

LON	LAT	CLASS TYPE
-82.4678	37.8155	hemlock
-82.4482	37.2761	hemlock
-82.4339	37.6512	hemlock
-82.3578	37.6954	hemlock
-82.2161	37.4354	hemlock
-82.1911	37.5592	hemlock
-82.1640	37.4477	hemlock
-82.1639	37.5013	hemlock
-82.1606	37.5256	hemlock
-82.0790	37.5539	hemlock
-82.0600	37.5066	hemlock
-82.0540	37.5221	hemlock
-82.0215	37.5077	hemlock
-83.3716	36.9368	hemlock
-83.3713	36.9369	hemlock
-83.3711	36.9367	hemlock
-83.3709	36.9367	hemlock
-83.3708	36.9369	hemlock
-84.7381	36.6114	hemlock
-84.7380	36.6133	hemlock
-84.7171	36.6485	hemlock
-84.7170	36.6504	hemlock
-84.7117	36.6426	hemlock
-84.7116	36.6445	hemlock
-84.6953	36.6204	hemlock
-84.6952	36.6223	hemlock
-84.6593	36.6156	hemlock
-84.6592	36.6175	hemlock
-84.6425	36.6039	hemlock
-84.6424	36.6059	hemlock
-84.6059	36.6666	hemlock
-84.6058	36.6685	hemlock
-84.6026	36.6441	hemlock
-84.6025	36.6460	hemlock
-84.5908	36.6913	hemlock
-84.5907	36.6932	hemlock
-84.5843	36.6512	hemlock
-84.5843	36.6531	hemlock
-84.5636	36.6956	hemlock
-84.5635	36.6975	hemlock
-84.5403	36.6730	hemlock
-84.5402	36.6749	hemlock
-84.5285	36.6797	hemlock
-84.5284	36.6816	hemlock
-84.5163	36.6300	hemlock
-84.5162	36.6320	hemlock

LON	LAT	CLASS TYPE
-84.5081	36.6211	hemlock
-84.5080	36.6231	hemlock
-84.5002	36.6112	hemlock
-84.5002	36.6130	hemlock
-84.4940	36.6672	hemlock
-84.4939	36.6691	hemlock
-84.4925	36.6122	hemlock
-84.4924	36.6141	hemlock
-84.4725	36.6127	hemlock
-84.4724	36.6146	hemlock
-84.4556	36.8399	hemlock
-84.4502	36.7427	hemlock
-84.4282	36.7430	hemlock
-84.4086	36.7439	hemlock
-84.4085	36.7458	hemlock
-84.4040	36.7285	hemlock
-84.4021	36.8143	hemlock
-84.3962	36.9712	hemlock
-84.3962	36.9732	hemlock
-84.3933	37.0063	hemlock
-84.3932	37.0082	hemlock
-84.3929	36.7458	hemlock
-84.3928	36.7477	hemlock
-84.3844	36.8138	hemlock
-84.3843	36.8157	hemlock
-84.3745	36.8062	hemlock
-84.3718	36.8013	hemlock
-84.3714	36.7422	hemlock
-84.3713	36.7442	hemlock
-84.3675	36.7197	hemlock
-84.3658	36.8688	hemlock
-84.3658	36.8708	hemlock
-84.3649	36.7618	hemlock
-84.3648	36.7553	hemlock
-84.3560	36.8367	hemlock
-84.3559	36.8387	hemlock
-84.3554	36.9557	hemlock
-84.3553	36.9577	hemlock
-84.3519	36.8978	hemlock
-84.3518	36.8997	hemlock
-84.3467	36.6857	hemlock
-84.3458	36.8367	hemlock
-84.3414	36.9365	hemlock
-84.3413	36.9384	hemlock
-84.3395	36.8392	hemlock
-84.3389	36.8391	hemlock

LON	LAT	CLASS TYPE
-84.3346	37.0236	hemlock
-84.3345	37.0255	hemlock
-84.3262	36.9573	hemlock
-84.3262	36.9592	hemlock
-84.2942	36.9279	hemlock
-84.2941	36.9298	hemlock
-84.2883	36.6088	hemlock
-84.2883	36.6096	hemlock
-84.2797	36.9022	hemlock
-84.2796	36.9041	hemlock
-84.2754	36.6044	hemlock
-84.2753	37.2267	hemlock
-84.2753	36.8493	hemlock
-84.2706	37.5193	hemlock
-84.2657	36.7428	hemlock
-84.2655	36.7447	hemlock
-84.2634	37.4511	hemlock
-84.2633	37.4530	hemlock
-84.2562	36.6042	hemlock
-84.2561	36.6041	hemlock
-84.2553	36.6043	hemlock
-84.2545	36.9808	hemlock
-84.2529	36.6035	hemlock
-84.2522	36.6840	hemlock
-84.2405	36.7893	hemlock
-84.2360	36.6178	hemlock
-84.2341	37.0070	hemlock
-84.2333	37.0088	hemlock
-84.2321	37.0487	hemlock
-84.2320	37.0507	hemlock
-84.2320	37.0487	hemlock
-84.2300	37.0913	hemlock
-84.2257	37.3449	hemlock
-84.2255	37.3468	hemlock
-84.2224	37.3318	hemlock
-84.2223	37.3337	hemlock
-84.2200	36.9780	hemlock
-84.2192	37.0657	hemlock
-84.2192	37.0637	hemlock
-84.2192	36.8125	hemlock
-84.2175	37.0510	hemlock
-84.2173	37.0528	hemlock
-84.2082	36.9528	hemlock
-84.2082	36.9547	hemlock
-84.2001	37.0903	hemlock
-84.2000	37.0922	hemlock

LON	LAT	CLASS TYPE
-84.1993	37.1032	hemlock
-84.1993	37.1013	hemlock
-84.1988	37.2395	hemlock
-84.1987	37.2412	hemlock
-84.1987	37.0922	hemlock
-84.1987	37.0902	hemlock
-84.1981	37.2445	hemlock
-84.1980	37.2463	hemlock
-84.1934	37.1140	hemlock
-84.1933	37.1158	hemlock
-84.1927	36.6628	hemlock
-84.1927	36.6610	hemlock
-84.1817	37.0207	hemlock
-84.1817	37.0187	hemlock
-84.1766	36.9224	hemlock
-84.1765	36.9243	hemlock
-84.1525	37.1213	hemlock
-84.1524	37.1196	hemlock
-84.1357	37.2877	hemlock
-84.1357	37.2897	hemlock
-84.1066	36.7362	hemlock
-84.0074	36.6261	hemlock
-83.9962	37.4269	hemlock
-83.9962	37.4270	hemlock
-83.9960	36.6303	hemlock
-83.9945	37.5101	hemlock
-83.9558	36.6355	hemlock
-83.9457	37.2055	hemlock
-83.8565	36.6730	hemlock
-83.8392	37.0055	hemlock
-83.8241	36.6745	hemlock
-83.8240	36.6752	hemlock
-83.8235	36.6747	hemlock
-83.8233	36.6751	hemlock
-83.8219	36.7030	hemlock
-83.8211	36.6934	hemlock
-83.8195	36.6937	hemlock
-83.8195	36.6936	hemlock
-83.8143	36.6089	hemlock
-83.8143	36.6090	hemlock
-83.8113	36.7022	hemlock
-83.8104	36.6896	hemlock
-83.7932	37.7915	hemlock
-83.7932	37.7896	hemlock
-83.7925	36.7161	hemlock
-83.7912	36.7093	hemlock

LON	LAT	CLASS TYPE
-83.7849	36.7204	hemlock
-83.7772	36.7245	hemlock
-83.7738	36.7262	hemlock
-83.7669	36.7226	hemlock
-83.7660	36.7300	hemlock
-83.7653	36.7292	hemlock
-83.7546	37.6688	hemlock
-83.7545	37.6707	hemlock
-83.7450	37.7642	hemlock
-83.7450	37.7617	hemlock
-83.7449	36.8695	hemlock
-83.7441	36.7303	hemlock
-83.7436	36.7273	hemlock
-83.7432	36.7276	hemlock
-83.7428	36.7415	hemlock
-83.7419	36.7420	hemlock
-83.7413	36.7340	hemlock
-83.7412	36.7393	hemlock
-83.7410	36.7396	hemlock
-83.7409	36.7379	hemlock
-83.7409	36.7422	hemlock
-83.7405	36.7411	hemlock
-83.7402	36.7379	hemlock
-83.7400	36.7397	hemlock
-83.7397	36.7380	hemlock
-83.7394	36.7386	hemlock
-83.7393	36.7310	hemlock
-83.7391	36.7379	hemlock
-83.7388	36.7296	hemlock
-83.7388	36.7299	hemlock
-83.7375	36.7326	hemlock
-83.7339	36.7293	hemlock
-83.7335	36.7290	non-hemlock
-83.7335	36.7298	hemlock
-83.7298	36.7412	hemlock
-83.7109	36.7087	non-hemlock
-83.7108	36.7071	non-hemlock
-83.7086	36.7100	hemlock
-83.7080	36.7061	non-hemlock
-83.7075	36.7063	non-hemlock
-83.7071	36.7094	hemlock
-83.7060	36.7084	non-hemlock
-83.7035	36.7434	hemlock
-83.6971	37.9569	hemlock
-83.6970	37.9588	hemlock
-83.6959	37.8393	hemlock

LON	LAT	CLASS TYPE
-83.6958	37.8412	hemlock
-83.6915	37.3408	hemlock
-83.6868	36.6652	hemlock
-83.6867	36.6652	hemlock
-83.6832	37.7827	hemlock
-83.6812	37.7748	hemlock
-83.6810	37.7767	hemlock
-83.6791	36.6124	hemlock
-83.6759	37.8811	hemlock
-83.6758	37.8830	hemlock
-83.6733	37.8698	hemlock
-83.6732	37.8717	hemlock
-83.6693	37.8653	hemlock
-83.6692	37.8672	hemlock
-83.6690	36.6347	hemlock
-83.6672	37.8178	hemlock
-83.6667	37.8174	hemlock
-83.6664	36.6399	hemlock
-83.6661	37.7949	hemlock
-83.6660	37.7968	hemlock
-83.6658	37.8048	hemlock
-83.6657	37.8067	hemlock
-83.6654	36.7427	hemlock
-83.6599	37.8321	hemlock
-83.6598	37.8340	hemlock
-83.6591	37.8062	hemlock
-83.6583	37.8175	hemlock
-83.6579	37.8182	hemlock
-83.6545	37.7417	hemlock
-83.6543	37.7435	hemlock
-83.6463	37.8897	hemlock
-83.6462	37.8917	hemlock
-83.6438	37.8376	hemlock
-83.6437	37.8395	hemlock
-83.6427	37.9755	hemlock
-83.6362	36.6483	hemlock
-83.6362	36.6484	hemlock
-83.6355	36.7476	hemlock
-83.6347	37.7832	hemlock
-83.6343	36.7752	hemlock
-83.6340	37.7813	hemlock
-83.6209	36.9266	hemlock
-83.6128	36.6528	hemlock
-83.6100	37.7978	hemlock
-83.6100	37.7960	hemlock
-83.6095	37.8368	hemlock

LON	LAT	CLASS TYPE
-83.6095	37.8348	hemlock
-83.6094	36.7156	hemlock
-83.6093	36.7157	hemlock
-83.6088	37.7720	hemlock
-83.6002	36.6627	hemlock
-83.5985	37.8259	hemlock
-83.5983	37.8278	hemlock
-83.5913	37.7971	hemlock
-83.5912	37.7990	hemlock
-83.5892	37.8084	hemlock
-83.5892	37.8103	hemlock
-83.5882	36.9383	hemlock
-83.5879	37.8110	hemlock
-83.5878	37.8130	hemlock
-83.5832	36.6571	hemlock
-83.5826	36.6676	hemlock
-83.5821	36.6515	hemlock
-83.5814	37.8216	hemlock
-83.5813	37.8235	hemlock
-83.5793	36.6491	hemlock
-83.5791	36.6491	hemlock
-83.5782	37.7733	hemlock
-83.5782	37.7715	hemlock
-83.5608	36.7276	hemlock
-83.5605	36.7269	hemlock
-83.5595	37.9177	hemlock
-83.5593	37.9197	hemlock
-83.5574	36.6642	hemlock
-83.5554	38.0286	hemlock
-83.5554	36.6934	hemlock
-83.5526	36.8139	hemlock
-83.5525	36.8138	hemlock
-83.5509	36.7052	hemlock
-83.5503	36.6842	hemlock
-83.5489	37.9356	hemlock
-83.5488	37.9375	hemlock
-83.5447	37.9417	hemlock
-83.5447	37.9435	hemlock
-83.5447	36.6674	hemlock
-83.5429	37.7247	hemlock
-83.5405	37.2794	hemlock
-83.5405	37.2795	hemlock
-83.5395	37.0187	hemlock
-83.5387	36.6693	hemlock
-83.5387	37.0191	hemlock
-83.5385	37.0190	hemlock

LON	LAT	CLASS TYPE
-83.5383	37.0191	hemlock
-83.5380	36.9763	hemlock
-83.5375	37.0192	hemlock
-83.5371	36.6694	hemlock
-83.5370	37.0194	hemlock
-83.5361	37.0196	hemlock
-83.5360	37.0197	hemlock
-83.5349	37.0202	hemlock
-83.5347	37.0204	non-hemlock
-83.5344	37.0203	hemlock
-83.5343	37.0206	hemlock
-83.5327	36.6705	hemlock
-83.5281	37.3207	hemlock
-83.5170	37.9661	hemlock
-83.5168	37.9680	hemlock
-83.5167	37.9304	hemlock
-83.5167	37.9323	hemlock
-83.5122	37.2643	hemlock
-83.5076	37.5010	hemlock
-83.5047	37.9470	hemlock
-83.5047	37.9451	hemlock
-83.5025	37.4828	hemlock
-83.4981	36.9716	hemlock
-83.4965	37.2132	hemlock
-83.4962	37.1045	hemlock
-83.4961	37.1065	hemlock
-83.4960	37.0469	hemlock
-83.4931	37.1262	hemlock
-83.4922	37.3731	hemlock
-83.4912	37.3355	hemlock
-83.4891	37.2132	hemlock
-83.4890	36.6937	hemlock
-83.4869	37.5978	hemlock
-83.4776	37.1004	hemlock
-83.4768	37.4885	hemlock
-83.4753	37.3467	hemlock
-83.4707	37.4473	hemlock
-83.4703	36.6816	hemlock
-83.4678	37.9587	hemlock
-83.4677	37.9607	hemlock
-83.4661	36.6826	hemlock
-83.4459	38.0086	hemlock
-83.4458	38.0106	hemlock
-83.4407	38.0513	hemlock
-83.4407	38.0494	hemlock
-83.4360	36.6982	hemlock

LON	LAT	CLASS TYPE
-83.4323	37.9858	hemlock
-83.4322	37.9877	hemlock
-83.4306	37.3067	hemlock
-83.4290	37.9632	hemlock
-83.4290	37.9613	hemlock
-83.4277	36.8758	hemlock
-83.4202	37.5076	hemlock
-83.4145	37.2325	hemlock
-83.4088	38.0693	hemlock
-83.4084	38.0680	hemlock
-83.4070	37.3293	hemlock
-83.4069	37.3294	hemlock
-83.4015	36.7000	hemlock
-83.3995	37.6607	hemlock
-83.3914	36.6955	hemlock
-83.3908	36.6974	hemlock
-83.3891	36.6995	hemlock
-83.3886	36.6988	hemlock
-83.3884	37.2152	hemlock
-83.3869	37.2425	hemlock
-83.3850	37.4397	hemlock
-83.3820	36.6973	hemlock
-83.3816	37.9740	hemlock
-83.3816	37.1858	hemlock
-83.3815	37.9759	hemlock
-83.3788	36.8614	hemlock
-83.3746	38.1043	hemlock
-83.3730	36.8630	hemlock
-83.3713	36.9367	hemlock
-83.3710	36.8626	hemlock
-83.3603	37.0310	hemlock
-83.3603	37.0311	hemlock
-83.3602	37.9869	hemlock
-83.3582	36.8816	hemlock
-83.3581	37.2770	hemlock
-83.3577	36.8818	hemlock
-83.3575	36.8815	hemlock
-83.3568	36.8859	hemlock
-83.3567	38.2668	hemlock
-83.3567	38.2650	hemlock
-83.3561	36.8853	hemlock
-83.3538	37.3284	hemlock
-83.3531	36.8906	hemlock
-83.3519	38.0682	hemlock
-83.3518	38.0701	hemlock
-83.3480	37.0005	hemlock

LON	LAT	CLASS TYPE
-83.3407	36.9038	hemlock
-83.3403	38.1817	hemlock
-83.3401	38.1836	hemlock
-83.3394	38.1137	hemlock
-83.3393	38.1157	hemlock
-83.3391	37.3013	hemlock
-83.3376	38.0179	hemlock
-83.3375	38.0199	hemlock
-83.3373	37.8509	hemlock
-83.3372	37.9806	hemlock
-83.3371	37.9826	hemlock
-83.3322	36.7774	hemlock
-83.3276	37.1415	hemlock
-83.3210	36.8765	hemlock
-83.3143	36.8158	hemlock
-83.3143	36.8158	hemlock
-83.3132	36.7230	hemlock
-83.3132	36.7231	hemlock
-83.3094	38.1897	hemlock
-83.3092	38.1915	hemlock
-83.3018	37.3044	hemlock
-83.3000	37.1362	hemlock
-83.3000	37.5368	hemlock
-83.2999	37.5368	hemlock
-83.2999	36.9009	hemlock
-83.2998	36.9011	hemlock
-83.2998	36.9012	hemlock
-83.2947	37.9404	hemlock
-83.2937	36.9998	hemlock
-83.2936	36.9998	hemlock
-83.2872	37.0832	hemlock
-83.2872	37.0833	hemlock
-83.2858	37.5578	hemlock
-83.2687	37.0704	hemlock
-83.2672	36.8967	hemlock
-83.2594	36.9151	hemlock
-83.2563	36.9765	hemlock
-83.2560	36.7335	hemlock
-83.2550	36.8988	hemlock
-83.2475	36.9065	hemlock
-83.2418	36.7562	hemlock
-83.2401	36.7382	hemlock
-83.2356	36.9055	hemlock
-83.2354	37.6062	hemlock
-83.2317	36.9129	hemlock
-83.2258	36.9138	hemlock

LON	LAT	CLASS TYPE
-83.2237	37.0472	hemlock
-83.2200	37.3637	hemlock
-83.2193	36.8434	hemlock
-83.2161	36.9139	hemlock
-83.2157	36.8397	hemlock
-83.2157	36.8397	hemlock
-83.2118	37.3956	hemlock
-83.2073	36.9297	hemlock
-83.2064	36.9193	hemlock
-83.2047	36.9390	hemlock
-83.2045	37.0458	hemlock
-83.2044	36.9306	hemlock
-83.2022	36.7506	hemlock
-83.1995	36.9216	hemlock
-83.1943	36.9270	hemlock
-83.1930	36.9256	hemlock
-83.1928	36.9242	hemlock
-83.1927	36.9245	hemlock
-83.1926	36.9212	hemlock
-83.1923	36.9268	hemlock
-83.1923	36.9204	hemlock
-83.1922	36.9245	hemlock
-83.1920	36.9195	hemlock
-83.1917	36.9253	hemlock
-83.1917	36.9191	hemlock
-83.1917	36.9185	hemlock
-83.1916	36.9210	hemlock
-83.1915	36.9266	hemlock
-83.1913	36.9286	hemlock
-83.1912	36.9287	hemlock
-83.1911	36.9206	hemlock
-83.1911	36.9277	hemlock
-83.1911	36.9277	hemlock
-83.1910	36.9264	hemlock
-83.1908	36.9203	hemlock
-83.1903	36.9205	hemlock
-83.1903	36.9207	hemlock
-83.1896	36.9209	hemlock
-83.1896	36.9271	hemlock
-83.1894	36.9273	hemlock
-83.1894	36.9281	hemlock
-83.1893	36.9279	hemlock
-83.1890	36.9270	hemlock
-83.1889	36.9269	hemlock
-83.1885	36.9268	hemlock
-83.1881	36.9265	hemlock

LON	LAT	CLASS TYPE
-83.1881	36.9228	hemlock
-83.1878	36.9239	hemlock
-83.1877	36.9241	hemlock
-83.1877	36.9236	hemlock
-83.1871	36.9239	hemlock
-83.1868	36.9242	hemlock
-83.1868	36.9237	hemlock
-83.1868	36.9289	hemlock
-83.1867	36.9280	hemlock
-83.1865	36.9288	hemlock
-83.1858	36.9307	hemlock
-83.1856	37.5657	hemlock
-83.1852	36.9495	hemlock
-83.1802	36.9481	hemlock
-83.1780	36.9426	hemlock
-83.1771	36.9429	hemlock
-83.1769	36.9431	hemlock
-83.1758	37.0030	hemlock
-83.1746	36.9449	hemlock
-83.1738	36.9456	hemlock
-83.1732	36.9454	hemlock
-83.1730	36.9291	hemlock
-83.1727	36.9462	hemlock
-83.1726	36.9460	hemlock
-83.1725	36.9461	hemlock
-83.1723	36.9461	hemlock
-83.1721	36.9465	hemlock
-83.1685	36.9464	hemlock
-83.1648	36.9479	hemlock
-83.1633	36.9486	hemlock
-83.1577	37.6459	hemlock
-83.1555	36.9514	hemlock
-83.1517	36.8843	hemlock
-83.1514	37.3831	hemlock
-83.1502	37.7807	hemlock
-83.1487	36.7985	hemlock
-83.1487	36.9610	hemlock
-83.1433	36.7574	hemlock
-83.1358	37.3493	hemlock
-83.1358	36.7478	hemlock
-83.1254	36.9606	hemlock
-83.1215	37.3374	hemlock
-83.1167	37.5668	hemlock
-83.1132	37.6821	hemlock
-83.1130	38.1283	hemlock
-83.1116	38.1266	hemlock

LON	LAT	CLASS TYPE
-83.1015	37.5261	hemlock
-83.0966	37.3766	hemlock
-83.0957	36.9773	hemlock
-83.0956	36.9772	hemlock
-83.0913	37.9888	hemlock
-83.0902	36.9705	hemlock
-83.0894	36.9709	hemlock
-83.0884	37.5756	hemlock
-83.0863	37.3842	hemlock
-83.0759	36.9218	hemlock
-83.0742	37.5513	hemlock
-83.0725	36.9757	hemlock
-83.0725	36.9757	hemlock
-83.0676	37.3673	hemlock
-83.0664	36.9769	hemlock
-83.0651	37.6125	hemlock
-83.0641	37.6051	hemlock
-83.0629	37.2618	hemlock
-83.0617	37.6146	hemlock
-83.0617	37.6145	hemlock
-83.0546	37.1729	hemlock
-83.0417	37.4021	hemlock
-83.0392	37.4573	hemlock
-83.0332	36.9978	hemlock
-83.0259	37.5438	hemlock
-83.0200	36.9925	hemlock
-83.0192	36.9952	hemlock
-83.0144	37.3253	hemlock
-83.0017	36.9941	hemlock
-83.0012	36.9943	hemlock
-83.0002	37.5555	hemlock
-82.9989	37.1638	hemlock
-82.9915	37.2947	hemlock
-82.9889	37.4220	hemlock
-82.9880	37.1477	hemlock
-82.9861	37.0816	hemlock
-82.9768	37.4555	hemlock
-82.9735	37.3130	hemlock
-82.9734	37.3155	hemlock
-82.9667	37.3849	hemlock
-82.9565	37.0247	hemlock
-82.9565	37.0246	hemlock
-82.9539	37.3457	hemlock
-82.9407	37.3743	hemlock
-82.9315	37.4363	hemlock
-82.9258	37.7310	hemlock

LON	LAT	CLASS TYPE
-82.9232	37.4025	hemlock
-82.9220	37.6956	hemlock
-82.9210	37.0347	hemlock
-82.9210	37.0347	hemlock
-82.9191	37.5323	hemlock
-82.9115	37.0016	hemlock
-82.9061	37.6652	hemlock
-82.9033	37.0440	hemlock
-82.9001	37.0297	hemlock
-82.8902	37.1948	hemlock
-82.8884	37.3809	hemlock
-82.8876	37.1974	hemlock
-82.8820	37.0160	hemlock
-82.8819	37.4160	hemlock
-82.8808	37.0158	hemlock
-82.8800	37.0435	hemlock
-82.8796	37.4588	hemlock
-82.8740	37.0583	hemlock
-82.8728	37.5455	hemlock
-82.8721	37.9966	hemlock
-82.8710	37.0247	hemlock
-82.8701	37.0294	hemlock
-82.8700	37.0303	hemlock
-82.8640	37.8655	hemlock
-82.8640	37.8655	hemlock
-82.8583	37.0522	hemlock
-82.8581	37.0523	hemlock
-82.8580	37.3498	hemlock
-82.8570	37.2744	hemlock
-82.8485	37.2746	hemlock
-82.8443	37.0972	hemlock
-82.8392	38.0100	hemlock
-82.8379	37.9836	hemlock
-82.8357	37.9657	hemlock
-82.8344	37.0622	hemlock
-82.8330	37.9673	hemlock
-82.8318	37.0656	hemlock
-82.8267	37.1977	hemlock
-82.8197	37.0708	hemlock
-82.8112	37.8945	hemlock
-82.7979	37.0892	hemlock
-82.7871	37.3849	hemlock
-82.7847	37.3807	hemlock
-82.7846	37.3806	hemlock
-82.7803	37.0729	hemlock
-82.7728	37.0755	hemlock

LON	LAT	CLASS TYPE
-82.7724	37.0784	hemlock
-82.7724	37.0681	hemlock
-82.7723	37.0718	hemlock
-82.7720	37.0691	hemlock
-82.7718	37.0705	hemlock
-82.7710	37.0794	hemlock
-82.7708	37.0787	hemlock
-82.7619	38.1031	hemlock
-82.7441	37.1413	hemlock
-82.7424	37.2419	hemlock
-82.7381	37.3794	hemlock
-82.7376	37.3771	hemlock
-82.7349	37.4299	hemlock
-82.7282	37.7149	hemlock
-82.7277	37.6024	hemlock
-82.7272	37.6947	hemlock
-82.7271	37.6981	hemlock
-82.7269	37.1377	hemlock
-82.7266	37.3927	hemlock
-82.7244	37.7168	hemlock
-82.7099	37.9893	hemlock
-82.6814	37.1530	hemlock
-82.6791	37.1941	hemlock
-82.6701	37.2804	hemlock
-82.6632	37.2934	hemlock
-82.6607	37.4592	hemlock
-82.6524	37.4463	hemlock
-82.6515	37.8547	hemlock
-82.6497	37.8554	hemlock
-82.6467	37.6671	hemlock
-82.6408	37.3367	hemlock
-82.6402	37.3341	hemlock
-82.6382	37.1642	hemlock
-82.6381	37.1641	hemlock
-82.6375	37.3136	hemlock
-82.6320	38.0687	hemlock
-82.6227	37.8099	hemlock
-82.6218	37.6888	hemlock
-82.6218	37.3182	hemlock
-82.6217	37.6924	hemlock
-82.6071	37.7757	hemlock
-82.5975	37.3455	hemlock
-82.5860	37.3745	hemlock
-82.5854	37.9307	hemlock
-82.5834	37.8844	hemlock
-82.5757	37.2058	hemlock

LON	LAT	CLASS TYPE
-82.5741	37.8743	hemlock
-82.5679	38.0804	hemlock
-82.5619	38.0678	hemlock
-82.5502	37.4558	hemlock
-82.5396	37.9422	hemlock
-82.5372	37.9496	hemlock
-82.5296	37.4007	hemlock
-82.5199	37.3282	hemlock
-82.5093	37.6915	hemlock
-82.5011	37.5764	hemlock
-82.5005	37.7199	hemlock
-82.4988	37.8442	hemlock
-82.4748	37.8989	hemlock
-82.4732	37.8989	hemlock
-82.4706	37.7982	hemlock
-82.4680	37.8155	hemlock
-82.4651	37.2681	hemlock
-82.4483	37.2760	hemlock
-82.4392	37.3314	hemlock
-82.4340	37.6512	hemlock
-82.3694	37.2798	hemlock
-82.3580	37.6954	hemlock
-82.2348	37.3680	hemlock
-82.2163	37.4353	hemlock
-82.1913	37.5592	hemlock
-82.1889	37.6464	hemlock
-82.1767	37.6476	hemlock
-82.1762	37.6449	hemlock
-82.1642	37.4476	hemlock
-82.1640	37.5012	hemlock
-82.1608	37.5255	hemlock
-82.1458	37.4204	hemlock
-82.0879	37.5548	hemlock
-82.0875	37.5546	hemlock
-82.0874	37.5547	hemlock
-82.0794	37.5524	hemlock
-82.0794	37.5538	hemlock
-82.0792	37.5535	hemlock
-82.0792	37.5538	hemlock
-82.0602	37.5066	hemlock
-82.0594	37.5281	hemlock
-82.0542	37.5220	hemlock
-82.0414	37.5189	hemlock
-82.0403	37.5139	hemlock
-82.0333	37.5113	hemlock
-82.0319	37.5213	hemlock

LON	LAT	CLASS TYPE
-82.0310	37.5213	hemlock
-82.0300	37.5205	hemlock
-82.0289	37.5190	hemlock
-82.0276	37.5213	hemlock
-82.0267	37.5192	hemlock
-82.0266	37.5216	hemlock
-82.0257	37.5097	hemlock
-82.0252	37.5226	hemlock
-82.0228	37.5227	hemlock
-82.0216	37.5076	hemlock
-82.0213	37.5249	hemlock
-82.0192	37.5275	hemlock
-82.0185	37.5029	hemlock
-82.0174	37.5286	hemlock
-82.0174	37.5174	hemlock
-82.0152	37.5178	hemlock
-82.0149	37.5328	hemlock
-82.0138	37.5200	hemlock
-82.0138	37.5166	hemlock
-82.0125	37.5166	hemlock
-82.0094	37.5325	hemlock
-82.0031	37.5194	hemlock
-82.0023	37.5259	hemlock
-82.0021	37.5216	hemlock
-82.0004	37.5247	hemlock

Appendix 2. Geometric rectification transformation parameters for the three satellite images used in the study. A third order polynomial model was used to rectify landsat 7 etm+ images in state plane survey feet to 1-meter winter doqqs. Geometric rectification processing was performed using erdas imagine 9.3.1 (erdas, inc., norcross, ga, u.s.).

a. Landsat 7 Path 18 / Row 34

b. Image ID: L71018034_03420000601

c. Control point error:

i. X = 24.7922 Y = 15.5578

ii. Total RMSE = 29.2694

iii. Number of GCPs = 20

TRANSFORMATION	X'	Y'
Const.	4234487.08527187	2676273.62443873
X	-0.8139144626849	-2.04717081007142
Y	-0.586777210565829	2.09788418664726
X^2	3.00850244064916e-007	4.58297753847458e-007
XY	3.71316954350791e-008	-3.50247654649285e-007
Y^2	1.28657984548288e-007	-2.2300320523387e-008
X^3	-2.10197740789931e-014	-3.01066028674651e-014
X^2Y	1.73018491653731e-014	1.97326794185472e-014
XY^2	-3.1726647375632e-014	1.59289986202027e-014
Y^3	4.84564940708212e-015	-6.063743197281e-015

2. Landsat 7 Path 19 / Row 35

a. Used 1935_jun as input file

b. Control point error:

i. X =13.7636 Y = 28.1188

ii. Total RMSE = 28.6425

iii. Number of GCPs = 21

TRANSFORMATION	X’	Y’
Const.	6338956.74598868	7715482.61122416
X	1.64796634931115	0.268684876634383
Y	-6.5679948165363	-6.16031319030466
X^2	-4.86781734856301e-008	-9.50833352032573e-008
XY	-2.21609858864588e-007	1.43729810023177e-007
Y^2	2.08806865824704e-006	1.97031422157103e-006
X^3	9.48420020388568e-016	6.29351275594007e-015
X^2Y	9.77441115139603e-015	-1.99004657658827e-015
XY^2	1.6381683547478e-014	-1.80017923520109e-014
Y^3	-2.11114439960713e-013	-1.81518032494296e-013

3. Landsat 7 Path 19 / Row 34

   a. Used 1934_jun as input file

   b. Control point error:

      i. X =23.8327   Y = 27.2185

      ii. Total RMSE = 36.1779

      iii. Number of GCPs = 60

TRANSFORMATION	X’	Y’
Const.	20907.9973482419	404167.979864859
X	0.940221267548133	-0.156224616426692
Y	0.072987668312302	0.904780777535563
X^2	1.92112071292262e-008	2.81643193045292e-008
XY	-2.57244841944678e-008	8.84199759361198e-010
Y^2	-1.93756154042469e-010	2.47805459782193e-008
X^3	-1.68088847956177e-015	-2.23950377554563e-015
X^2Y	2.42619861140096e-015	2.39321740862993e-015
XY^2	-1.86140615787708e-016	-3.70844990083419e-015
Y^3	9.86391200509748e-017	-3.53177177604588e-016

Appendix 3. Equations used in c-correction of radiance for each band of all landsat 7 emt+ images.

1. $\boldsymbol{\rho_H = \rho_T (\cos \Theta_z + c_k) / (\cos i + c_k)}$

   ρ_H = terrain-corrected radiance

   Θ_z = solar zenith angle

   $c_k = b_k / m_k$ for $\rho_T = b_k + m_k \cos i$

2. $\boldsymbol{\rho_T = b_k + m_k \cos i}$

   m_k = slope of the regression line for band *k*

   ρ_T = uncorrected radiance

3. $\boldsymbol{\cos i = \cos\Theta_p \cos \Theta_z + \sin \Theta_p \sin \Theta_z \cos (\Theta_a - \Theta_o)}$

   Θ_p = slope angle

   Θ_z = solar zenith angle

   Θ_a = solar azimuth angle

   Θ_o = aspect angle

Appendix 4. Decision tree tables for hemlock classifications created using pasw 17 statistics software (spss inc., chicago, il, u.s.). For each decision tree a chi-squared automatic interaction detection (chaid) growing method was applied with a pearson chi-square statistic, maximum tree depth set to ten levels, and a significance level of 0.1 for splitting nodes.

COAL FIELD PHYSIOGRAPHIC REGION

TREE-ETM+: ECB 1935

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	85	42.7%	114	57.3%	199	100.0%	non-hemlock						
1	63	67.7%	30	32.3%	93	46.7%	hemlock	0	Geologic formations	.000	50.159	2	Pg; Qal; Pbrr
2	22	26.8%	60	73.2%	82	41.2%	non-hemlock	0	Geologic formations	.000	50.159	2	Ppk; Pac; Mp; Pgc
3	0	.0%	24	100.0%	24	12.1%	non-hemlock	0	Geologic formations	.000	50.159	2	Ph; Pgm; Mmk; Mmg; Mbha; Pfc
4	14	60.9%	9	39.1%	23	11.6%	hemlock	2	Streams	.000	18.868	1	<= 278.387939
5	8	13.6%	51	86.4%	59	29.6%	non-hemlock	2	Streams	.000	18.868	1	> 278.387939
6	0	.0%	20	100.0%	20	10.1%	non-hemlock	5	Maximum temperature	.029	4.746	1	<= 85.0
7	8	20.5%	31	79.5%	39	19.6%	non-hemlock	5	Maximum temperature	.029	4.746	1	> 85.0

TREE-ETM+: ECB 1934

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	479	41.4%	678	58.6%	1157	100.0%	Non-hemlock						
1	226	63.3%	131	36.7%	357	30.9%	Hemlock	0	Streams	0.00	137.643	3	<= 139.193969727000
2	105	46.3%	122	53.7%	227	19.6%	Non-hemlock	0	Streams	0.00	137.643	3	(139.193969727000, 393.700012207000]
3	103	30.6%	234	69.4%	337	29.1%	Non-hemlock	0	Streams	0.00	137.643	3	(393.700012207000, 846.683898926000]
4	45	19.1%	191	80.9%	236	20.4%	Non-hemlock	0	Streams	0.00	137.643	3	> 846.683898926000
5	32	43.2%	42	56.8%	74	6.4%	Non-hemlock	1	DEM	0.00	16.174	1	<= 236.095520020000
6	194	68.6%	89	31.4%	283	24.5%	Hemlock	1	DEM	0.00	16.174	1	> 236.095520020000
7	5	35.7%	9	64.3%	14	1.2%	Non-hemlock	2	Band 4	0.00	28.188	2	<= 83.878250122100
8	66	66.0%	34	34.0%	100	8.6%	Hemlock	2	Band 4	0.00	28.188	2	(83.878250122100, 101.503379822000]
9	34	30.1%	79	69.9%	113	9.8%	Non-hemlock	2	Band 4	0.00	28.188	2	> 101.503379822000
10	81	37.5%	135	62.5%	216	18.7%	Non-hemlock	3	Band 4	0.00	13.638	1	<= 108.328063965000
11	22	18.2%	99	81.8%	121	10.5%	Non-hemlock	3	Band 4	0.00	13.638	1	> 108.328063965000
12	29	33.3%	58	66.7%	87	7.5%	Non-hemlock	4	Band 4	0.00	18.172	1	<= 101.503379822000

13	16	10.7%	133	89.3%	149	12.9%	Non-hemlock	4	Band 4	0.00	18.172	1	> 101.503379822000
14	15	29.4%	36	70.6%	51	4.4%	Non-hemlock	5	TRMIM	0.00	12.79	1	<= 12.0
15	17	73.9%	6	26.1%	23	2.0%	Hemlock	5	TRMIM	0.00	12.79	1	> 12.0
16	176	72.4%	67	27.6%	243	21.0%	Hemlock	6	Minimum temp	0.00	11.985	1	<= 23.0
17	18	45.0%	22	55.0%	40	3.5%	Non-hemlock	6	Minimum temp	0.00	11.985	1	> 23.0
18	6	37.5%	10	62.5%	16	1.4%	Non-hemlock	8	TRMIM	0.06	6.895	1	<= 8.0
19	60	71.4%	24	28.6%	84	7.3%	Hemlock	8	TRMIM	0.06	6.895	1	> 8.0
20	13	19.1%	55	80.9%	68	5.9%	Non-hemlock	9	Band 2	0.02	9.77	1	<= 40.294647216800
21	21	46.7%	24	53.3%	45	3.9%	Non-hemlock	9	Band 2	0.02	9.77	1	> 40.294647216800
22	0	0.0%	11	100.0%	11	1.0%	Non-hemlock	10	DEM	0.08	6.954	1	<= 236.095520020000
23	81	39.5%	124	60.5%	205	17.7%	Non-hemlock	10	DEM	0.08	6.954	1	> 236.095520020000
24	22	48.9%	23	51.1%	45	3.9%	Non-hemlock	12	Band 5	0.01	10.15	1	<= 9.703559875490
25	7	16.7%	35	83.3%	42	3.6%	Non-hemlock	12	Band 5	0.01	10.15	1	> 9.703559875490
26	11	8.3%	122	91.7%	133	11.5%	Non-hemlock	13	Band 2	0.05	7.868	1	<= 44.175231933600
27	5	31.3%	11	68.8%	16	1.4%	Non-hemlock	13	Band 2	0.05	7.868	1	> 44.175231933600
28	14	48.3%	15	51.7%	29	2.5%	Non-hemlock	14	Geologic formations	0.04	11.523	1	Qal; Ppk; Plc; Mb

29	1	4.5%	21	95.5%	22	1.9%	Non-hemlock	14	Geologic formations	0.04	11.523	1	Pfc; Ph; Scb
30	13	100.0%	0	0.0%	13	1.1%	Hemlock	15	Band 5	0.01	10.553	1	<= 10.715889930700
31	4	40.0%	6	60.0%	10	0.9%	Non-hemlock	15	Band 5	0.01	10.553	1	> 10.715889930700
32	124	80.0%	31	20.0%	155	13.4%	Hemlock	16	Band 4	0.00	12.289	1	<= 101.503379822000
33	52	59.1%	36	40.9%	88	7.6%	Hemlock	16	Band 4	0.00	12.289	1	> 101.503379822000
34	14	66.7%	7	33.3%	21	1.8%	Hemlock	17	Maximum temperature	0.01	8.386	1	<= 85.0
35	4	21.1%	15	78.9%	19	1.6%	Non-hemlock	17	Maximum temperature	0.01	8.386	1	> 85.0
36	8	42.1%	11	57.9%	19	1.6%	Non-hemlock	19	Band 1	0.01	10.345	1	<= 50.046665191700
37	52	80.0%	13	20.0%	65	5.6%	Hemlock	19	Band 1	0.01	10.345	1	> 50.046665191700
38	9	36.0%	16	64.0%	25	2.2%	Non-hemlock	20	Band 1	0.05	7.287	1	<= 49.061317443800
39	4	9.3%	39	90.7%	43	3.7%	Non-hemlock	20	Band 1	0.05	7.287	1	> 49.061317443800
40	14	73.7%	5	26.3%	19	1.6%	Hemlock	21	Band 4	0.01	9.644	1	<= 108.328063965000
41	7	26.9%	19	73.1%	26	2.2%	Non-hemlock	21	Band 4	0.01	9.644	1	> 108.328063965000
42	51	34.0%	99	66.0%	150	13.0%	Non-hemlock	23	TRMIM	0.05	7.108	1	<= 11.0
43	30	54.5%	25	45.5%	55	4.8%	Hemlock	23	TRMIM	0.05	7.108	1	> 11.0
44	14	58.3%	10	41.7%	24	2.1%	Hemlock	32	TPI	0.04	8.332	1	<= -16.275033950800
45	110	84.0%	21	16.0%	131	11.3%	Hemlock	32	TPI	0.04	8.332	1	> -16.275033950800
46	19	82.6%	4	17.4%	23	2.0%	Hemlock	33	TPI	0.06	7.124	1	<= -16.275033950800

47	33	50.8%	32	49.2%	65	5.6%	Hemlock	33	TPI	0.06	7.124	1	> -16.275033950800
48	10	76.9%	3	23.1%	13	1.1%	Hemlock	44	Maximum temperature	0.09	4.033	1	<= 85.0
49	4	36.4%	7	63.6%	11	1.0%	Non-hemlock	44	Maximum temperature	0.09	4.033	1	> 85.0

TREE-ETM+: ECB 1834

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	230	33.2%	462	66.8%	692	100.0%	Non-hemlock						
1	10	19.6%	41	80.4%	51	7.4%	Non-hemlock	0	Maximum temperature	0	23.061	3	<= 83.0
2	94	43.1%	124	56.9%	218	31.5%	Non-hemlock	0	Maximum temperature	0	23.061	3	(83.0, 85.0]
3	124	31.4%	271	68.6%	395	57.1%	Non-hemlock	0	Maximum temperature	0	23.061	3	(85.0, 87.0]
4	2	7.1%	26	92.9%	28	4.0%	Non-hemlock	0	Maximum temperature	0	23.061	3	> 87.0
5	26	31.7%	56	68.3%	82	11.8%	Non-hemlock	2	TPI	0.07	6.979	1	<= -14.122595787000
6	68	50.0%	68	50.0%	136	19.7%	Non-hemlock	2	TPI	0.07	6.979	1	> -14.122595787000
7	80	29.5%	191	70.5%	271	39.2%	Non-hemlock	3	Geologic formations	0	39.631	2	Ph; Ppk; Qal; Ppr
8	41	57.7%	30	42.3%	71	10.3%	Hemlock	3	Geologic formations	0	39.631	2	Plc; Pg
9	3	5.7%	50	94.3%	53	7.7%	Non-hemlock	3	Geologic formations	0	39.631	2	Pfc; Pfch; Pc
10	13	56.5%	10	43.5%	23	3.3%	Hemlock	5	Band 5	0.02	9.09	1	<= 11.140611648600
11	13	22.0%	46	78.0%	59	8.5%	Non-hemlock	5	Band 5	0.02	9.09	1	> 11.140611648600
12	64	54.2%	54	45.8%	118	17.1%	Hemlock	6	Streams	0.08	6.403	1	<= 1046.272094730000

13	4	22.2%	14	77.8%	18	2.6%	Non-hemlock	6	Streams	0.08	6.403	1	> 1046.272094730000
14	18	20.9%	68	79.1%	86	12.4%	Non-hemlock	7	TPI	0.02	19.411	3	<= -14.122595787000
15	13	39.4%	20	60.6%	33	4.8%	Non-hemlock	7	TPI	0.02	19.411	3	(-14.122595787000, -11.629308700600]
16	1	3.4%	28	96.6%	29	4.2%	Non-hemlock	7	TPI	0.02	19.411	3	(-11.629308700600, -8.779476165770]
17	48	39.0%	75	61.0%	123	17.8%	Non-hemlock	7	TPI	0.02	19.411	3	> -8.779476165770
18	5	22.7%	17	77.3%	22	3.2%	Non-hemlock	8	Slope	0	16.022	1	<= 10.497280120800
19	36	73.5%	13	26.5%	49	7.1%	Hemlock	8	Slope	0	16.022	1	> 10.497280120800
20	13	35.1%	24	64.9%	37	5.3%	Non-hemlock	14	Band 5	0.04	7.918	1	<= 11.863170623800
21	5	10.2%	44	89.8%	49	7.1%	Non-hemlock	14	Band 5	0.04	7.918	1	> 11.863170623800
22	1	9.1%	10	90.9%	11	1.6%	Non-hemlock	15	Aspect	0.09	6.346	1	<= 187.225051880000
23	12	54.5%	10	45.5%	22	3.2%	Hemlock	15	Aspect	0.09	6.346	1	> 187.225051880000
24	17	25.0%	51	75.0%	68	9.8%	Non-hemlock	17	TRMIM	0	12.57	1	<= 10.0
25	31	56.4%	24	43.6%	55	7.9%	Hemlock	17	TRMIM	0	12.57	1	> 10.0
26	0	0.0%	10	100.0%	10	1.4%	Non-hemlock	18	Streams	0.08	5.392	1	<= .000000000000
27	5	41.7%	7	58.3%	12	1.7%	Non-hemlock	18	Streams	0.08	5.392	1	> .000000000000
28	34	87.2%	5	12.8%	39	5.6%	Hemlock	19	Soil type	0.07	18.428	1	HsF; KsF; MaF; UdB; Ye; NeD; ShC; RoF

29	2	20.0%	8	80.0%	10	1.4%	Non-hemlock	19	Soil type	0.07	18.428	1	FmF; MmF; MyD; FgE; Co
30	0	0.0%	13	100.0%	13	1.9%	Non-hemlock	20	Band 2	0.01	10.856	1	<= 44.584003448500
31	13	54.2%	11	45.8%	24	3.5%	Hemlock	20	Band 2	0.01	10.856	1	> 44.584003448500
32	0	0.0%	30	100.0%	30	4.3%	Non-hemlock	21	Geologic formations	0.01	8.792	1	Ph; Ppk
33	5	26.3%	14	73.7%	19	2.7%	Non-hemlock	21	Geologic formations	0.01	8.792	1	Qal
34	10	52.6%	9	47.4%	19	2.7%	Hemlock	24	Streams	0.01	10.737	1	<= 139.193969727000
35	7	14.3%	42	85.7%	49	7.1%	Non-hemlock	24	Streams	0.01	10.737	1	> 139.193969727000
36	11	100.0%	0	0.0%	11	1.6%	Hemlock	31	Soil type	0.04	17.183	1	ShF; CsF; Ye; PsC; NeD; AeC; ClF
37	2	15.4%	11	84.6%	13	1.9%	Non-hemlock	31	Soil type	0.04	17.183	1	KsF; FmF; HpC; Dm

TREE-OMIT: Coal Field (No satellites)

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	661	38.5%	1058	61.5%	1719	100.0%	Non-hemlock						
1	433	49.9%	434	50.1%	867	50.4%	Non-hemlock	0	Streams	0	108.72	2	<= 295.275024414000
2	201	29.6%	479	70.4%	680	39.6%	Non-hemlock	0	Streams	0	108.72	2	(295.275024414000, 1122.217651370000]
3	27	15.7%	145	84.3%	172	10.0%	Non-hemlock	0	Streams	0	108.72	2	> 1122.217651370000
4	407	52.4%	370	47.6%	777	45.2%	Hemlock	1	Minimum temperature	0	17.805	1	<= 23.0
5	26	28.9%	64	71.1%	90	5.2%	Non-hemlock	1	Minimum temperature	0	17.805	1	> 23.0
6	1	3.8%	25	96.2%	26	1.5%	Non-hemlock	2	DEM	0.03	8.584	1	<= 229.949066162000
7	200	30.6%	454	69.4%	654	38.0%	Non-hemlock	2	DEM	0.03	8.584	1	> 229.949066162000
8	26	18.8%	112	81.2%	138	8.0%	Non-hemlock	3	Minimum temperature	0.05	5.211	1	<= 23.0
9	1	2.9%	33	97.1%	34	2.0%	Non-hemlock	3	Minimum temperature	0.05	5.211	1	> 23.0
10	296	55.1%	241	44.9%	537	31.2%	Hemlock	4	Geologic formations	0	60.527	2	Qal; Pfc; Ppr; Ph; Pg; Pac; Mp; Msla; Mbu
11	62	33.3%	124	66.7%	186	10.8%	Non-hemlock	4	Geologic formations	0	60.527	2	Ppk; Mmk; Mbr; MDna
12	49	90.7%	5	9.3%	54	3.1%	Hemlock	4	Geologic formations	0	60.527	2	Plc; Pbrr; Pgc; Pbm; Pacl; Mb; Mpsl

13	15	55.6%	12	44.4%	27	1.6%	Hemlock	5	Maximum temperature	0	13.352	1	<= 85.0
14	11	17.5%	52	82.5%	63	3.7%	Non-hemlock	5	Maximum temperature	0	13.352	1	> 85.0
15	5	13.5%	32	86.5%	37	2.2%	Non-hemlock	7	Maximum temperature	0.06	5.382	1	<= 83.0
16	195	31.6%	422	68.4%	617	35.9%	Non-hemlock	7	Maximum temperature	0.06	5.382	1	> 83.0
17	58	42.6%	78	57.4%	136	7.9%	Non-hemlock	10	Slope	0.01	11.456	1	<= 7.053810596470
18	238	59.4%	163	40.6%	401	23.3%	Hemlock	10	Slope	0.01	11.456	1	> 7.053810596470
19	12	20.7%	46	79.3%	58	3.4%	Non-hemlock	11	TPI	0.07	12.471	2	<= -13.960262298600
20	49	42.6%	66	57.4%	115	6.7%	Non-hemlock	11	TPI	0.07	12.471	2	(-13.960262298600, 5.686920166020]
21	1	7.7%	12	92.3%	13	0.8%	Non-hemlock	11	TPI	0.07	12.471	2	> 5.686920166020
22	23	100.0%	0	0.0%	23	1.3%	Hemlock	12	Curvature	0.03	14.1	2	<= -.126416578889
23	6	60.0%	4	40.0%	10	0.6%	Hemlock	12	Curvature	0.03	14.1	2	(-.126416578889, -.053089194000]
24	20	95.2%	1	4.8%	21	1.2%	Hemlock	12	Curvature	0.03	14.1	2	> -.053089194000
25	0	0.0%	10	100.0%	10	0.6%	Non-hemlock	13	Aspect	0	19.853	1	<= 77.574325561500
26	15	88.2%	2	11.8%	17	1.0%	Hemlock	13	Aspect	0	19.853	1	> 77.574325561500
27	4	40.0%	6	60.0%	10	0.6%	Non-hemlock	15	Streams	0.01	8.226	1	<= 440.169982910000
28	1	3.7%	26	96.3%	27	1.6%	Non-hemlock	15	Streams	0.01	8.226	1	> 440.169982910000
29	7	17.5%	33	82.5%	40	2.3%	Non-hemlock	16	Minimum temperature	0.09	3.937	1	<= 21.0

30	188	32.6%	389	67.4%	577	33.6%	Non-hemlock	16	Minimum temperature	0.09	3.937	1	> 21.0
31	17	36.2%	30	63.8%	47	2.7%	Non-hemlock	18	DEM	0.01	11.859	1	<= 229.949066162000
32	221	62.4%	133	37.6%	354	20.6%	Hemlock	18	DEM	0.01	11.859	1	> 229.949066162000
33	6	31.6%	13	68.4%	19	1.1%	Non-hemlock	29	Streams	0.08	4.969	1	<= 622.494384766000
34	1	4.8%	20	95.2%	21	1.2%	Non-hemlock	29	Streams	0.08	4.969	1	> 622.494384766000
35	4	16.0%	21	84.0%	25	1.5%	Non-hemlock	31	TRMIM	0.02	9.412	1	<= 11.0
36	13	59.1%	9	40.9%	22	1.3%	Hemlock	31	TRMIM	0.02	9.412	1	> 11.0
37	22	44.0%	28	56.0%	50	2.9%	Non-hemlock	32	TPI	0.02	15.527	2	<= -18.315753936800
38	196	66.9%	97	33.1%	293	17.0%	Hemlock	32	TPI	0.02	15.527	2	(-18.315753936800, 11.171836853000]
39	3	27.3%	8	72.7%	11	0.6%	Non-hemlock	32	TPI	0.02	15.527	2	> 11.171836853000
40	4	40.0%	6	60.0%	10	0.6%	Non-hemlock	35	Geologic formations	0.05	7.143	1	Qal; Msla
41	0	0.0%	15	100.0%	15	0.9%	Non-hemlock	35	Geologic formations	0.05	7.143	1	Ppr; Ph

PINE MOUNTAIN PHYSIOGRAPHIC REGION

TREE-ETM+: Pine 1935

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	77	49.7%	78	50.3%	155	100.0%	non-hemlock						
1	42	91.3%	4	8.7%	46	29.7%	hemlock	0	Streams	.000	50.082	2	<= 139.193970
2	10	55.6%	8	44.4%	18	11.6%	hemlock	0	Streams	.000	50.082	2	(139.193970, 220.084991]
3	25	27.5%	66	72.5%	91	58.7%	non-hemlock	0	Streams	.000	50.082	2	> 220.084991
4	34	100.0%	0	.0%	34	21.9%	hemlock	1	Band 7	.003	12.413	1	<= 1.356862
5	8	66.7%	4	33.3%	12	7.7%	hemlock	1	Band 7	.003	12.413	1	> 1.356862
6	9	56.3%	7	43.8%	16	10.3%	hemlock	3	Band 5	.083	16.280	3	<= 9.027792
7	3	13.0%	20	87.0%	23	14.8%	non-hemlock	3	Band 5	.083	16.280	3	(9.027792, 9.761443]
8	10	43.5%	13	56.5%	23	14.8%	non-hemlock	3	Band 5	.083	16.280	3	(9.761443, 10.526074]
9	3	10.3%	26	89.7%	29	18.7%	non-hemlock	3	Band 5	.083	16.280	3	> 10.526074
10	2	18.2%	9	81.8%	11	7.1%	non-hemlock	8	Streams	.096	5.490	1	<= 1027.587158
11	8	66.7%	4	33.3%	12	7.7%	hemlock	8	Streams	.096	5.490	1	> 1027.587158

TREE-ETM+: Pine 1934

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	160	49.7%	162	50.3%	322	100.0%	Non-hemlock						
1	62	93.9%	4	6.1%	66	20.5%	Hemlock	0	Streams	0	73.994	2	<= 98.425003051800
2	34	54.8%	28	45.2%	62	19.3%	Hemlock	0	Streams	0	73.994	2	(98.425003051800, 354.876403809000]
3	64	33.0%	130	67.0%	194	60.2%	Non-hemlock	0	Streams	0	73.994	2	> 354.876403809000
4	8	72.7%	3	27.3%	11	3.4%	Hemlock	1	Aspect	0.01	10.432	1	<= 46.987003326400
5	54	98.2%	1	1.8%	55	17.1%	Hemlock	1	Aspect	0.01	10.432	1	> 46.987003326400
6	28	70.0%	12	30.0%	40	12.4%	Hemlock	2	Band 5	0.01	10.463	1	<= 10.432502746600
7	6	27.3%	16	72.7%	22	6.8%	Non-hemlock	2	Band 5	0.01	10.463	1	> 10.432502746600
8	23	20.5%	89	79.5%	112	34.8%	Non-hemlock	3	TRMIM	0	18.591	1	<= 9.0
9	41	50.0%	41	50.0%	82	25.5%	Hemlock	3	TRMIM	0	18.591	1	> 9.0
10	17	39.5%	26	60.5%	43	13.4%	Non-hemlock	8	Geologic formations	0.04	15.439	1	Pah; Mp
11	6	8.7%	63	91.3%	69	21.4%	Non-hemlock	8	Geologic formations	0.04	15.439	1	Pg; Qal; Ppk; Psw; Pbr; Pbm; Ph; Pfc
12	2	20.0%	8	80.0%	10	3.1%	Non-hemlock	11	TRMIM	0.05	8.063	2	<= 6.0
13	0	0.0%	38	100.0%	38	11.8%	Non-hemlock	11	TRMIM	0.05	8.063	2	(6.0, 8.0]

14	4	19.0%	17	81.0%	21	6.5%	Non-hemlock	11	TRMIM	0.05	8.063	2	> 8.0

TREE-ETM+: Pine 1834

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	75	48.1%	81	51.9%	156	100.0%	Non-hemlock						
1	0	0.0%	14	100.0%	14	9.0%	Non-hemlock	0	Maximum temperature	0	21.945	2	<= 79.0
2	20	37.7%	33	62.3%	53	34.0%	Non-hemlock	0	Maximum temperature	0	21.945	2	(79.0, 81.0]
3	55	61.8%	34	38.2%	89	57.1%	Hemlock	0	Maximum temperature	0	21.945	2	> 81.0
4	9	24.3%	28	75.7%	37	23.7%	Non-hemlock	2	Curvature	0.02	9.383	1	<= .357747703791
5	11	68.8%	5	31.3%	16	10.3%	Hemlock	2	Curvature	0.02	9.383	1	> .357747703791
6	36	80.0%	9	20.0%	45	28.8%	Hemlock	3	Aspect	0.01	17.688	2	<= 158.996994019000
7	2	16.7%	10	83.3%	12	7.7%	Non-hemlock	3	Aspect	0.01	17.688	2	(158.996994019000, 187.723159790000]
8	17	53.1%	15	46.9%	32	20.5%	Hemlock	3	Aspect	0.01	17.688	2	> 187.723159790000

TREE-OMIT: Pine Mountain (No satellites)

Node	Hemlock		Non-hemlock		Total		Predicted Category	Parent Node	Primary Independent Variable				
	N	Percent	N	Percent	N	Percent			Variable	Sig	Chi-Square	df	Split Values
0	183	48.0%	198	52.0%	381	100.0%	Non-Hemlock						
1	73	90.1%	8	9.9%	81	21.3%	Hemlock	0	Streams	0	85.718	2	<= 98.425003051800
2	40	54.8%	33	45.2%	73	19.2%	Hemlock	0	Streams	0	85.718	2	(98.425003051800, 354.876403809000]
3	70	30.8%	157	69.2%	227	59.6%	Non-Hemlock	0	Streams	0	85.718	2	> 354.876403809000
4	8	66.7%	4	33.3%	12	3.1%	Hemlock	1	Slope	0.03	8.708	1	<= 4.892313957210
5	65	94.2%	4	5.8%	69	18.1%	Hemlock	1	Slope	0.03	8.708	1	> 4.892313957210
6	8	23.5%	26	76.5%	34	8.9%	Non-Hemlock	2	Geologic formations	0	25.115	1	Ppk; Psw; Qal; Pss; Qc; Mnl; Pbl
7	32	82.1%	7	17.9%	39	10.2%	Hemlock	2	Geologic formations	0	25.115	1	Pg; Pah; Pbru; Mp; Pbr; Pbm; MDc
8	27	20.9%	102	79.1%	129	33.9%	Non-Hemlock	3	TRMIM	0	13.75	1	<= 9.0
9	43	43.9%	55	56.1%	98	25.7%	Non-Hemlock	3	TRMIM	0	13.75	1	> 9.0
10	8	72.7%	3	27.3%	11	2.9%	Hemlock	5	Aspect	0.01	11.052	1	<= 52.474617004400
11	57	98.3%	1	1.7%	58	15.2%	Hemlock	5	Aspect	0.01	11.052	1	> 52.474617004400
12	22	95.7%	1	4.3%	23	6.0%	Hemlock	7	Aspect	0.06	7.042	1	<= 200.108551025000
13	10	62.5%	6	37.5%	16	4.2%	Hemlock	7	Aspect	0.06	7.042	1	> 200.108551025000
14	11	12.9%	74	87.1%	85	22.3%	Non-Hemlock	8	Curvature	0.02	9.611	1	<= .180334284902
15	16	36.4%	28	63.6%	44	11.5%	Non-Hemlock	8	Curvature	0.02	9.611	1	> .180334284902

16	31	37.3%	52	62.7%	83	21.8%	Non-Hemlock	9	Curvature	0.02	9.385	1	<= .468888282776
17	12	80.0%	3	20.0%	15	3.9%	Hemlock	9	Curvature	0.02	9.385	1	> .468888282776
18	4	6.8%	55	93.2%	59	15.5%	Non-Hemlock	14	TRMIM	0.03	6.5	1	<= 8.0
19	7	26.9%	19	73.1%	26	6.8%	Non-Hemlock	14	TRMIM	0.03	6.5	1	> 8.0
20	7	70.0%	3	30.0%	10	2.6%	Hemlock	15	Streams	0.06	6.327	1	<= 530.034851074000
21	9	26.5%	25	73.5%	34	8.9%	Non-Hemlock	15	Streams	0.06	6.327	1	> 530.034851074000
22	4	16.7%	20	83.3%	24	6.3%	Non-Hemlock	18	TPI	0.09	6.258	1	<= 4.314359188080
23	0	0.0%	35	100.0%	35	9.2%	Non-Hemlock	18	TPI	0.09	6.258	1	> 4.314359188080

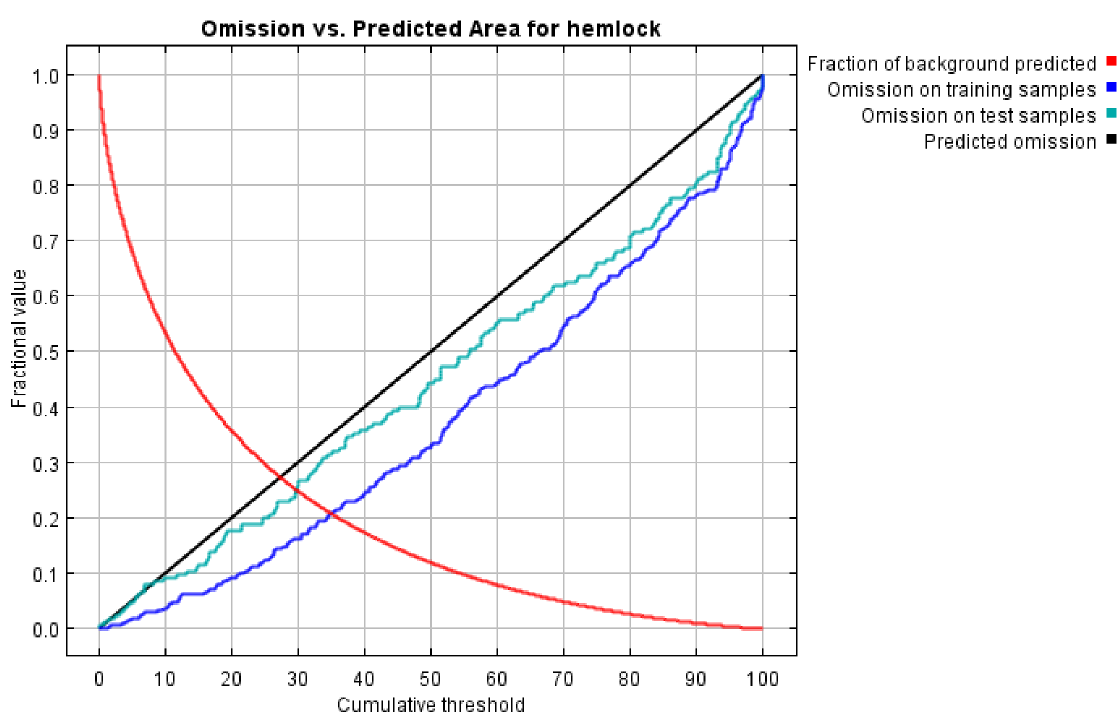
Appendix 5. Maxent results for hemlock classification models with the highest test auc values in each physiographic region. This report was created by the maxent program, version 3.2.19.

COAL FIELD RUN

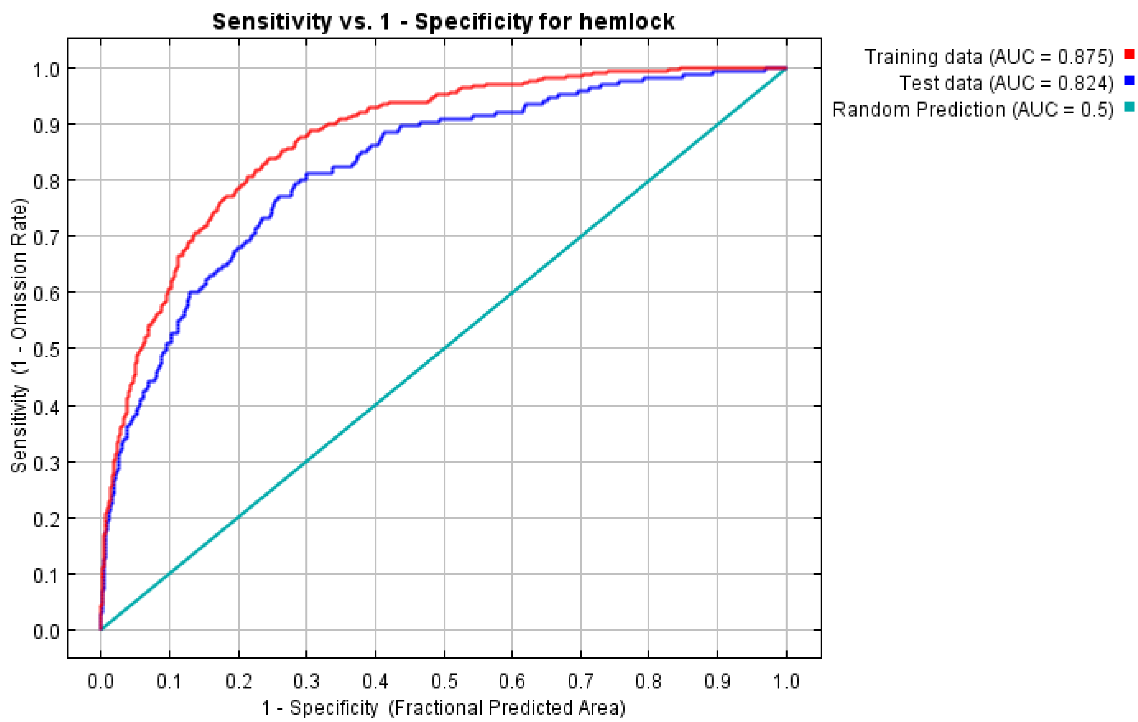
This page contains some analysis of the Maxent model for hemlock, created Thu Jun 04 14:10:58 CDT 2009 using Maxent version 3.2.19. If you would like to do further analyses, the raw data used here is linked to at the end of this page.

Analysis of omission/commission

The following picture shows the omission rate and predicted area as a function of the cumulative threshold. The omission rate is is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.



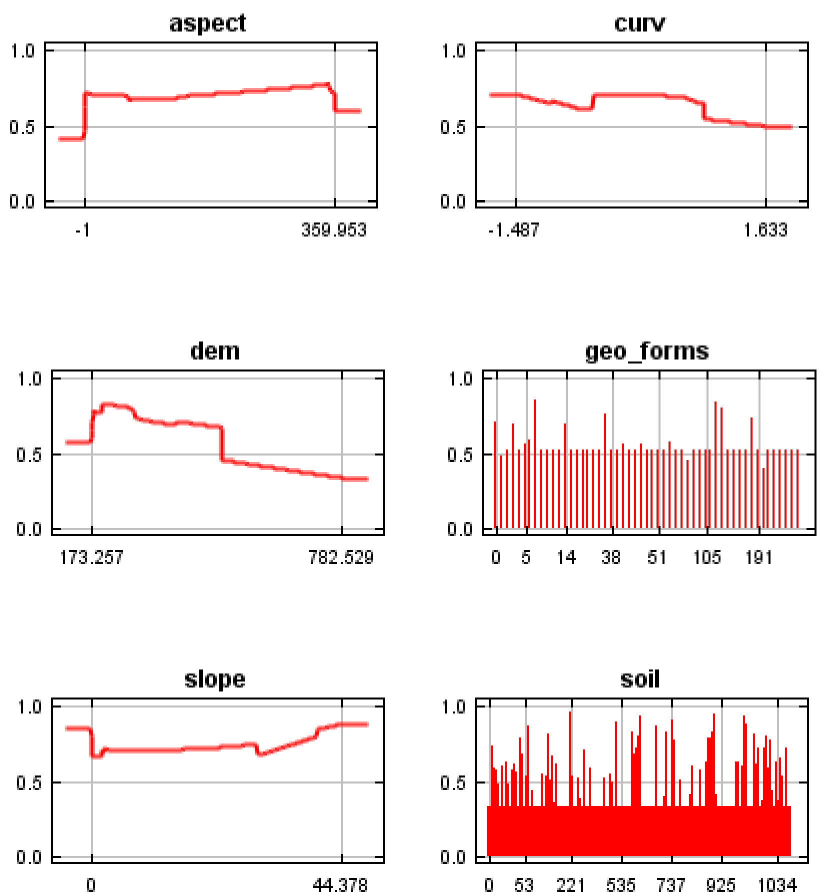
The next picture is the receiver operating characteristic (ROC) curve for the same data. Note that the specificity is defined using predicted area, rather than true commission (see the paper by Phillips, Anderson and Schapire cited on the help page for discussion of what this means). This implies that the maximum achievable AUC is less than 1. If test data is drawn from the Maxent distribution itself, then the maximum possible test AUC would be 0.799 rather than 1; in practice the test AUC may exceed this bound.

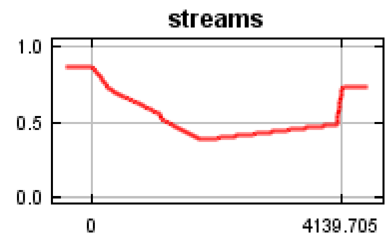


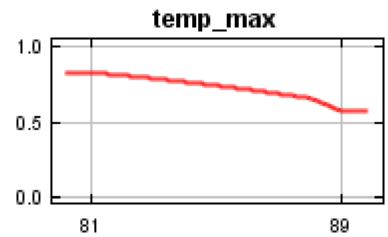
Some common thresholds and corresponding omission rates are as follows. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6 * training omission rate + .04 * cumulative threshold + 1.6 * fractional predicted area.

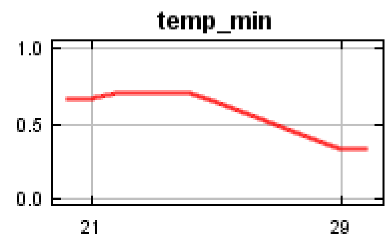
Cumulative threshold	Logistic threshold	Description	Fractional predicted area	Training omission rate	Test omission rate	P-value
1.000	0.063	Fixed cumulative value 1	0.878	0.002	0.012	8.43E-6
5.000	0.123	Fixed cumulative value 5	0.679	0.018	0.048	3.085E-14
10.000	0.179	Fixed cumulative value 10	0.532	0.036	0.091	1.505E-22
0.772	0.057	Minimum training presence	0.897	0.000	0.006	2.052E-5
21.151	0.290	10 percentile training presence	0.342	0.099	0.176	2.25E-39
34.907	0.409	Equal training sensitivity and specificity	0.208	0.208	0.315	1.009E-51
30.393	0.372	Maximum training sensitivity plus specificity	0.245	0.162	0.267	1.215E-48
29.743	0.367	Equal test sensitivity and specificity	0.250	0.162	0.248	2.681E-50
26.417	0.337	Maximum test sensitivity plus specificity	0.282	0.141	0.206	1.002E-48
3.979	0.111	Balance training omission, predicted area and threshold value	0.718	0.010	0.036	1.246E-12
10.730	0.186	Equate entropy of thresholded and non-thresholded distributions	0.516	0.046	0.091	2.337E-24

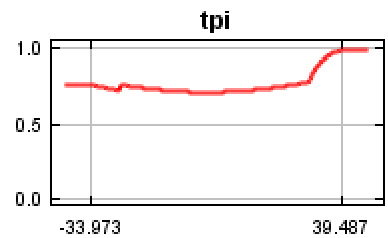
These curves show how each environmental variable affects the Maxent prediction. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. Click on a response curve to see a larger version. Note that the curves can be hard to interpret if you have strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together.

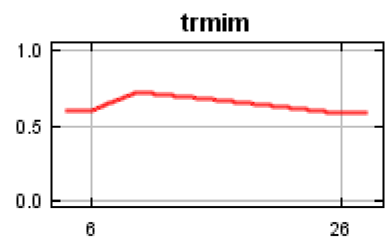




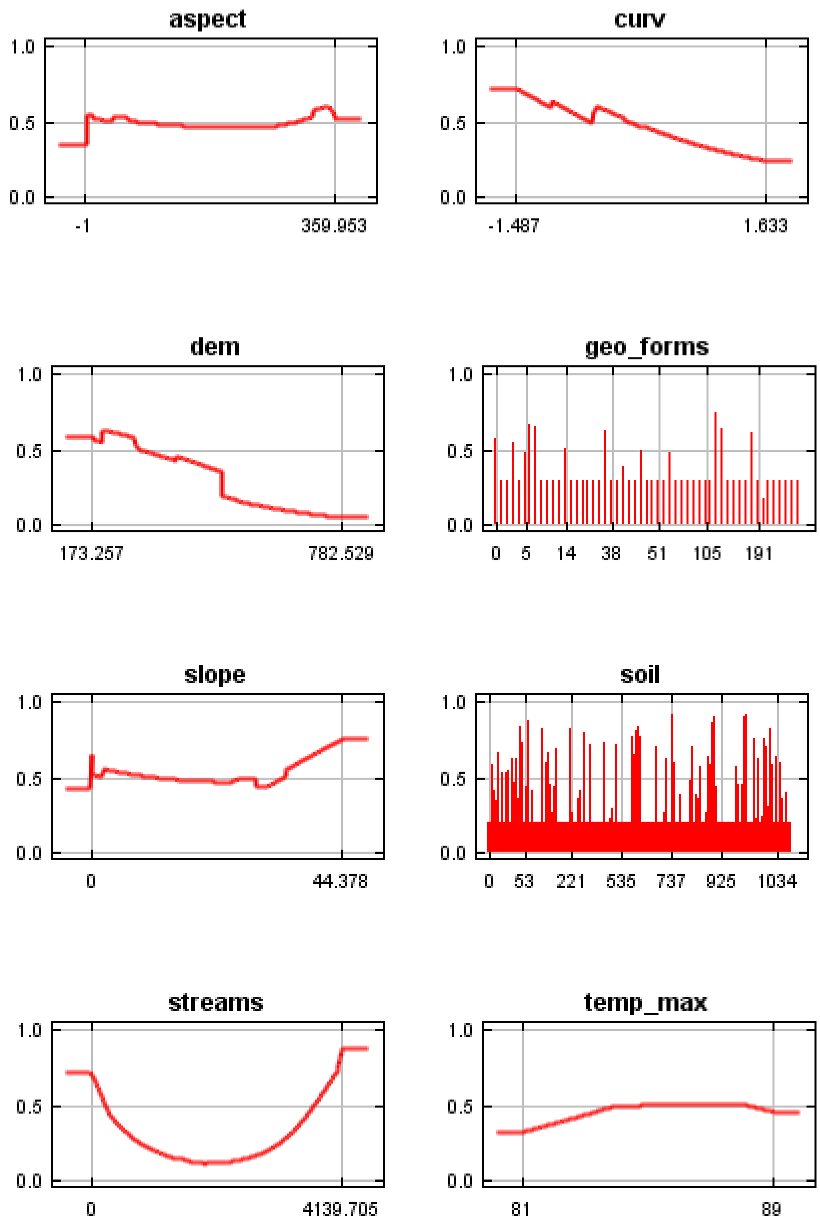








In contrast to the above marginal response curves, each of the following curves represents a different model, namely, a Maxent model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables.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0.0
-1
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curv
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0.5
0.0
-1.487
1.633
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0.5
0.0
173.257
782.529
geo_forms
1.0
0.5
0.0
0 5 14 38 51 105 191
slope
1.0
0.5
0.0
0
44.378
soil
1.0
0.5
0.0
0 53 221 535 737 925 1034
streams
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0
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temp_max
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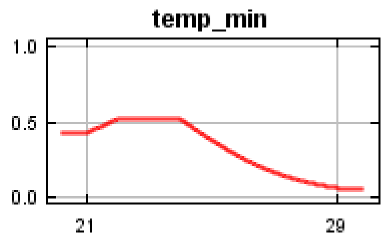
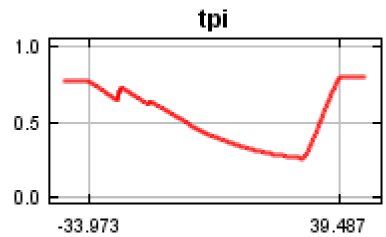
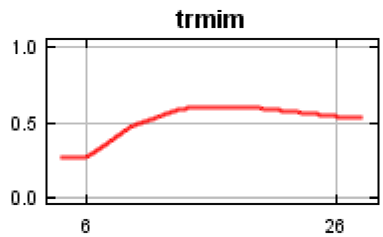
0.5
0.0
81
89





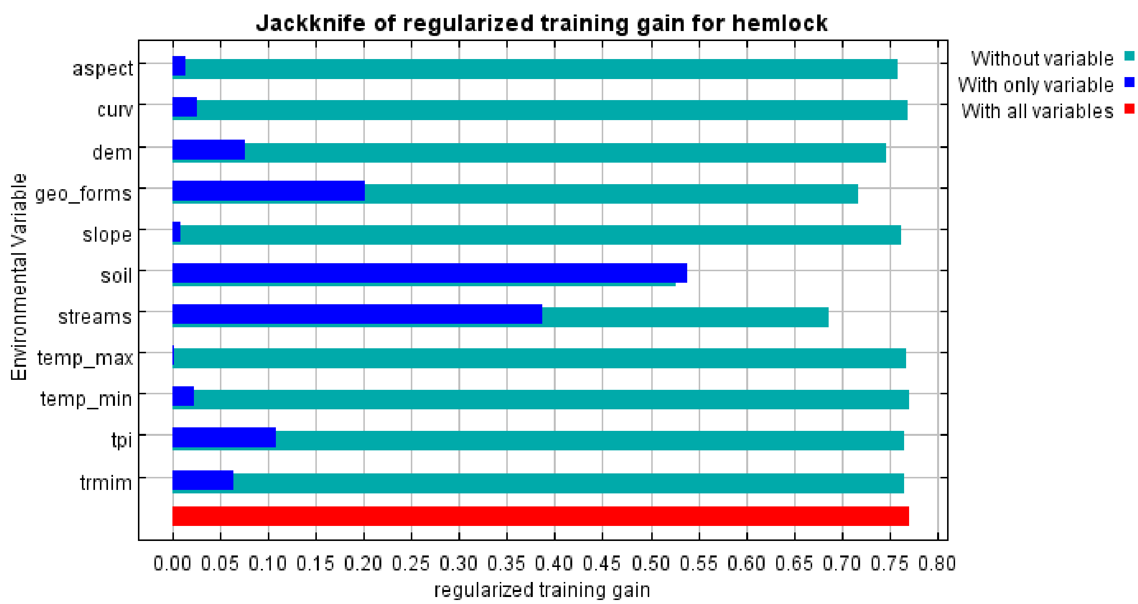


Analysis of variable contributions

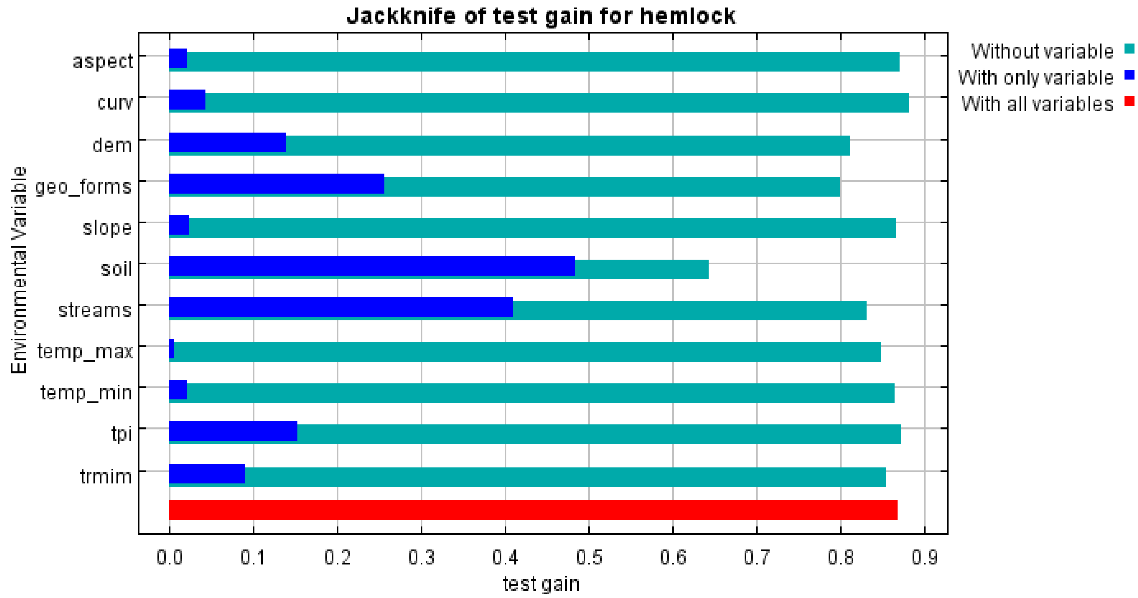
The following table gives a heuristic estimate of relative contributions of the environmental variables to the Maxent model. To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. As with the jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated.

Variable	Percent contribution
streams	41
soil	37.1
geo_forms	12
dem	2.4
tpi	2
aspect	1.6
temp_min	1.5
slope	1
trmim	0.5
curv	0.5
temp_max	0.4

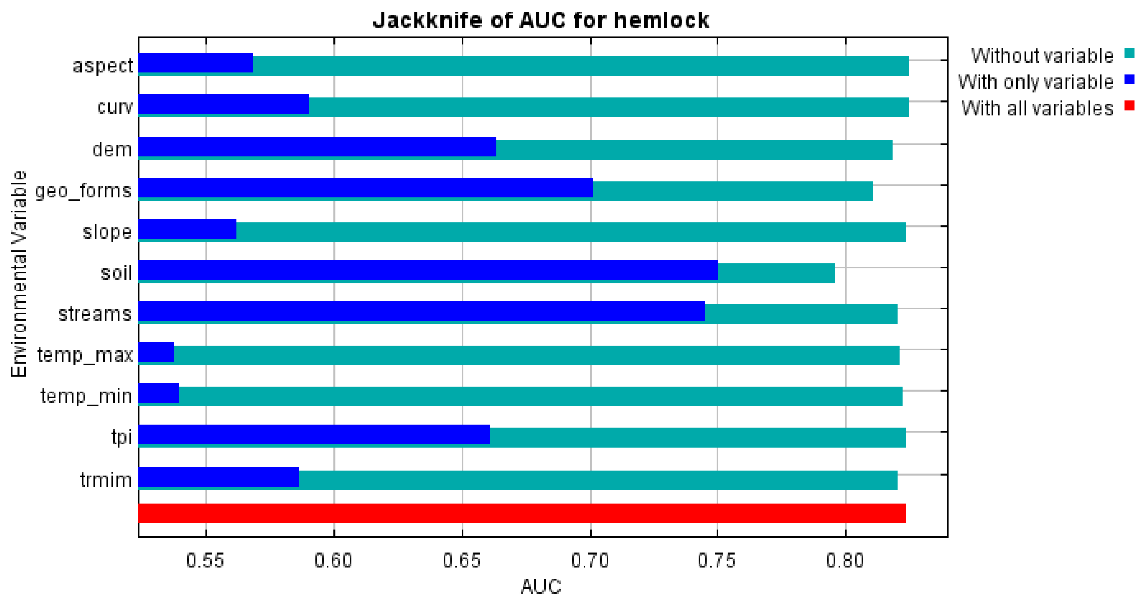
The following picture shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is soil, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is soil, which therefore appears to have the most information that isn't present in the other variables.



The next picture shows the same jackknife test, using test gain instead of training gain. Note that conclusions about which variables are most important can change, now that we're looking at test data.



Lastly, we have the same jackknife test, using AUC on test data.



Raw data outputs and control parameters

- Regularized training gain is 0.771, training AUC is 0.875, unregularized training gain is 0.975.
- Unregularized test gain is 0.870.

- Test AUC is 0.824, standard deviation is 0.017 (calculated as in DeLong, DeLong & Clarke-Pearson 1988, equation 2).
- Algorithm terminated after 1000 iterations (72 seconds).

The follow parameters and settings were used during the run:

- 495 presence records used for training, 165 for testing.
- 10495 points used to determine the Maxent distribution (background points and presence points).
- Environmental layers used:
    - aspect
    - curv
    - dem
    - geo_forms(categorical)
    - slope soil(categorical)
    - streams
    - temp_max
    - temp_min
    - tpi trmim

Command line:

- Feature types used: Linear, Quadratic, Product, Threshold, Hinge
- Regularization multiplier is 1.0
- Regularization values:

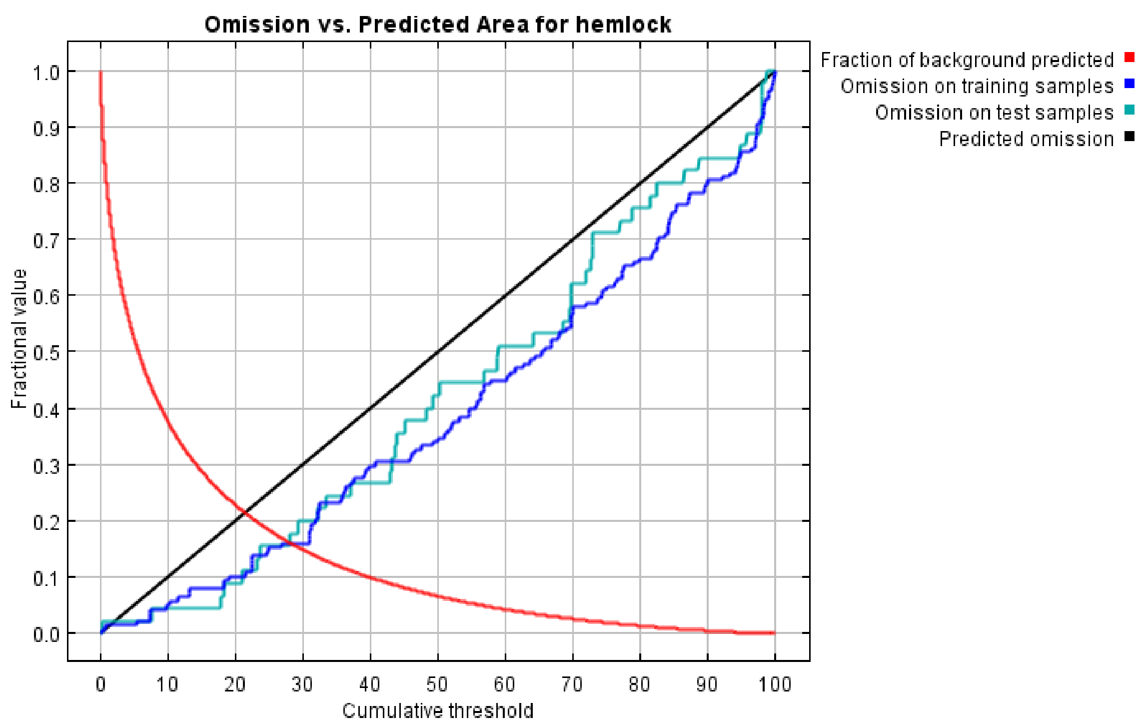
    - linear/quadratic/product: 0.050
    - categorical: 0.250
    - threshold: 1.000
    - hinge: 0.500
- Output format is Logistic
- Output file type is .asc
- Maximum iterations is 1000
- Convergence threshold is 1.0E-5
- Random test percentage is 25
- Jackknife selected
- Make pictures selected
- Create response curves selected

PINE MOUNTAIN RUN

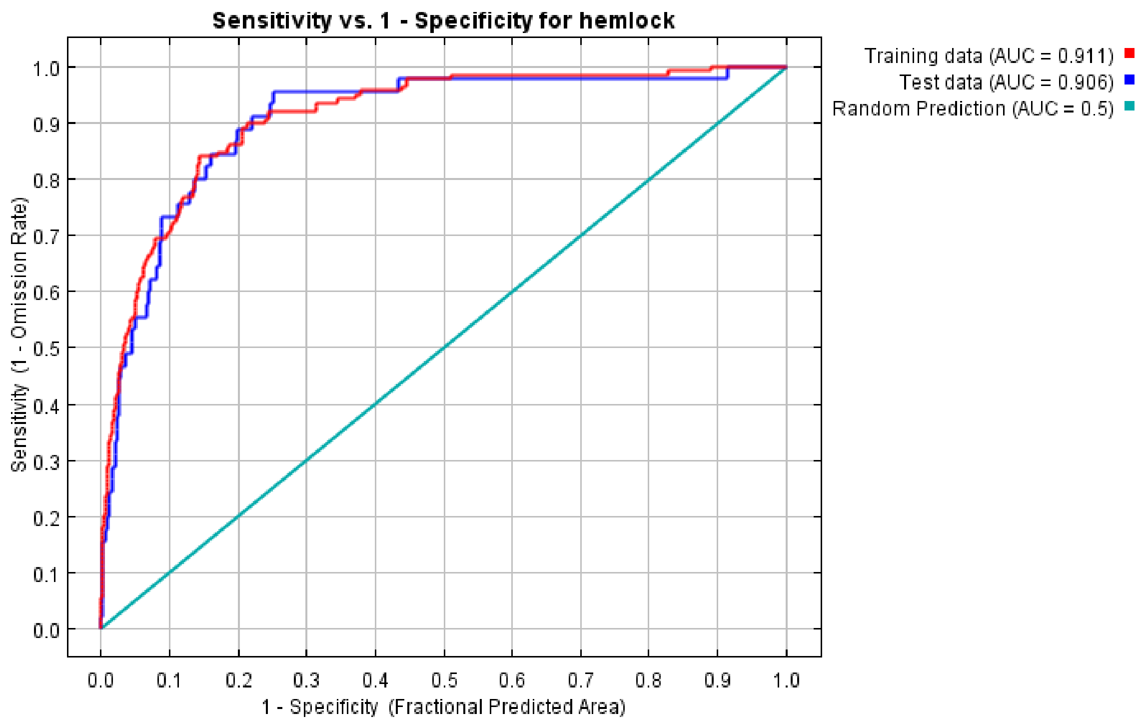
This page contains some analysis of the Maxent model for hemlock, created Thu Jul 09 05:48:22 CDT 2009 using Maxent version 3.2.19. If you would like to do further analyses, the raw data used here is linked to at the end of this page.

Analysis of omission/commission

The following picture shows the omission rate and predicted area as a function of the cumulative threshold. The omission rate is is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.



The next picture is the receiver operating characteristic (ROC) curve for the same data. Note that the specificity is defined using predicted area, rather than true commission (see the paper by Phillips, Anderson and Schapire cited on the help page for discussion of what this means). This implies that the maximum achievable AUC is less than 1. If test data is drawn from the Maxent distribution itself, then the maximum possible test AUC would be 0.863 rather than 1; in practice the test AUC may exceed this bound.

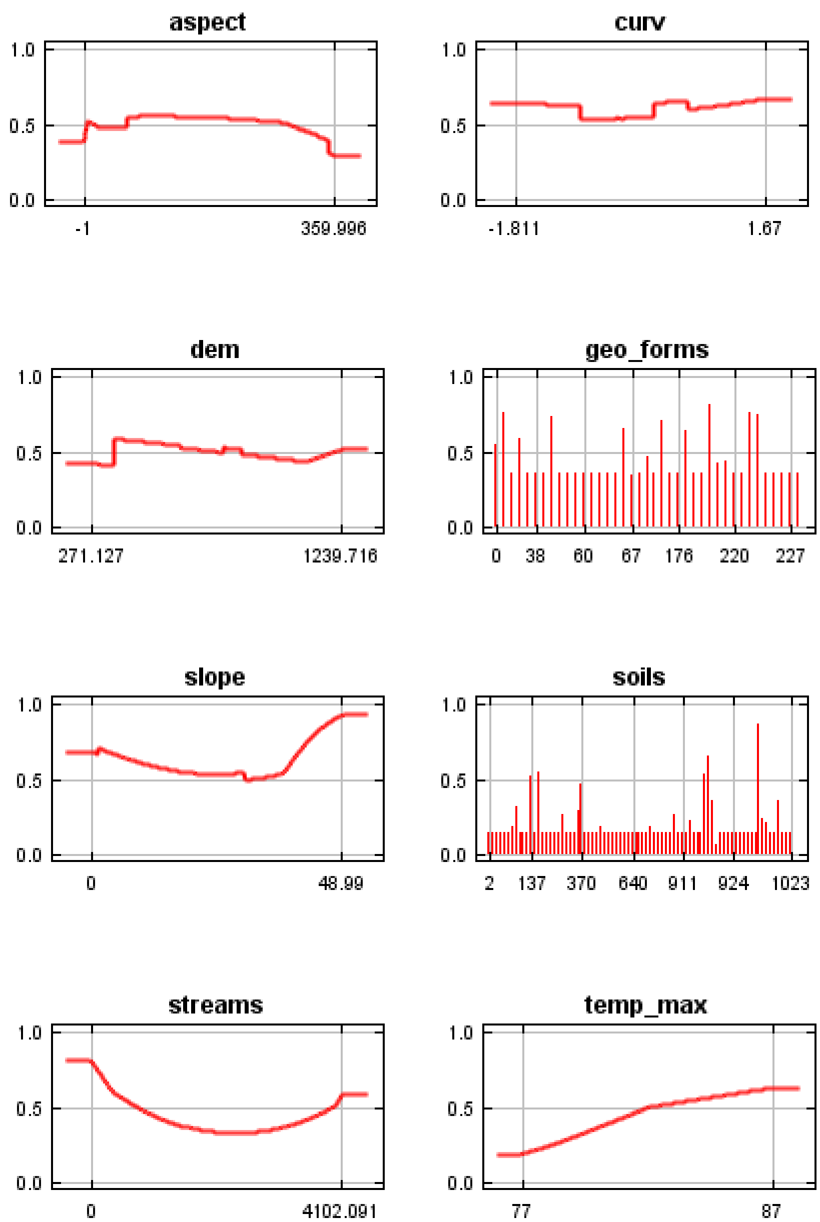


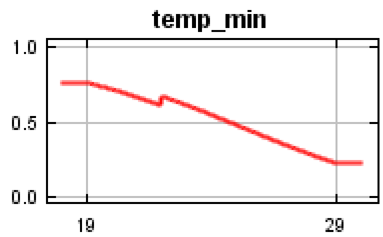
Some common thresholds and corresponding omission rates are as follows. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6 * training omission rate + .04 * cumulative threshold + 1.6 * fractional predicted area.

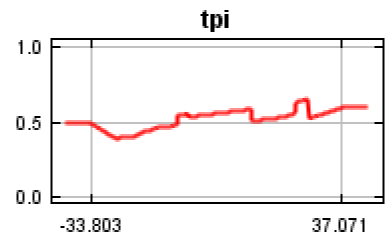
Cumulative threshold	Logistic threshold	Description	Fractional predicted area	Training omission rate	Test omission rate	P-value
1.000	0.027	Fixed cumulative value 1	0.782	0.014	0.022	7.343E-4
5.000	0.077	Fixed cumulative value 5	0.522	0.014	0.022	4.692E-10
10.000	0.132	Fixed cumulative value 10	0.375	0.051	0.044	4.398E-16
0.305	0.015	Minimum training presence	0.889	0.000	0.022	2.908E-2
18.978	0.237	10 percentile training presence	0.239	0.094	0.089	1.761E-26
28.281	0.332	Equal training sensitivity and specificity	0.159	0.159	0.178	2.98E-34
30.919	0.364	Maximum training sensitivity plus specificity	0.143	0.159	0.200	1.045E-36
28.043	0.330	Equal test sensitivity and specificity	0.161	0.159	0.156	5.157E-36
17.897	0.223	Maximum test sensitivity plus specificity	0.251	0.080	0.044	5.028E-28
5.266	0.080	Balance training omission, predicted area and threshold value	0.512	0.014	0.022	1.973E-10
12.118	0.158	Equate entropy of thresholded and non-thresholded distributions	0.333	0.065	0.044	4.181E-19

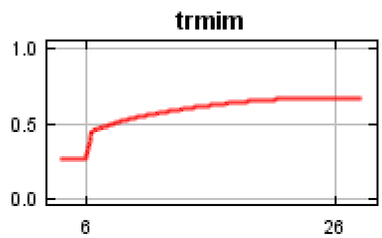
Response curves

These curves show how each environmental variable affects the Maxent prediction. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. Click on a response curve to see a larger version. Note that the curves can be hard to interpret if you have strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together.

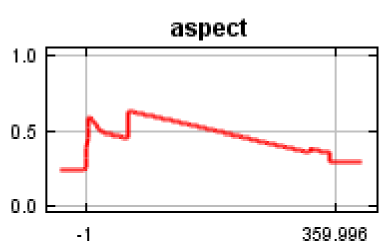


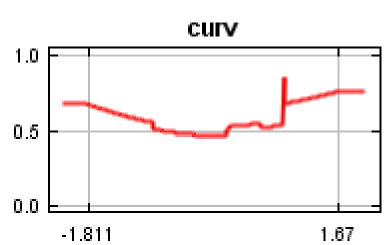


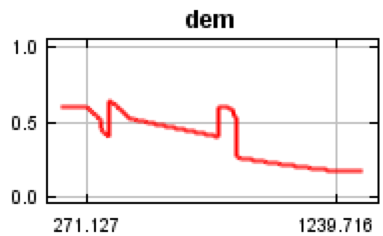




In contrast to the above marginal response curves, each of the following curves represents a different model, namely, a Maxent model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables.



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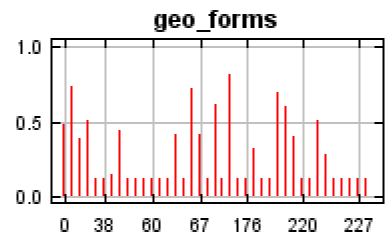
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0.0
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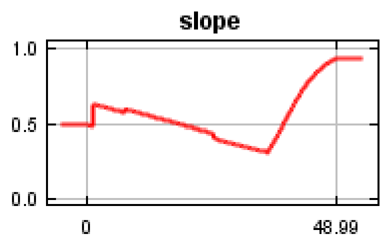
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0.0
0
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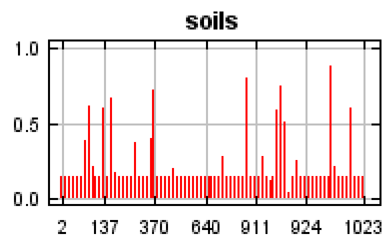
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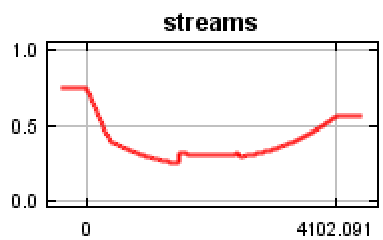
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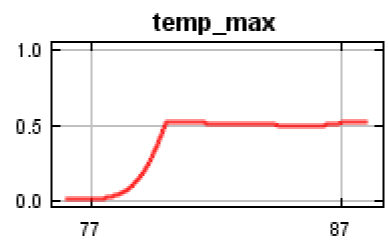
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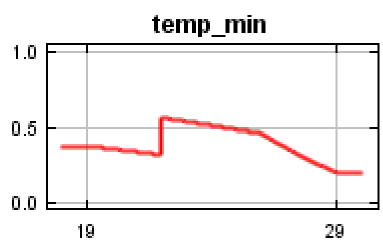
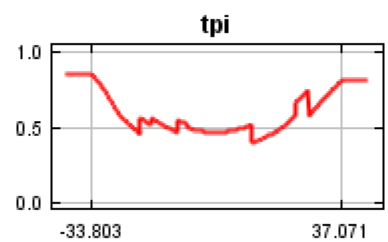
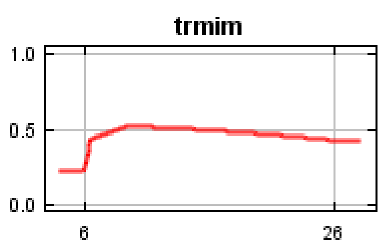
87


temp_min
1.0
0.5
0.0
19
29


tpi
1.0
0.5
0.0
-33.803
37.071

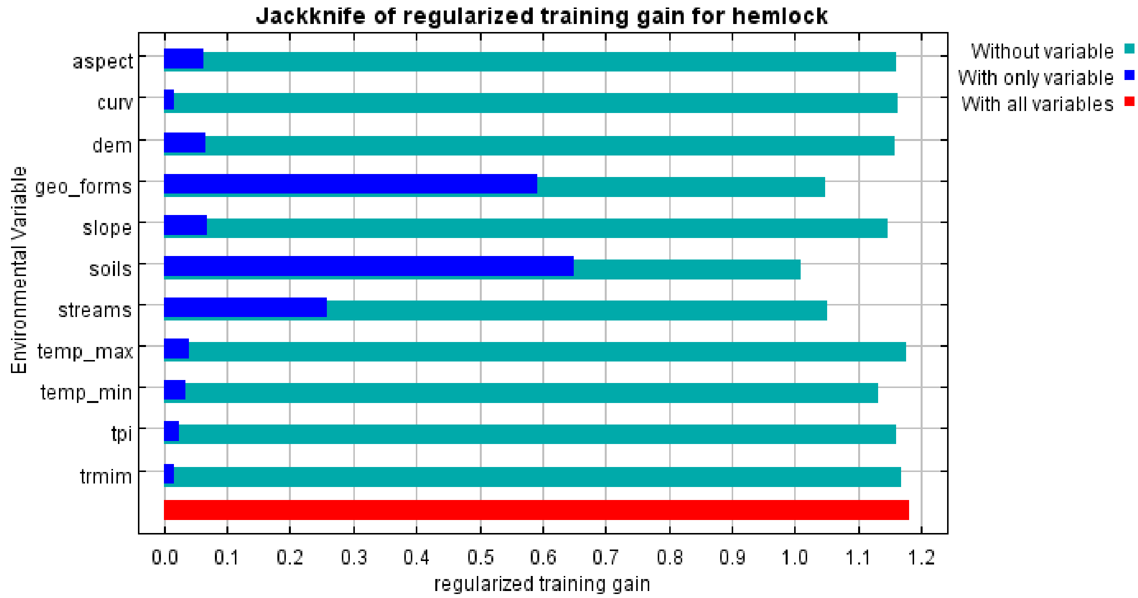

trmim
1.0
0.5
0.0
6
26

Analysis of variable contributions

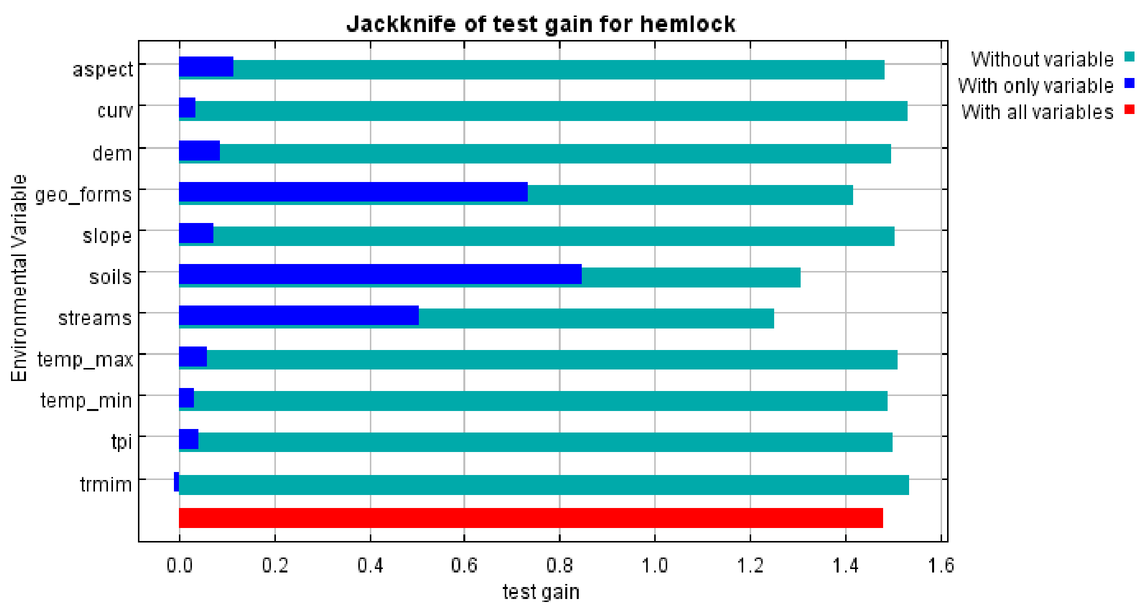
The following table gives a heuristic estimate of relative contributions of the environmental variables to the Maxent model. To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. As with the jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated.

Variable	Percent contribution
soils	43.8
geo_forms	21.2
streams	21.1
temp_min	3.1
dem	2.3
curv	2.3
tpi	1.8
slope	1.6
aspect	1.2
trmim	1.1
temp_max	0.5

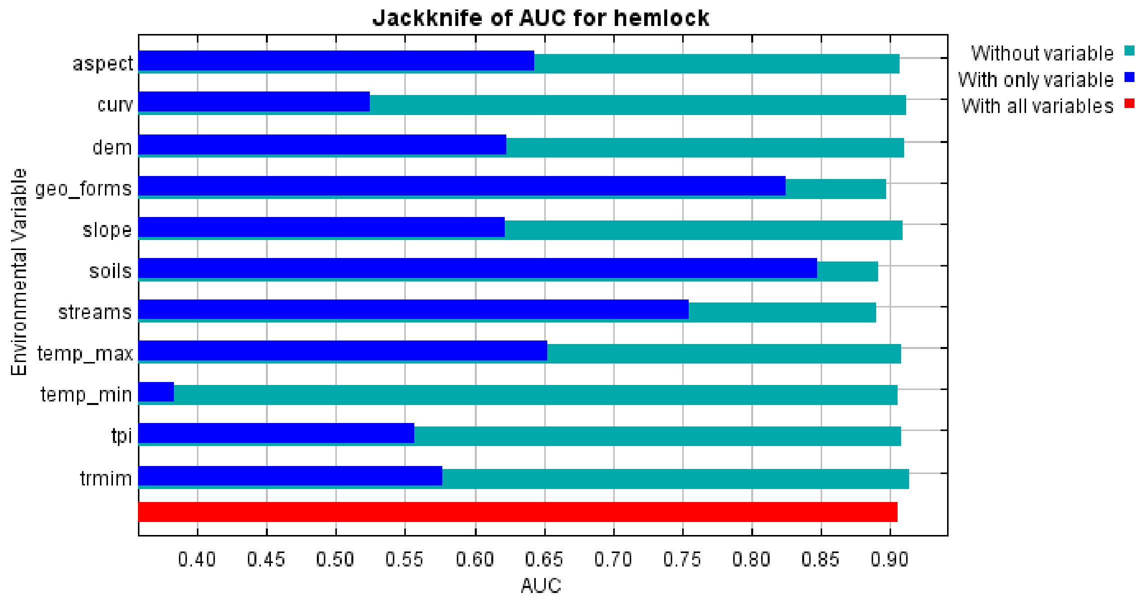
The following picture shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is soils, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is soils, which therefore appears to have the most information that isn't present in the other variables.



The next picture shows the same jackknife test, using test gain instead of training gain. Note that conclusions about which variables are most important can change, now that we're looking at test data.



Lastly, we have the same jackknife test, using AUC on test data.



Raw data outputs and control parameters

- Regularized training gain is 1.182, training AUC is 0.911, unregularized training gain is 1.495.
- Unregularized test gain is 1.478.
- Test AUC is 0.906, standard deviation is 0.023 (calculated as in DeLong, DeLong & Clarke-Pearson 1988, equation 2).
- Algorithm terminated after 1000 iterations (58 seconds).

The follow parameters and settings were used during the run:

- 138 presence records used for training, 45 for testing.
- 10138 points used to determine the Maxent distribution (background points and presence points).

- Environmental layers used: aspect curv dem geo_forms(categorical) slope soils(categorical) streams temp_max temp_min tpi trmim

Command line:

- Feature types used: Linear, Quadratic, Product, Threshold, Hinge
- Regularization multiplier is 1.0
- Regularization values:
  - linear/quadratic/product: 0.050
  - categorical: 0.250
  - threshold: 1.000
  - hinge: 0.500
- Output format is Logistic
- Output file type is .asc
- Maximum iterations is 1000
- Convergence threshold is 1.0E-5
- Random test percentage is 25
- Jackknife selected
- Make pictures selected
- Create response curves selected

Appendix 6. Test auc values for all ten iterations of the maxent models generated in each physiographic region for use in hemlock classification.

COAL FIELD

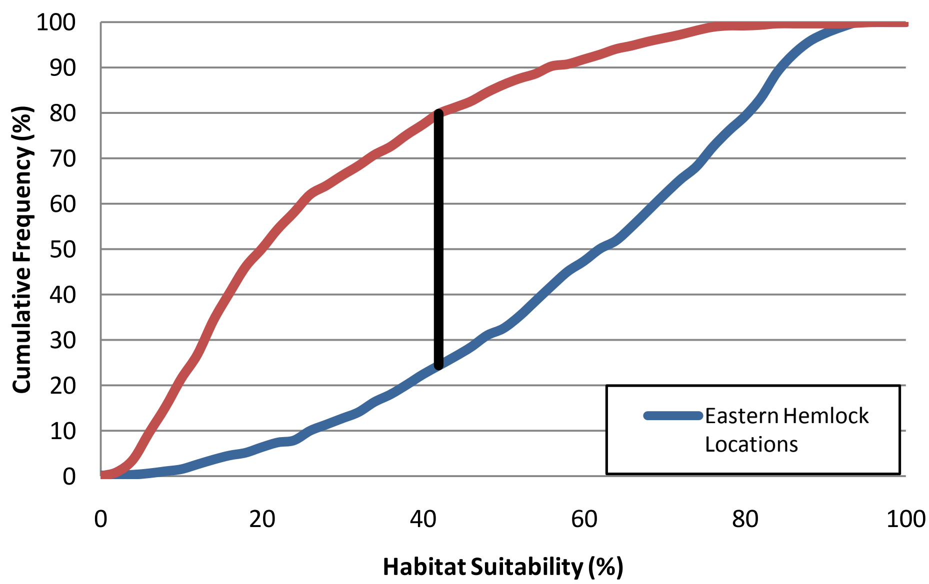
Model Run	Test AUC
1	0.812
2	0.810
3	0.807
4	0.806
5	0.815
6	0.793
7	0.795
8	0.799
9	0.805
10	0.824
Mean	0.807

PINE MOUNTAIN

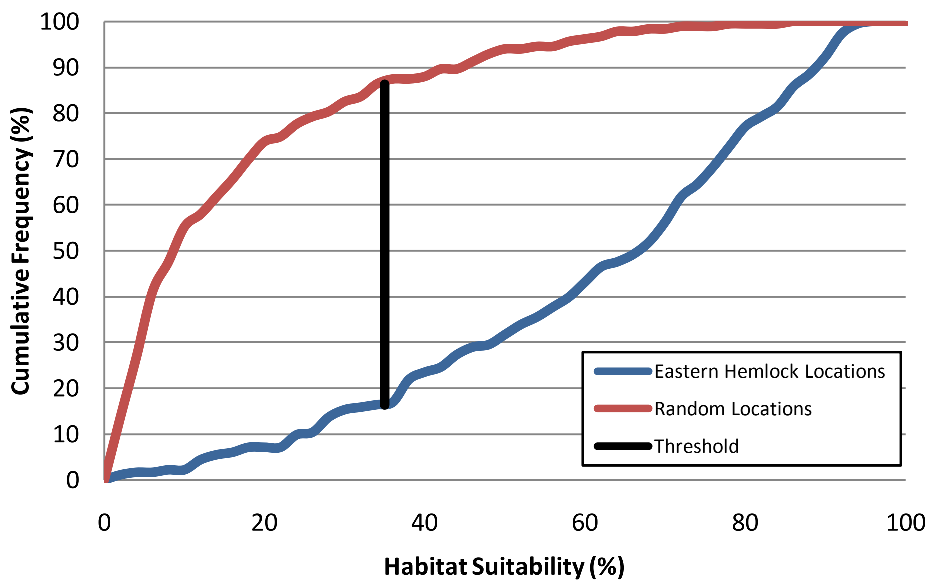
Model Run	Test AUC
1	0.839
2	0.891
3	0.863
4	0.844
5	0.888
6	0.889
7	0.859
8	0.906
9	0.863
10	0.871
Mean	0.871

Appendix 7. Graphs of the hemlock classification thresholds used to reclassify the continuous maxent outputs into nominal classes for both physiographic regions. The threshold was established using the maximum cumulative frequency difference method.

COAL FIELD



PINE MOUNTAIN



Appendix 8. Error matrices and kappa statistics for eastern hemlock classifications.

8a. Accuracy results of TREE-EMT+ decision trees for each satellite image coverage area in each physiographic region. The accuracies were calculated using a 30 m buffer of test points that were withheld from model training.

Upper Eastern Coal Field Physiographic Region

ECB 1935

Classification Totals	Reference Totals: Hemlock	Reference Totals: Non-hemlock	Total	User's Accuracy
Hemlock	25	12	37	67.6%
Non-hemlock	3	25	28	89.3%
Total	28	37	65	
Producer's Accuracy	89.3%	67.6%		
			Overall Accuracy	76.9%
			Kappa	0.547

ECB 1934

Classification Totals	Reference Totals: Hemlock	Reference Totals: Non-hemlock	Total	User's Accuracy
Hemlock	132	4	136	97.1%
Non-hemlock	38	244	282	86.5%
Total	170	248	418	
Producer's Accuracy	77.6%	98.4%		
			Overall Accuracy	90.0%
			Kappa	0.785

ECB 1834

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	58	19	77	75.3%
	Non-hemlock	12	144	156	92.3%
	Total	70	163	233	
	Producer's Accuracy	82.9%	88.3%		
				Overall Accuracy	86.7%
				Kappa	0.692

Pine Mountain Physiographic Region

Pine 1935

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	24	1	25	96.0%
	Non-hemlock	3	24	27	88.9%
	Total	27	25	52	
	Producer's Accuracy	88.9%	96.0%		
				Overall Accuracy	92.3%
				Kappa	0.846

Pine 1934

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	34	3	37	91.9%
	Non-hemlock	21	51	72	70.8%
	Total	55	54	109	
	Producer's Accuracy	61.8%	94.4%		
				Overall Accuracy	78.0%
				Kappa	0.561

Pine 1834

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	27	12	39	69.2%
	Non-hemlock	1	21	22	95.5%
	Total	28	33	61	
	Producer's Accuracy	96.4%	63.6%		

Overall Accuracy 78.7%
Kappa 0.583

8b. Accuracy results of TREE-ETM+ decision trees that resulted from merging hemlock classifications for all three satellite images within each physiographic region. The accuracies were calculated using a 30 m buffer of test points that were withheld from model training.

Upper Eastern Coal Field Physiographic Region

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	172	19	191	90.1%
	Non-hemlock	40	322	362	89.0%
	Total	212	341	553	
	Producer's Accuracy	81.1%	94.4%		

Overall Accuracy 89.3%
Kappa 0.770

Pine Mountain Physiographic Region

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	40	19	59	67.8%
	Non-hemlock	21	47	68	69.1%
	Total	61	66	127	
	Producer's Accuracy	65.6%	71.2%		

Overall Accuracy 68.5%
Kappa 0.368

8c. Accuracy results of TREE-OMIT decision trees for each physiographic region. The accuracies were calculated using a 30 m buffer of test points that were withheld from model training.

Upper Eastern Coal Field Physiographic Region

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	144	5	149	96.6%
	Non-hemlock	77	348	425	81.9%
	Total	221	353	574	
	Producer's Accuracy	65.2%	98.6%		

Overall Accuracy 85.7%
Kappa 0.679

Pine Mountain Physiographic Region

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	45	3	48	93.8%
	Non-hemlock	16	63	79	79.7%
	Total	61	66	127	
	Producer's Accuracy	73.8%	95.5%		

Overall Accuracy 85.0%
Kappa 0.698

8d. Accuracy results of MaxEnt models each physiographic region. The accuracies were calculated using a 30 m buffer of test points that were withheld from model training.

Upper Eastern Coal Field Physiographic Region

Classification Totals		Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
	Hemlock	184	85	269	68.4%
	Non-hemlock	37	268	305	87.9%
	Total	221	353	574	
	Producer's Accuracy	83.3%	75.9%		

Overall Accuracy 78.7%
Kappa 0.569

Pine Mountain Physiographic Region

Classification Totals	Reference Totals: Hemlock	Non-hemlock	Total	User's Accuracy
Hemlock	54	18	72	75.0%
Non-hemlock	7	48	55	87.3%
Total	61	66	127	
Producer's Accuracy	88.5%	72.7%		

Overall Accuracy 80.3%
Kappa 0.608

Appendix 9. Hemlock woolly adelgid infestation data points used in distribution modeling. Lon and lat represent longitude and latitude, respectively, which is reported in the north american datum 1983 geographic coordinate system. The remaining columns denote which infestation sites were used as test (t) points for model evaluation in each of the ten model runs. In each run, the remaining data points not used for evaluation were used in model calibration.

LON	LAT	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run_10
-84.2529	36.6035						T	T			
-83.9558	36.6355				T	T		T	T		T
-83.8240	36.6752		T		T	T				T	
-83.8211	36.6934								T		
-83.8104	36.6896		T					T			
-83.7925	36.7161	T	T						T		T
-83.7738	36.7262			T		T			T	T	
-83.7669	36.7226									T	
-83.7653	36.7292		T		T				T		
-83.7441	36.7303				T				T	T	T
-83.7432	36.7276			T					T		
-83.7413	36.7340	T			T			T	T		
-83.7298	36.7412	T					T	T			
-83.7035	36.7434		T					T			
-83.6672	37.8178				T	T			T	T	T
-83.6667	37.8174	T		T							T
-83.6579	37.8182		T	T					T		
-83.6654	36.7427		T	T							
-83.5370	37.0194	T					T			T	T
-83.4962	37.1045		T	T				T	T	T	
-83.4961	37.1065	T	T			T	T				
-83.4931	37.1262	T		T	T					T	
-83.4776	37.1004		T			T					T
-83.3788	36.8614	T		T			T	T			T
-83.3716	36.9368	T				T					
-83.3713	36.9369					T		T		T	
-83.3713	36.9367	T	T								
-83.3709	36.9367				T	T				T	
-83.3708	36.9369			T				T			T
-83.3730	36.8630	T		T			T				
-83.3710	36.8626		T		T	T					
-83.3582	36.8816			T	T			T			

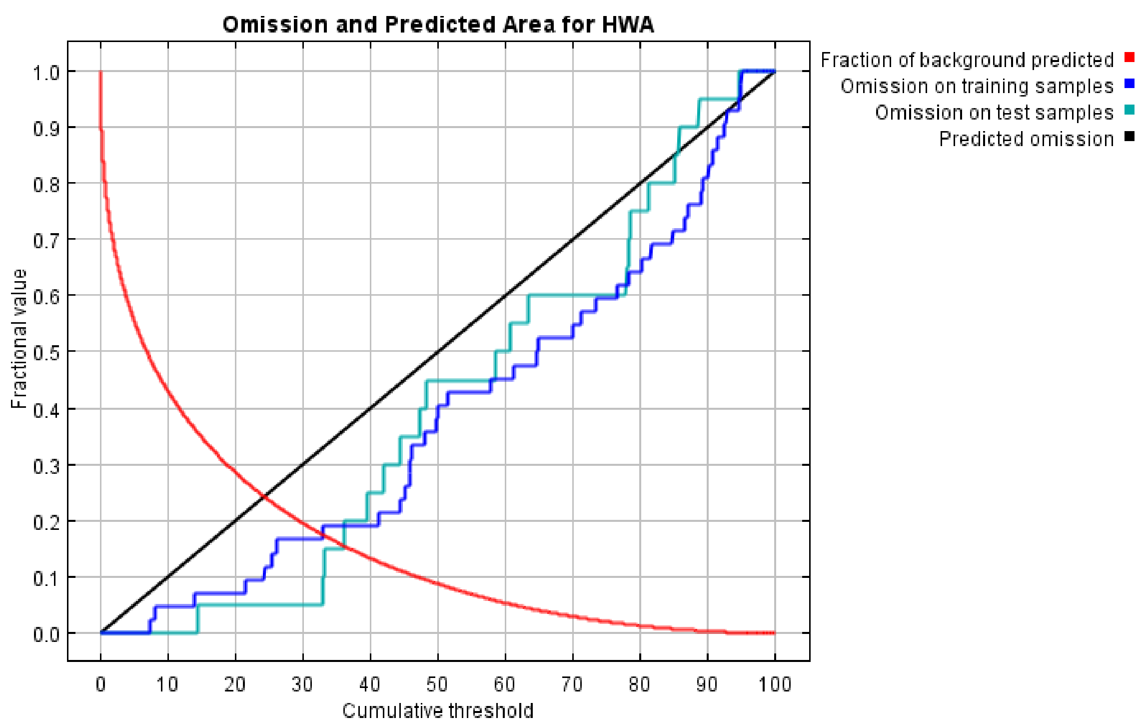
-83.3577	36.8818					T					
-83.3575	36.8815					T					
-83.3568	36.8859	T		T	T		T	T			T
-83.3561	36.8853		T						T	T	
-83.2672	36.8967		T		T	T	T			T	
-83.2550	36.8988							T			
-83.2475	36.9065	T	T				T				T
-83.2356	36.9055			T	T				T	T	
-83.2317	36.9129				T		T		T		
-83.2258	36.9138				T	T	T				
-83.2161	36.9139						T	T			
-83.2064	36.9193					T	T		T	T	
-83.1995	36.9216				T		T	T			
-83.2022	36.7506	T				T	T			T	T
-83.1913	36.9286		T				T	T			
-83.1889	36.9269	T		T	T	T			T		T
-83.1885	36.9268			T		T	T			T	
-83.1881	36.9265		T					T			T
-83.1877	36.9241	T			T		T	T			
-83.1877	36.9238			T					T		T
-83.1867	36.9280		T			T					T
-83.1865	36.9288							T			
-83.1802	36.9481	T			T				T		T
-83.1730	36.9291		T	T					T	T	T
-83.1433	36.7574	T	T	T			T			T	
-82.9115	37.0016	T			T			T			T
-82.7803	37.0729			T		T				T	
-82.4836	37.3098										T
-82.3105	37.4013								T	T	
-82.3095	37.4013	T		T			T				

Appendix 10. Results of maxent and mahalanobis distance models with the highest test auc values used in hwa infestation susceptibility analyses. The reports were generated by the respective model software.

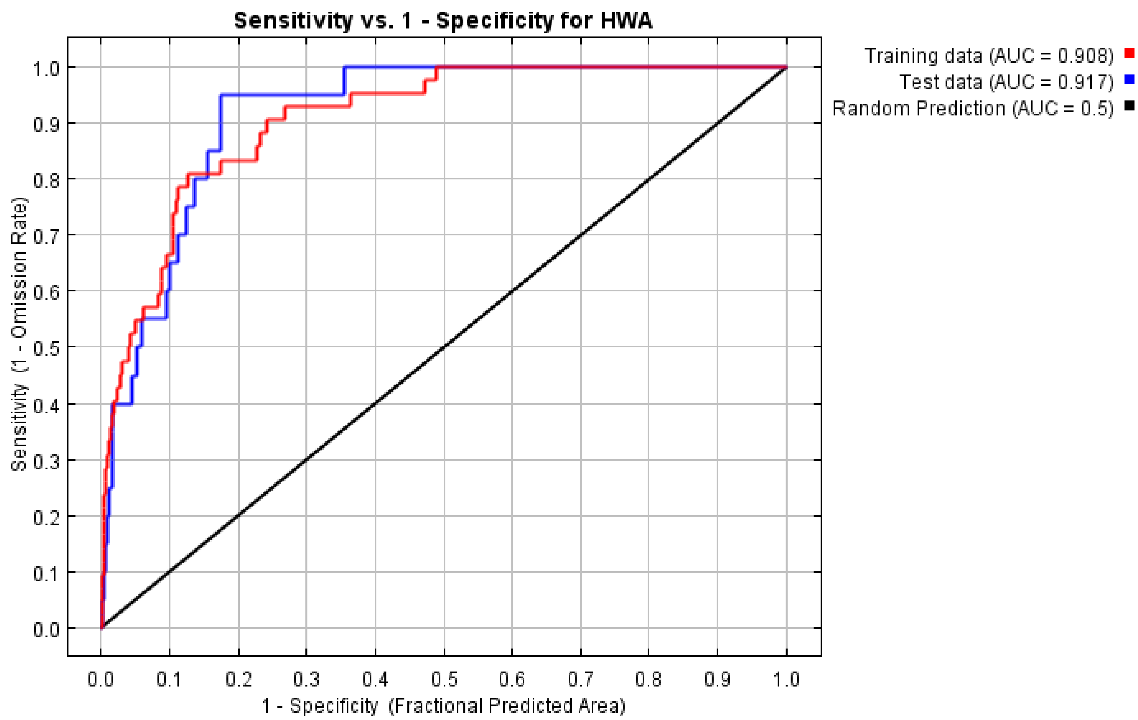
MAXENT

Analysis of omission/commission

The following picture shows the omission rate and predicted area as a function of the cumulative threshold. The omission rate is is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.



The next picture is the receiver operating characteristic (ROC) curve for the same data. Note that the specificity is defined using predicted area, rather than true commission (see the paper by Phillips, Anderson and Schapire cited on the help page for discussion of what this means). This implies that the maximum achievable AUC is less than 1. If test data is drawn from the Maxent distribution itself, then the maximum possible test AUC would be 0.840 rather than 1; in practice the test AUC may exceed this bound.

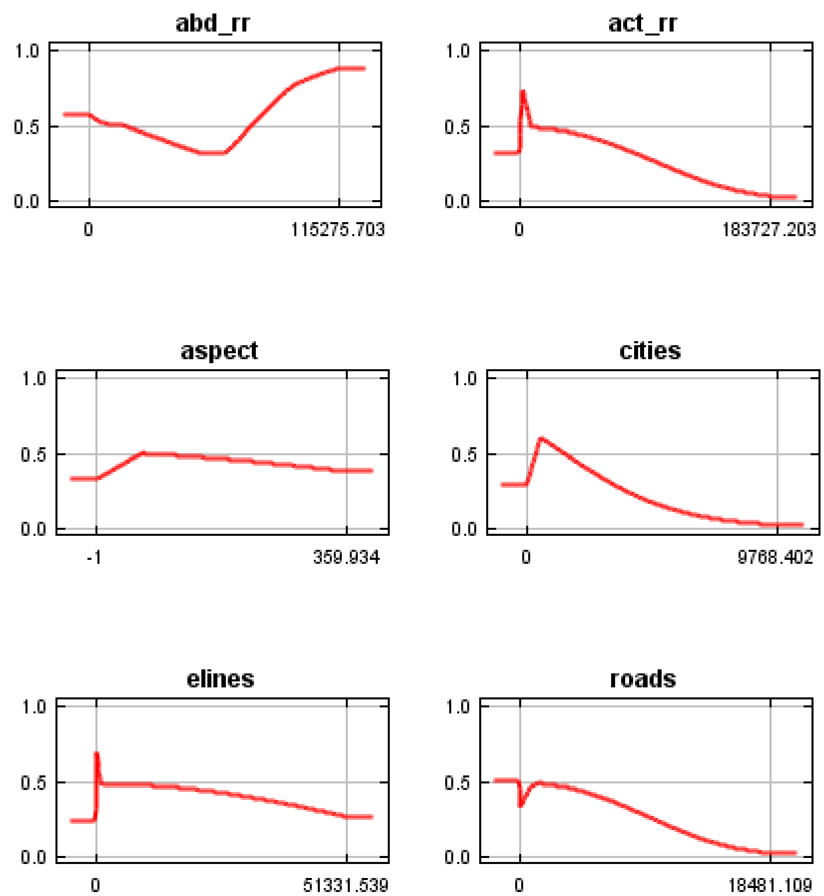


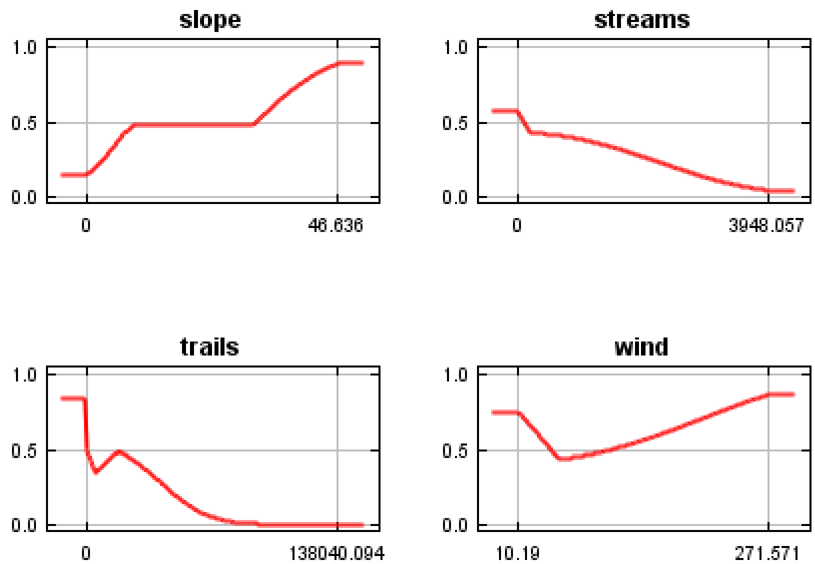
Some common thresholds and corresponding omission rates are as follows. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6 * training omission rate + .04 * cumulative threshold + 1.6 * fractional predicted area.

Cumulative threshold	Logistic threshold	Description	Fractional predicted area	Training omission rate	Test omission rate	P-value
1.000	0.039	Fixed cumulative value 1	0.760	0.000	0.000	4.122E-3
5.000	0.105	Fixed cumulative value 5	0.554	0.000	0.000	7.497E-6
10.000	0.166	Fixed cumulative value 10	0.430	0.048	0.000	4.584E-8
7.256	0.132	Minimum training presence	0.490	0.000	0.000	6.289E-7
24.263	0.295	10 percentile training presence	0.243	0.095	0.050	3.213E-11
32.998	0.367	Equal training sensitivity and specificity	0.175	0.167	0.050	6.841E-14
41.269	0.431	Maximum training sensitivity plus specificity	0.127	0.190	0.250	2.935E-10
36.080	0.390	Equal test sensitivity and specificity	0.155	0.190	0.150	1.287E-11
33.021	0.367	Maximum test sensitivity plus specificity	0.175	0.190	0.050	6.695E-14
7.256	0.132	Balance training omission, predicted area and threshold value	0.490	0.000	0.000	6.289E-7
12.660	0.193	Equate entropy of thresholded and original distributions	0.383	0.048	0.000	4.637E-9

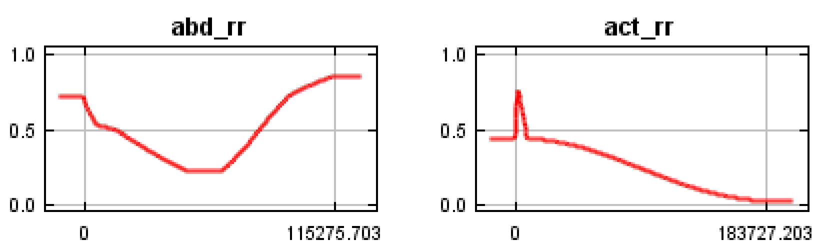
Response curves

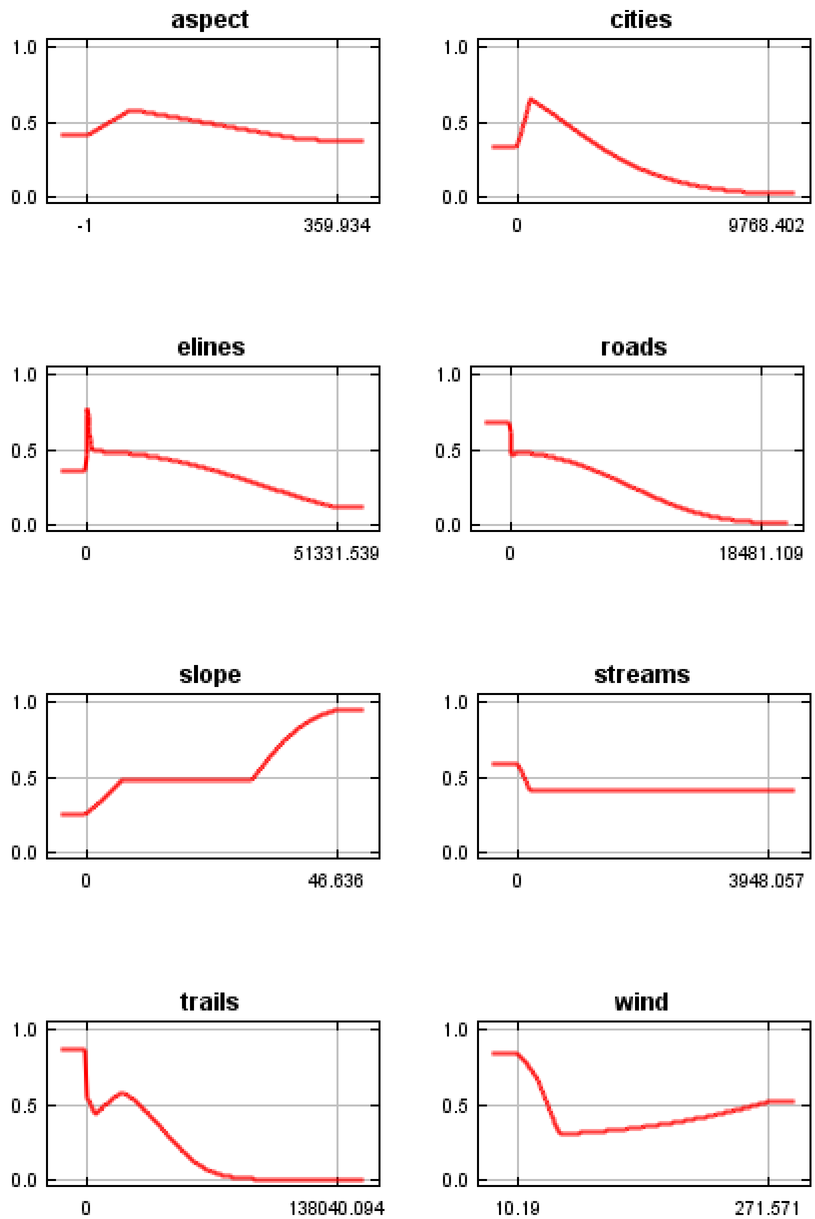
These curves show how each environmental variable affects the Maxent prediction. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. Click on a response curve to see a larger version. Note that the curves can be hard to interpret if you have strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together.





In contrast to the above marginal response curves, each of the following curves represents a different model, namely, a Maxent model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables.



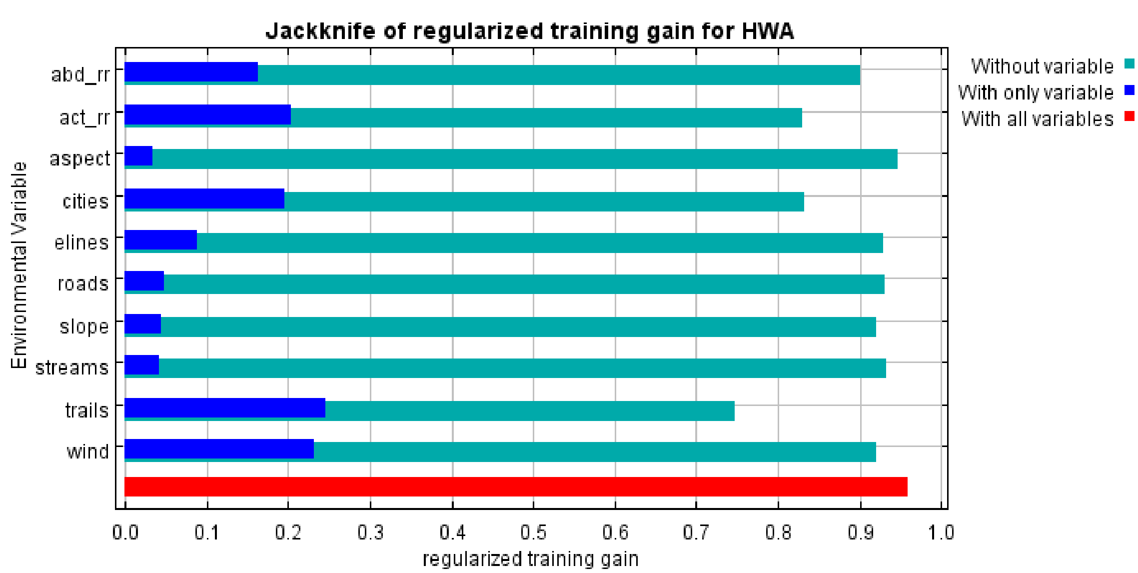


Analysis of variable contributions

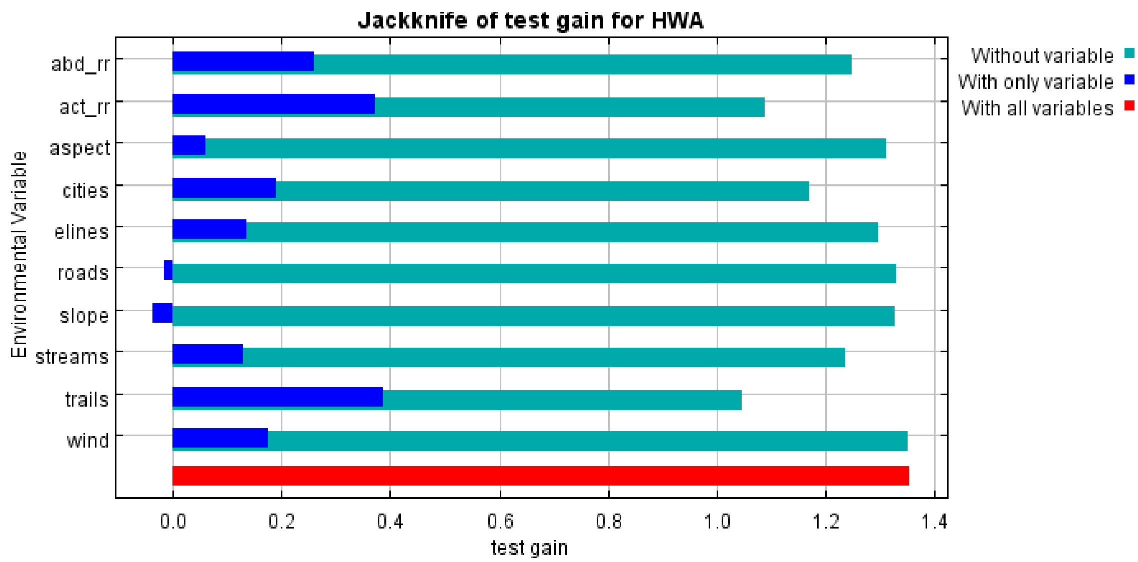
The following table gives a heuristic estimate of relative contributions of the environmental variables to the Maxent model. To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. As with the jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated.

Variable	Percent contribution
trails	25
act_rr	18.3
wind	17.3
cities	15.9
abd_rr	8.3
elines	4.1
roads	4
streams	3.4
aspect	2
slope	1.9

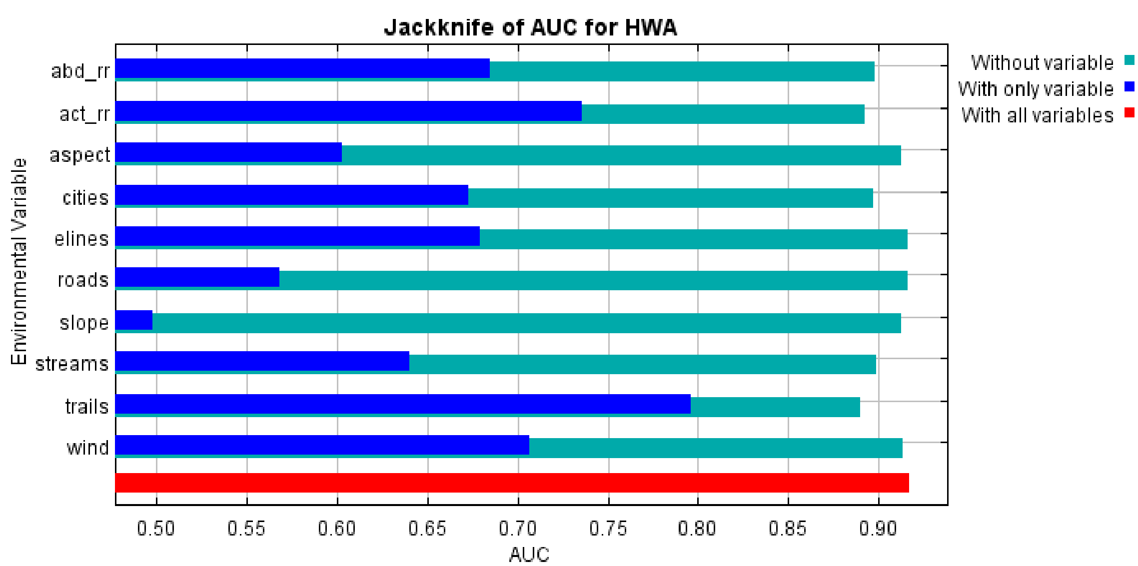
The following picture shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is trails, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is trails, which therefore appears to have the most information that isn't present in the other variables.



The next picture shows the same jackknife test, using test gain instead of training gain. Note that conclusions about which variables are most important can change, now that we're looking at test data.



Lastly, we have the same jackknife test, using AUC on test data.



Raw data outputs and control parameters

- Regularized training gain is 0.960, training AUC is 0.908, unregularized training gain is 1.445.
- Unregularized test gain is 1.352.
- Test AUC is 0.917, standard deviation is 0.019 (calculated as in DeLong, DeLong & Clarke-Pearson 1988, equation 2).
- Algorithm converged after 720 iterations (41 seconds).

The follow settings were used during the run:

- 42 presence records used for training, 20 for testing.
- 10000 points used to determine the Maxent distribution (background points).
- Environmental layers used (all continuous):
    - abd_rr
    - act_rr
    - aspect
    - cities
    - elines
    - roads
    - slope
    - streams
    - trails
    - wind
- Regularization values:

- linear/quadratic/product: 0.216
- categorical: 0.250
- threshold: 1.580
- hinge: 0.500

- Feature types used: linear, quadratic, hinge
- responsecurves: true
- jackknife: true
- addsamplestobackground: false
- maximumiterations: 1000
- threads: 2
- testsamplesfile=C:\All_GIS_Data\HWA_Distribution_Models\HWA_Test_Points\HWA_Test_4.csv

MAHALANOBIS DISTANCE

Mean and Covariance Source Options: Option to use All Points (n = 42)

Mahalanobis Input Variable Options:

10 selected data layers:

1. RASTER: abd_rr
2. RASTER: act_rr
3. RASTER: aspect
4. RASTER: cities
5. RASTER: elines
6. RASTER: roads
7. RASTER: slope
8. RASTER: streams
9. RASTER: trails
10. RASTER: wind

Mahalanobis Mean Vector =

Raster	Means
abd_rr	20300.7
act_rr	22073.2
aspect	138.0
cities	1661.7
elines	8602.8
roads	1151.9
slope	19.2
streams	134.9
trails	19291.0
wind	47.7

Mahanalobis Covariance Matrix =

	abd_rr	act_rr	aspect	cities	elines	roads	slope	streams	trails	wind
abd_rr	618320377.0	295760316.2	720029.5	5155894.7	118265150.2	-810879.6	-58830.4	-841304.4	-55161215.4	-29859.4
act_rr	295760316.2	542858381.1	-2213.5	-268361.5	144854285.3	276082.6	-37818.6	-950820.2	-94708988.2	101222.6
aspect	720029.5	-2213.5	8817.8	-19373.6	159237.5	12723.4	-387.2	-2322.1	83904.9	-308.9
cities	5155894.7	-268361.5	-19373.6	1410350.9	-1440421.3	827639.5	-1183.1	-46901.5	-2354164.3	15324.2
elines	118265150.2	144854285.3	159237.5	-1440421.3	66332376.0	2284165.3	-10602.1	-179666.2	-8502650.7	2917.1
roads	-810879.6	276082.6	12723.4	827639.5	2284165.3	1700522.3	-3357.0	-37942.5	3407943.5	14862.3
slope	-58830.4	-37818.6	-387.2	-1183.1	-10602.1	-3357.0	79.0	329.1	-5194.3	-3.6
streams	-841304.4	-950820.2	-2322.1	-46901.5	-179666.2	-37942.5	329.1	34288.8	-250722.1	-1162.7
trails	-55161215.4	-94708988.2	83904.9	-2354164.3	-8502650.7	3407943.5	-5194.3	-250722.1	177173042.1	-89390.5
wind	-29859.4	101222.6	-308.9	15324.2	2917.1	14862.3	-3.6	-1162.7	-89390.5	523.7

Mahanalobis Inverse Covariance Matrix =

	abd_rr	act_rr	aspect	cities	elines	roads	slope	streams	trails	wind
abd_rr	1.00E-08	0.00E+00	-3.10E-07	-8.00E-08	-1.00E-08	6.00E-08	2.24E-06	1.00E-08	0.00E+00	5.50E-07
act_rr	0.00E+00	1.00E-08	3.70E-07	-3.00E-08	-2.00E-08	6.00E-08	5.36E-06	9.00E-08	0.00E+00	-1.84E-06
aspect	-3.10E-07	3.70E-07	2.01E-04	7.13E-06	-2.80E-07	-2.98E-06	8.27E-04	1.36E-05	1.70E-07	-2.68E-05
cities	-8.00E-08	-3.00E-08	7.13E-06	2.65E-06	3.00E-07	-1.73E-06	-3.17E-05	1.11E-06	3.00E-08	-1.71E-05
elines	-1.00E-08	-2.00E-08	-2.80E-07	3.00E-07	1.00E-07	-3.60E-07	-1.83E-05	-7.00E-08	0.00E+00	4.30E-06
roads	6.00E-08	6.00E-08	-2.98E-06	-1.73E-06	-3.60E-07	2.63E-06	9.73E-05	-1.15E-06	-6.00E-08	-4.45E-05
slope	2.24E-06	5.36E-06	8.27E-04	-3.17E-05	-1.83E-05	9.73E-05	2.23E-02	-6.63E-05	-5.80E-07	-2.25E-03
streams	1.00E-08	9.00E-08	1.36E-05	1.11E-06	-7.00E-08	-1.15E-06	-6.63E-05	3.84E-05	1.90E-07	1.09E-04
trails	0.00E+00	0.00E+00	1.70E-07	3.00E-08	0.00E+00	-6.00E-08	-5.80E-07	1.90E-07	1.00E-08	2.48E-06
wind	5.50E-07	-1.84E-06	-2.68E-05	-1.71E-05	4.30E-06	-4.45E-05	-2.25E-03	1.09E-04	2.48E-06	4.67E-03

Check Multiplication =

	abd_rr	act_rr	aspect	cities	elines	roads	slope	streams	trails	wind
abd_rr	1	0	0	0	0	0	0	0	0	0
act_rr	0	1	0	0	0	0	0	0	0	0
aspect	0	0	1	0	0	0	0	0	0	0
cities	0	0	0	1	0	0	0	0	0	0
elines	0	0	0	0	1	0	0	0	0	0
roads	0	0	0	0	0	1	0	0	0	0
slope	0	0	0	0	0	0	1	0	0	0
streams	0	0	0	0	0	0	0	1	0	0
trails	0	0	0	0	0	0	0	0	1	0
wind	0	0	0	0	0	0	0	0	0	1

Correlation Matrix (coefficients > 0.70 or < -0.70 are shown in bold) =

	abd_rr	act_rr	aspect	cities	elines	roads	slope	streams	trails	wind
abd_rr	1.0000	0.5105	0.3084	0.1746	0.5840	-0.0250	-0.2661	-0.1827	-0.1667	-0.0525
act_rr	0.5105	1.0000	-0.0010	-0.0097	**0.7634**	0.0091	-0.1826	-0.2204	-0.3054	0.1898
aspect	0.3084	-0.0010	1.0000	-0.1737	0.2082	0.1039	-0.4638	-0.1335	0.0671	-0.1437
cities	0.1746	-0.0097	-0.1737	1.0000	-0.1489	0.5344	-0.1121	-0.2133	-0.1489	0.5638
elines	0.5840	**0.7634**	0.2082	-0.1489	1.0000	0.2151	-0.1464	-0.1191	-0.0784	0.0157
roads	-0.0250	0.0091	0.1039	0.5344	0.2151	1.0000	-0.2896	-0.1571	0.1963	0.4980
slope	-0.2661	-0.1826	-0.4638	-0.1121	-0.1464	-0.2896	1.0000	0.2000	-0.0439	-0.0176
streams	-0.1827	-0.2204	-0.1335	-0.2133	-0.1191	-0.1571	0.2000	1.0000	-0.1017	-0.2744
trails	-0.1667	-0.3054	0.0671	-0.1489	-0.0784	0.1963	-0.0439	-0.1017	1.0000	-0.2935
wind	-0.0525	0.1898	-0.1437	0.5638	0.0157	0.4980	-0.0176	-0.2744	-0.2935	1.0000

Appendix 11. Test auc values of maxent and mahalanobis distance models used in hwa infestation susceptibility analyses.

MAXENT

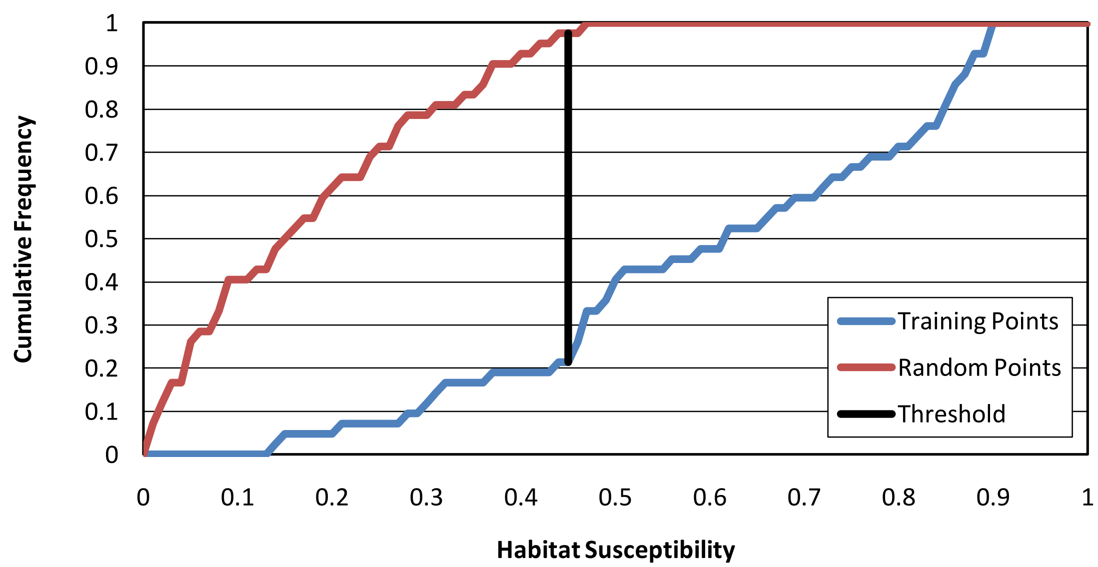
Model Run	Test AUC
1	0.842
2	0.807
3	0.867
4	0.915
5	0.846
6	0.843
7	0.824
8	0.867
9	0.818
10	0.863
Mean (± 1 SD)	0.849 (± 0.031)

MAHALANOBIS DISTANCE

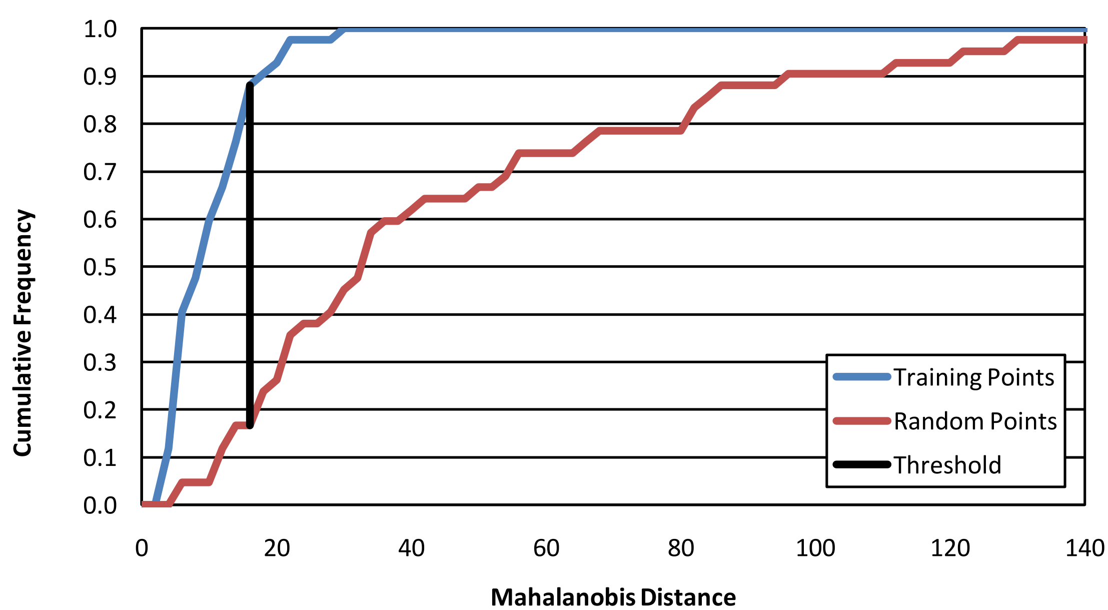
Model Run	Test AUC
1	0.767
2	0.724
3	0.729
4	0.855
5	0.823
6	0.754
7	0.823
8	0.782
9	0.768
10	0.788
Mean (± 1 SD)	0.781 (± 0.042)

Appendix 12. Threshold used to classify continuous logistic maxent and mahalanobis distance model values into areas of high or low susceptibility. The maximum cumulative frequencies difference method was estimated using hwa training points and an equal number of random locations.

MAXENT



MAHALANOBIS DISTANCE



Appendix 13. Results from the one-tailed binomial tests of significance of model sensitivity. Calculations were performed using ibm spss statistics 18 (spss inc., chicago, il, u.s.). The test was generated for maxent and mahalanobis distance models.

<u>MAXENT</u>

NPar Tests

Notes

Output Created		10-Feb-2010 17:19:31
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each test are based on all cases with valid data for the variable(s) used in that test.
Syntax		NPAR TESTS /BINOMIAL (0.115)=MaxEnt /STATISTICS DESCRIPTIVES QUARTILES /MISSING ANALYSIS.
Resources	Processor Time	00:00:00.040
	Elapsed Time	00:00:00.041
	Number of Cases Allowed[a]	196608

a. Based on availability of workspace memory.

[DataSet0]

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
MaxEnt	20	.70	.470	0	1

Descriptive Statistics

	Percentiles		
	25th	50th (Median)	75th
MaxEnt	.00	1.00	1.00

Binomial Test

		Category	N	Observed Prop.	Test Prop.	Exact Sig. (1-tailed)
MaxEnt	Group 1	1	14	.700000	.115000	1.3890479718E-9
	Group 2	0	6	.300000		
	Total		20	1.000000		

MAHALANOBIS DISTANCE

NPar Tests

Notes

Output Created		10-Feb-2010 17:01:02
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each test are based on all cases with valid data for the variable(s) used in that test.
Syntax		NPAR TESTS /BINOMIAL (0.230)=Mahalanobis /STATISTICS DESCRIPTIVES QUARTILES /MISSING ANALYSIS.
Resources	Processor Time	00:00:00.040
	Elapsed Time	00:00:00.041
	Number of Cases Allowed[a]	196608

a. Based on availability of workspace memory.

[DataSet0]

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Mahalanobis	20	.85	.366	0	1

Descriptive Statistics

	Percentiles		
	25th	50th (Median)	75th
Mahalanobis	1.00	1.00	1.00

Binomial Test

		Category	N	Observed Prop.	Test Prop.	Exact Sig. (1-tailed)
Mahalanobis	Group 1	1	17	.850000	.230000	7.7180352968E-9
	Group 2	0	3	.150000		
	Total		20	1.000000		

Appendix 14. Error matrix used in calculation of kappa statistic in comparison of HWA MaxEnt and Mahalanobis distance models.

MD Predictions	MaxEnt Predictions: Hemlock	MaxEnt Predictions: Non-hemlock	Total
Hemlock	239,431	543,578	783,009
Non-hemlock	153,744	2,467,725	2,621,469
Total	393,175	3,011,303	3,404,478

Kappa = 0.299
Overall Agreement = 79.5%

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Current Position

Research Assistant, Department of Entomology, University of Kentucky. Aug 2007 – Sep 2009.

Advisors: Dr. Songlin Fei and Dr. Lynne Rieske-Kinney

Thesis: Distribution of eastern hemlock resources in eastern Kentucky and the susceptibility to invasion by the hemlock woolly adelgid

Objective: Mapping eastern hemlock using remote sensing classifications and analyzing the invasion of hemlock woolly adelgid using species distribution models

Education

B.S., Biology, University of Central Arkansas, 2006.

Awards, Fellowships, Grants

Karri Casner Environmental Sciences Fellowship. Tracy Farmer Center for the Environment. $1,000 research support, February 2008.

Student Support Funding. UK Graduate School. $400 travel support. March 2008.

Publications

Clark, J.T., M. French, R. McNertney, M. Pulliam, and S. Fei. 2008. An invasive species trail map of the University of Kentucky campus. University of Kentucky College of Agriculture, Lexington, KY.

Clark, J.T., S. Fei, and L.K. Rieske-Kinney. *In prep*. Comparison of classification techniques in eastern hemlock mapping.

Clark, J.T., S. Fei, and L.K. Rieske-Kinney. *In prep*. Predicting eastern hemlock susceptibility to infestations by the hemlock woolly adelgid using species distribution models.

Conference Presentations

Clark, J.T., N. Kong, S. Fei, L.K. Rieske-Kinney, and J. Obrycki. Mapping eastern hemlock in Bell County, Kentucky using remote sensing and GIS. 6th Southern Forestry and Natural Resources GIS Conference. 24-26 March 2008, Orlando, FL.

Clark, J.T., M. French, R. McNertney, M. Pulliam, M. Shouse, and S. Fei. University of Kentucky Invasive Species Trail. 6th Southern Forestry and Natural Resources GIS Conference. 24-26 March 2008, Orlando, FL.

Clark, J.T. and S. Fei. The invasive species trail: A map of invasive plants on the campus of the University of Kentucky. Invited Presentation for the 2007-2008 Service-Learning Showcase of the University of Kentucky's J. W. Stuckert Career Center. 18 April 2008, Lexington, KY.

Clark, J.T. and S. Fei. Mapping eastern hemlock and hemlock woolly adelgid in southeastern Kentucky. 2008 KY GIS Conference. 7-9 July 2008, Lexington, KY.

Clark, J.T., S. Fei, L.K. Rieske-Kinney, N. Kong, and J. Obrycki. Mapping eastern hemlock and modeling hemlock woolly adelgid invasion in eastern Kentucky. Association of American Geographers 2009 Annual Meeting. 22-27 March 2009, Las Vegas, NV.

Professional Development

Service

Session Moderator: Species Composition and Distribution, 6th Southern Forestry and Natural Resources GIS Conference. 24-26 March 2008, Orlando, FL.

Invasive Species Management: Participated in work days for hemlock woolly adelgid suppression (November 2007, March 2008) and bush honeysuckle removal (Oct. 2007).

Skills

GIS: ArcView Desktop, ArcInfo Workstation, Erdas Imagine

GPS: Trimble GeoXM, Trimble GeoXH, Trimble Ranger, ArcPad, Pathfinder Office

Statistical Software: JMP, SPSS, ASTSA, S-GeMS

Membership and Professional Meetings

Association of American Geographers (AAG). Oct 2008 – Present

Associate of American Geographers 2009 Annual Meeting, 22-27 March 2009, Las Vegas, NV.

2008 Kentucky GIS Conference. 7-9 July 2008, Lexington, KY.

6th Southern Forestry and Natural Resources GIS Conference. 24-26 March 2008, Orlando, FL.

2007 Kentucky GIS Conference. 30 Jul – 1 Aug 2007, Louisville, KY.