

Saguaro National Park Exotic Plant Early Detection Predictive Modeling



Cirsium vulgare (bull thistle). Source: <http://www.golatofski.de/Pflanzenreich/gattung/c/cirsium.htm>.

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Abstract

As a first step in the development of the Sonoran Desert Inventory & Monitoring Network's (SODN) exotic plant early detection monitoring protocol, comprehensive surveys are being undertaken. An initial survey also provides the foundation for the development of status and trends monitoring for existing species. However, it is infeasible to perform comprehensive baseline surveys on larger SODN parks (>2,000 ha) due to financial and time constraints. In these larger park units, probability-based sampling is being used to establish the baseline exotic plant condition maps.

To guide the probability-based field sampling for exotic plants at the two units of Saguaro National Park, simple GIS-based index models of suitable habitat for the target species were built using knowledge of their observed relationship with environmental variables. To generate a map of overall suitability for target species within the park, all 20 final species models were summed. This overall suitability map served as the inclusion probability surface for a random sample drawn using the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm. This sample will be used to perform field surveys of target exotic plant species. This randomly drawn sample will allow inference to be drawn to the entirety of both park units.

Acknowledgements

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Introduction

Non-indigenous invasive species are a major threat to native species diversity and ecosystem function, causing economic impacts within the U.S. estimated at more than \$100 billion annually (Pimentel et al. 2000). In addition to competing with and displacing native species, these introduced species can hybridize with natives and alter conditions to promote the establishment and spread of other non-native species. Invasive species have been called the “single most formidable threat of natural disaster of the 21st century” (Schnase et al. 2002).

“Exotic species” are those species that occupy or could occupy park lands directly or indirectly as the result of deliberate or accidental human activities (USDI 2001). Exotic species are also commonly referred to as non-native, alien, or invasive species. Because an exotic species did not evolve in concert with the species native to the place, the exotic species is not a natural component of the natural ecosystem at that place. According to NPS Management Policies (2001), “(e)xotic species will not be allowed to displace native species if displacement can be prevented.” In addition, these policies state that “high priority will be given to managing exotic species that have, or potentially could have, a substantial impact on park resources, and that can reasonably be expected to be successfully controllable.”

Sonoran Desert Network Exotic Plant Monitoring

The Sonoran Desert Network intends to monitor exotic plant species on SODN park lands in two ways: 1) **early detection** of newly invading species, and 2) **status and trends** of established species. Careful identification and mapping of already established exotic plant populations is an important first step to initiating long-term exotic plant monitoring. An initial survey provides the foundation for the development of status and trends monitoring for existing species. Following comprehensive surveys, SODN Status and Trends monitoring of established species will be developed on a park-by-park basis, possibly specific to certain species, and likely following principles described in Elzinga et al. (1998), with the goal of monitoring spread or contraction of the existing populations. SODN Early Detection monitoring will require repeated surveys, likely targeted to regions of park units that are most vulnerable to species introductions (ie, near roads and trails), with the goal of identifying new invasions before they become established populations.

New exotic plants are continually arriving in the Sonoran Desert. Rough estimates suggest that upwards of 40,000 new plants could be introduced to the U.S. in the coming decades (National Research Council 2002), implying several hundred new invasions could occur within SODN park lands. However, typically less than 10%, of species introduced to a new environment become invasive (Williamson 1996). No systematic tools yet exist for assessing invasive potential of introduced species, and this determination is beyond the abilities of SODN staff. Instead, the Sonoran Desert Network has chosen to use the Arizona Wildland Invasive Plant Working Group's list of exotic species to monitor for early detection and status and trends. Currently, no mechanism exists to add species to this list, but the importance of remaining vigilant is understood and a mechanism may be developed in the coming years. SODN will also work with others around the states of Arizona and New Mexico to keep apprised of newly introduced invasive plants.

To establish a baseline of exotic invasive plant distributions, smaller SODN parks (less than 2,000 ha) are being completely surveyed, resulting in comprehensive maps of the spatial distribution and abundance of exotic plants in the park (Mau-Crimmins et al. 2004, Studd et al. 2006). However, it is infeasible to perform comprehensive baseline surveys on larger SODN parks (>2,000 ha) due to financial and time constraints. In these larger park units, probability-based sampling is being used to establish the baseline exotic plant condition maps. Probability-based sampling is appropriate when a complete survey cannot be undertaken because it allows statistical inference to the entire population (Stehman 1999). In this approach, sample locations are selected within the park unit(s) with a known probability that reflects factors such as physical characteristics. That is, rather than treating all parts of a park's landscape as possessing equal likelihood of hosting a particular species, areas believed to have a higher likelihood of hosting a target species are assigned a higher likelihood to be sampled. In this effort, likelihood of hosting target species (plant species on the AZ-WIPWG list) was modeled using index models within a geographic information system (GIS) environment based on environmental characteristics. The purpose of these models was to serve as the input for a random sample. It will be possible to extrapolate the data collected from this sample to the entire park through statistical inference. These data will provide insight into the spatial location, distribution, and abundance of target exotic plant species within Saguaro NP, and will serve as the basis for exotic plant status and trends monitoring.

Methods

Guisan and Zimmerman (2000) define species distribution models as “empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces.” Numerous methods exist for building predictive habitat distribution models, described well in Guisan and Zimmerman (2000) and Guisan and Thuiller (2005), including regression, ordination techniques, environmental envelopes, classification techniques, and neural networks. Many of these techniques require known locations of species presence (and ideally, absence as well), collected following a sampling strategy employing a random component. Using these point data, a statistical relationship is constructed between the point data and the environmental

variables. We did not have the luxury of randomly sampled species presence data available, nor could we collect such data to use as a model input. Instead, we built simple GIS-based index models of suitable habitat for the target species using knowledge of their observed relationship with environmental variables.

An index model is a raster-based model in which a ranked map results from summing scored and weighted input layers. The model is a simple linear function of the inputs and is commonly used in suitability analysis and vulnerability analysis (Davis 2001). The basic steps are to 1) score each input parameter; 2) multiply the scored parameter by a weight; and 3) sum the weighted scores (Chang 2000).

In this effort, separate models were built for each species. For each species, literature searches were undertaken to ascertain which environmental variables seem to exert control over the species' presence and the conditions under which it seems to grow most abundantly. The factors were then scored individually for each species. Environmental inputs and scores assigned for each species modeled appear in Appendix A. We did not apply weights to the environmental factors, as information regarding relative importance of various environmental factors was not available in the literature. A schematic diagram of the general steps followed appears in Figure 1. All data manipulation and modeling was performed within ArcGIS 9.0. A detailed description of the steps undertaken in ArcGIS 9.0 to accomplish the modeling appears in Appendix B.

Selection of Target Species

The subset of species on the AZ-WIPWG list known to exist in Saguaro NP was first chosen. Several species were then added by park staff, as many of the species known to occur within the park are lower-elevation species, and this is a function of emphasis on lower elevations (D. Foster and D. Backer, pers. comms. 2006). Table 1 summarizes the list of species targeted for this effort.

Abiotic Factor Justification and Scoring

Species-specific information was obtained from four primary sources: The Nature Conservancy's Element Stewardship Abstracts (<http://tncweeds.ucdavis.edu/esadocs.html>), the U.S. Forest Service's Fire Effects Information database (<http://www.fs.fed.us/database/feis/plants/index.html>), the Arizona Wildland Invasive Plant Working Group's Plant Assessment Forms (<http://www.usgs.nau.edu/SWEPIC/aspDB/species.asp>), and fact sheets prepared as a part of the Weeds in the West project (Halvorson and Guertin 2003). Table 1 shows which sources provided information for each of the species considered.

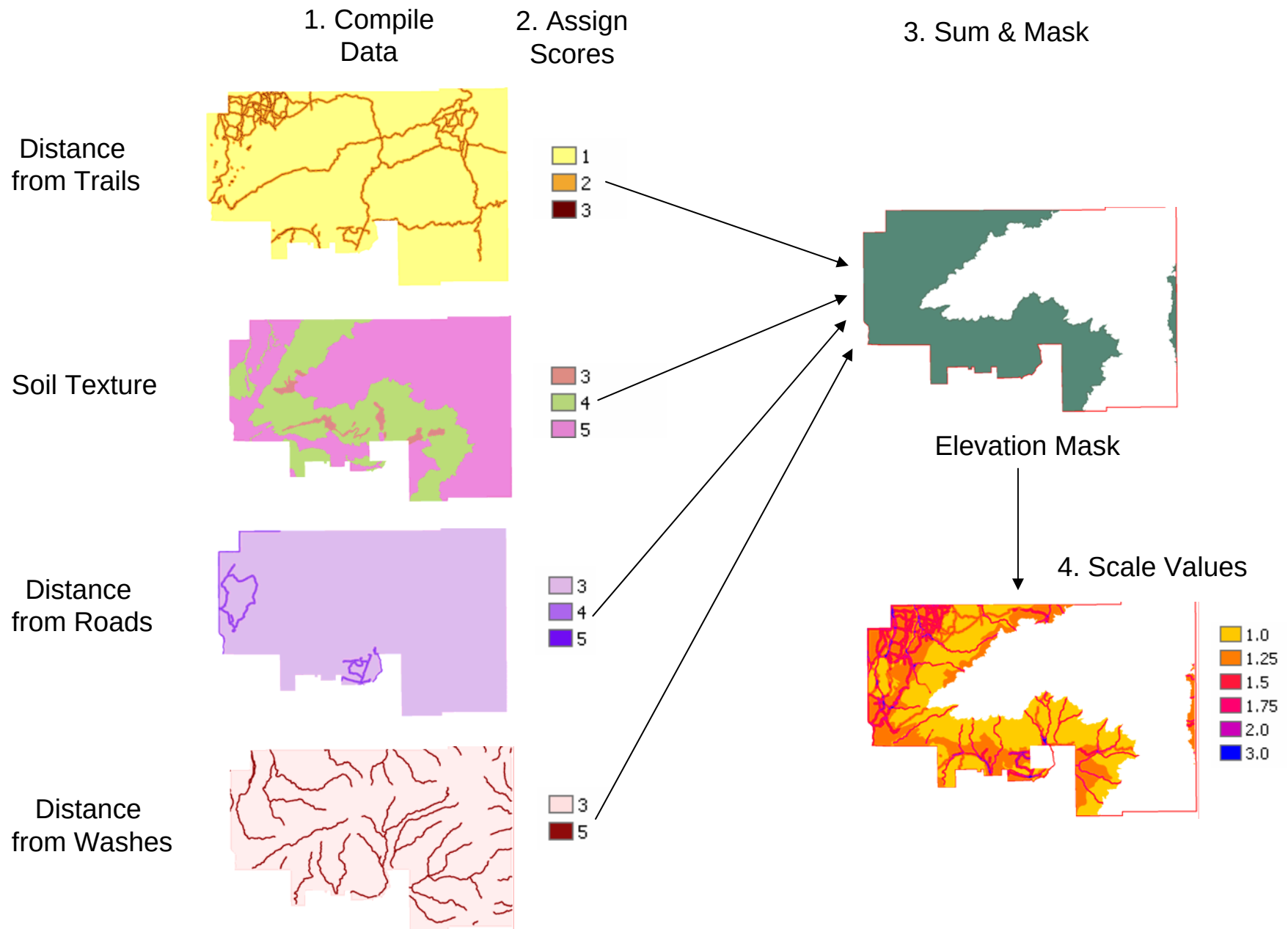


Figure 1. General steps followed for building index models of exotic plant suitable habitat in Saguaro National Park.

Table 1. Sources of information and models constructed for exotic plant species within Saguaro National Park.

	TNC ESA	USFS FEIS	AZ-WIPWG PAF	Weeds in West Fact Sheet	Model Created
<i>Avena fatua</i> L.	N	N	Y	Y	*
<i>Brassica tournefortii</i> Gouan	N	N	Y	Y	*
<i>Bromus rubens</i> L.	Y	N	Y	Y	*
<i>Bromus tectorum</i> L.	Y	Y	Y	Y	*
<i>Centaurea melitensis</i> L.	N	N	Y	Y	*
<i>Centaurea solstitialis</i> L.	Y	Y	Y	Y	*
<i>Chenopodium murale</i> L.	N	N	N	Y	--
<i>Cirsium arvense</i> (L.) Scop.	Y	Y	Y	N	--
<i>Cirsium vulgare</i> (Savi) Ten.	N	Y	Y	N	*
<i>Cynodon dactylon</i> (L.) Pers.	Y	Y	Y	Y	*
<i>Eragrostis curvula</i> (Schrud.) Nees	N	Y	Y	Y	nested within <i>E. lehmanniana</i>
<i>Eragrostis lehmanniana</i> Nees	N	Y	Y	Y	*
<i>Erodium cicutarium</i> (L.) L'Her. Ex Ait.	N	Y	Y	Y	*
<i>Euphorbia esula</i> L.	Y	Y	Y	N	--
<i>Hordeum murinum</i> L.	Y	N	N	Y	*
<i>Lamium amplexicaule</i> L.	N	N	N	N	--
<i>Marrubium vulgare</i> L.	N	N	N	Y	*
<i>Pennisetum ciliare</i> (L.) Link	Y	N	Y	Y	*
<i>Pennisetum setaceum</i> (Forssk.) Chiov.	N	N	Y	Y	*
<i>Poa pratensis</i> L.	Y	Y	N	N	--
<i>Rhus lancea</i> L. f.	N	N	N	N	--
<i>Rumex acetosella</i> L.	N	Y	N	N	--
<i>Rumex crispus</i> L.	N	N	N	Y	--
<i>Salsola tragus</i> L.	Y	Y	Y	Y	*
<i>Schismus arabicus</i> Nees	N	N	Y	Y	*
<i>Schismus barbatus</i> (Loefl. ex L.) Thellung	N	N	Y	Y	nested within <i>S. arabicus</i>
<i>Sonchus asper</i> (L.) Hill	N	N	Y	Y	nested within <i>S. oleraceus</i>
<i>Sonchus oleraceus</i> L.	N	N	Y	Y	*
<i>Sorghum halepense</i> (L.) Pers.	Y	Y	Y	Y	*
<i>Tamarix aphylla</i> (L.) Karst.	Y	Y	Y	Y	*
<i>Tamarix chinensis</i> Lour.	Y	Y	Y	Y	nested within <i>T. aphylla</i>
<i>Tamarix parviflora</i> DC.	Y	Y	Y	Y	nested within <i>T. aphylla</i>

<i>Tamarix ramosissima</i> Ledeb.	Y	Y	Y	Y	nested within <i>T. aphylla</i>
<i>Taraxacum officinale</i> G.H. Webers ex Wiggers	N	Y	N	N	*

Environmental variables included within the models were constrained to existing GIS layers. These were then narrowed down to layers which seemed to be representative of the information available in the literature. Environmental layers included and specific modifications made to them are described below.

Elevation

The 10 meter digital elevation model (DEM) clipped to the Saguaro National Park boundary was used for this effort. Typically, elevations above or below a specific value were masked out. These values were ascertained through the literature.

Soil

The existing soil map (located on the SODN server) was generalized based on the “texture” field. The 28 texture complexes were reduced to six texture classes based on the dominant texture:

- Loam
- Loam/clay loam
- Loam/sandy loam
- Loamy sand
- Sandy loam
- Sandy loam/clay loam

This generalized polygon layer was then converted to a raster layer with the same extent and resolution (10m pixels) as the DEM.

Distance from Roads, Trails, or Disturbed Areas

Road and trail corridors are prime habitat for many exotic plant species and are frequently host to greater densities of these species (Tyser and Worley 1992, McIntyre and Lavorel 1994, Gelbard and Belnap 2003, Gelbard and Harrison 2003, Larson 2003). Seeds are often introduced to these areas through vehicle and foot traffic as well as by animals. These corridors provide favorable habitat for opportunistic exotic species by providing increased light and soil moisture (Wester and Jurvik 1983, Parendes and Jones 2000, Silveri et al. 2001). In their analysis of distance from roads and the impacts on plant diversity, Gelbard and Harrison (2003) recognized three corridors around roads and trails: <10m, 10-100m, and >100m. These classes were adopted in this modeling effort.

Disturbed areas were obtained from Saguaro NP’s “disturbed lands” layers (D. Foster and D. Backer, pers. comms.). Polygons equal to or greater than 100m² in size and exhibiting

“medium” or “heavy” disturbance were extracted from the disturbed lands polygon layer. Lines with a designation of “old road”, “social trail”, or “trail in wash” were extracted from the disturbed lands lines layer. Where these lines overlapped with washes, trails, or roads, they were excluded.

The trails layers for the two park units were merged. Hope Camp was moved from the “roads” layer to the “trails” layer based on recommendation from park staff (D. Backer, pers. comm.).

Distance was calculated from roads, trails, and disturbed lands using the Euclidian Distance function in ArcGIS 9.0. Distance was also calculated from roads only, and from trails and disturbed lands only. Each of these layers was clipped to the park boundary. One of these layers was used in the species models, depending on the information known about the species.

Proximity to Drainages and Water Sources

Distance from the existing hydrography layer for the park was calculated using the Euclidian Distance function. This layer was clipped to the park boundary.

Fire

The most recent layer of fire boundaries was acquired from park staff (M. Daniels, pers. comm.). Fires within the past 20 years and equal to or greater than 20 acres in size were extracted. Where fire polygons overlapped, only the most recent fire was preserved. From this, time (in years) since fire was calculated. This shapefile was then converted to a raster layer with the same extent and resolution (10m pixels) as the DEM.

Scoring Schemes

Based on the information collected via literature searches, scores were assigned for the environmental factors listed above. If no information was available for a particular species and environmental factor combination, the layer was not used in the model. Environmental factor scores ranged from 0 - 5 for each layer, with 5 representing very high suitability for that factor for that species. A score of 1 represented low suitability, and a score of 0 meant the species could not occupy the conditions of that particular factor. All environmental factor scores and justification for their assignment appear in Appendix A.

Building Species-specific Models

Individual species models were built by summing the scored environmental factor grids for that species (Figure 1). High values represent the most suitable conditions for that species based on the model and low scores represent least suitable conditions. Areas not suitable did not receive a score.

Because model inputs varied by species, the range of final model scores differed across species. All final models were scaled to range from 1 to 3, with 1 representing low suitability and 3 representing high suitability for the species. Final suitability maps appear in Appendix C.

To generate a map of overall suitability for target species within the park, all 20 final species models were summed (Figure 2). This raster was scaled to range from 0 to 1 using 20 classes.

Testing Model Accuracy

A simple test of model accuracy was performed by overlaying existing points of target species observations over the species-specific models. These points were obtained from Saguaro NP and represent all recorded observations for the target species. Formal tests of model performance were not invoked because these points were not collected using any type of randomization, rather, they were observational data collected by Saguaro NP staff over several years. Because only occurrence points are available, only errors of omission could be evaluated – that is, if a location is known to host a target species and the model failed to predict it, an error of omission has occurred. Errors of commission could be evaluated, which occur when an area is predicted to host the species but the species is not found in that location. However, it is likely more desirable to be conservative when building models of suitable habitat for exotic species and to identify all possible habitat for the species than to overlook large portions of a park which may actually be affected by the species. It is important to note that this test is not a strong measure of model accuracy because the majority of points may fall within areas of the park most easily accessible by park staff, not areas of highest density of the species. Therefore, this test may show low agreement between known species observations and high modeled suitability, but this may not reflect reality.

Drawing a Random Sample

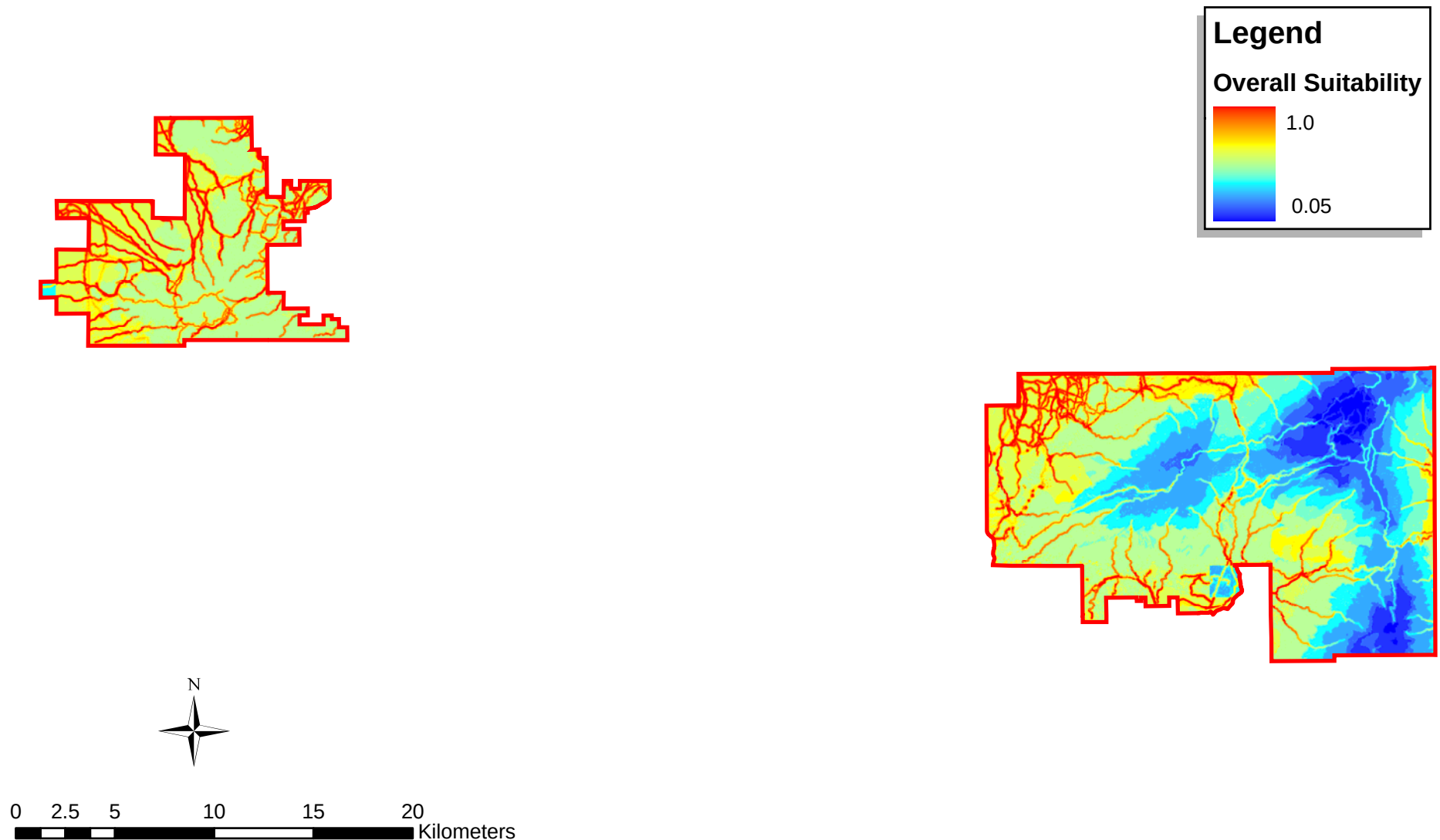
Using the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. 2005), a spatially-balanced random sample was drawn using the final map of overall suitability for target species within the park as the inclusion probability. Details on how to apply the RRQRR tool within the ArcGIS environment to draw a spatially-balanced random sample can be found in Appendix D.

Results and Discussion

The results of the model accuracy tests appear in Table 2. For many species, the majority of the known occurrence points fall within the medium suitability class. At a first glance, this appears to suggest that the models do not well capture the conditions under which these species have been observed. However, this may also be a function of where the observations have been collected. Nearly all of the observance points fall within low elevations (below 3,500'). Under these conditions, low-elevation species are more likely to appear to have better model performance than upper-elevation species. One important



Figure 2. Overall habitat suitability for 20 exotic plant species.



point to note is that for most species, very few or none of the verification points fell within regions predicted not to host the species. The exceptions are *Erodium cicutarium*, *Schismus* spp., and *Sorghum halepense*. These results are understandable for *Schismus* spp., where only one of two points fell outside of the predicted suitable habitat. However, these results suggest that the models constructed for *Erodium cicutarium* and *Sorghum halepense* may not be capturing the conditions under which these species thrive well. It may be worth revising these models as more information becomes available.

Table 2. Results of model accuracy tests for species distribution models of exotic plants at Saguaro National Park.

Species Model	Points within high suitability (2 – 3)	Points within medium suitability (1 – 2)	Points within low suitability (0.1 – 1)	Points not predicted by model (0)
<i>Avena fatua</i>	20 (24%)	53 (65%)	9 (11%)	0 (0%)
<i>Brassica tournefortii</i>	2 (3%)	74 (97%)	0 (0%)	0 (0%)
<i>Bromus rubens</i>	225 (57%)	70 (18%)	102 (26%)	0 (0%)
<i>Bromus tectorum</i>	No verification points available			
<i>Centaurea melitensis</i>	79 (20%)	315 (79%)	0 (0%)	5 (1%)
<i>Centaurea solstitialis</i>	No verification points available			
<i>Cirsium vulgare</i>	No verification points available			
<i>Cynodon dactylon</i>	1 (1%)	47 (46%)	54 (53%)	0 (0%)
<i>Eragrostis</i> spp.	369 (20%)	1,314 (70%)	180 (9%)	8 (1%)
<i>Erodium cicutarium</i>	2 (4%)	17 (34%)	15 (30%)	16 (32%)
<i>Marrubium vulgare</i>	0 (0%)	1 (50%)	1 (50%)	0 (0%)
<i>Pennisetum ciliare</i>	913 (41%)	1,136 (52%)	153 (7%)	0 (0%)
<i>Pennisetum setaceum</i>	263 (24%)	842 (76%)	6 (1%)	0 (0%)
<i>Schismus</i> spp.	0 (0%)	0 (0%)	1 (50%)	1 (50%)
<i>Sonchus</i> spp.	3 (14%)	11 (50%)	8 (36%)	0 (0%)
<i>Sorghum halepense</i>	0 (0%)	0 (0%)	1 (25%)	3 (75%)
<i>Tamarix</i> spp.	1 (3%)	0 (0%)	36 (97%)	0 (0%)

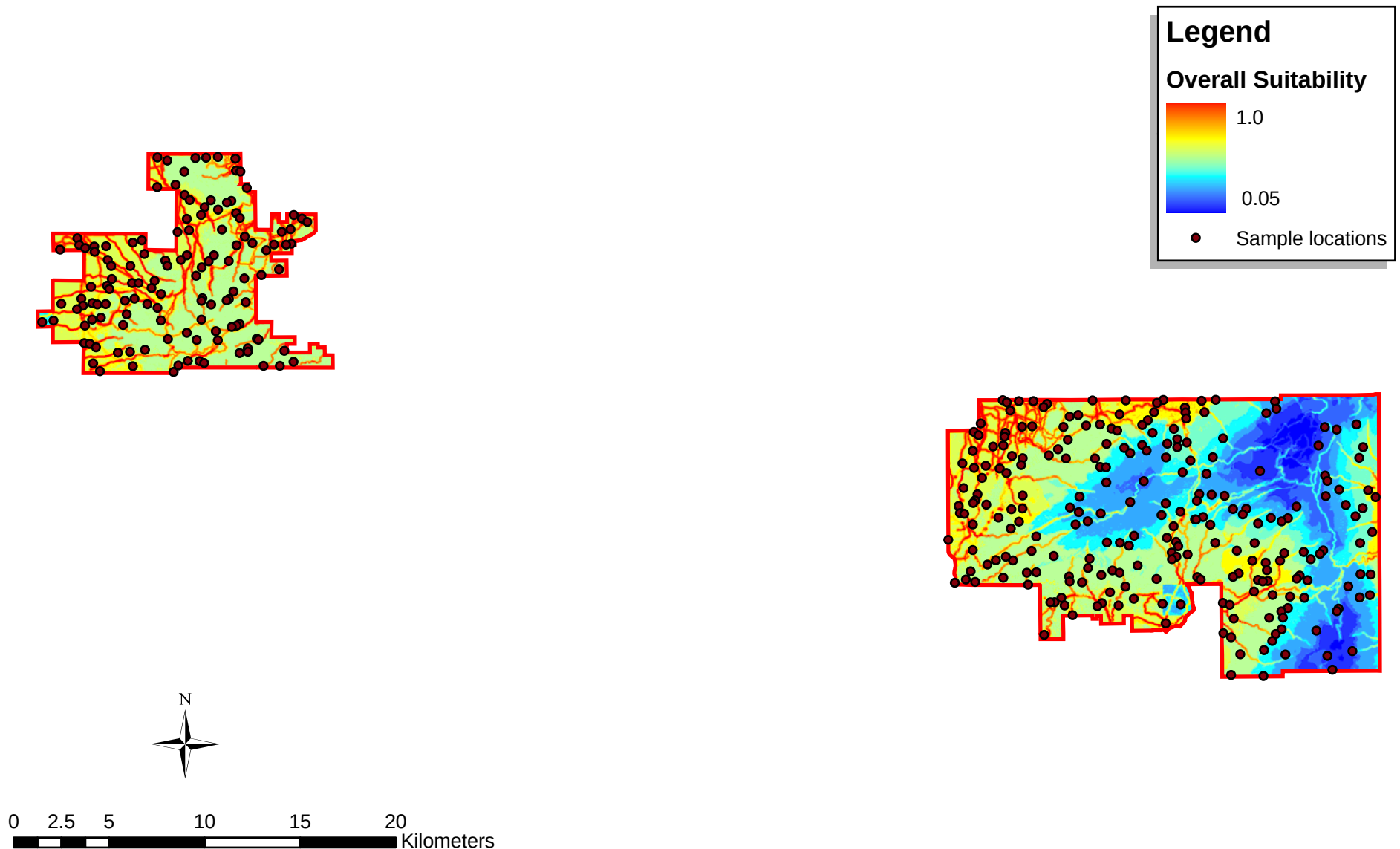
Spatially-balanced Random Sample

The resulting sample drawn using the RRQRR tool, with 373 sample points, is shown in Figure 3. This approach resulted in a spatially-balanced sample with higher suitability areas having a higher probability of being selected for sampling than low suitability areas. A spatially-balanced sample is desirable because natural resource data are commonly spatially autocorrelated (Stevens and Olsen 2004).

This sample could be used for field data collection to develop a map of exotic plant location, distribution, and abundance within Saguaro NP. Alternatively, a different random sample could be drawn for the same purpose. For example, it may make sense to partition the park and run the RRQRR algorithm on each park unit independently, or to draw samples for different portions of each park unit separately, depending on logistics.



Figure 3. Spatially-balanced random sample of suitable habitat for exotic plant species.



Details on how to apply the RRQRR tool within the ArcGIS environment to draw a spatially-balanced random sample can be found in Appendix D.

Comments on Species Models

For several of the target species, efficacy of model construction was reduced because input layers were limited and did not match up well with information that was available in the literature. For example, soils information available in the literature often mentioned nutrient information or soil depth. Neither of these characteristics were included in the soils GIS coverage currently available for Saguaro NP, so this information couldn't be included in the model. It will be possible to refine species-specific models as GIS coverage information is expanded. An alternative to refining these index-based models would be to build statistical models (see Guisan and Zimmerman 2000 for more information). One such model was constructed for *Pennisetum ciliare* within Saguaro NP (Ward 2003). Though this approach is much more time- and labor-intensive, the models generally are much more insightful.

Next Steps

The purpose of developing the species habitat models was to generate the inclusion probability surface for drawing a random sample. The intention is that plots located at the sample points drawn will now be surveyed for target species. Because the sampling method invoked is a probability-based design, inference to the entire park will be possible based on the data collected at these plots. The inference drawn to the entire park regarding exotic plant location, distribution, and abundance, will then serve as the basis for exotic plant status and trends monitoring.

Conclusions and Recommendations

Field Sampling Based on Sample

All raster files used in this analysis were 10m². The sampling points selected represent the centers of the pixels selected. An appropriate sampling approach would be to search the entire pixel for any of the target species. Polygon files representing the boundaries of each sample pixel could be generated and then loaded into the Pocket PCs. Each sample pixel/polygon could be considered a plot. Field technicians would visit each plot in the order given by the RRQRR algorithm (using the PointID field) and then search the plot in its entirety. Any observations of the target species within the plot would be mapped, ideally following standards already in place for exotic plant mapping at small parks.

To increase efficiency in the field, plots would not need to be visited in the *exact* order specified by the RRQRR algorithm. Plots located in close proximity and likely to be included in the sample (say, plots numbered 22, 35, and 72 if a sample of 50 plots was desired) may all be visited in one field outing if a trip could be planned to easily include them all. Data from plot 72 may not actually be used in the final analysis, if 50 plots could be covered before plot 72 was reached, but the tradeoff should be considered: is it

more efficient to send the crew out to plot 72 later in the field if it is found to be necessary, or collect the data when they are out there, risking that it may not get used?

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Appendix A: Species Scoring Justifications

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Avena fatua

Included	Factor	Justification	Model Scores
Y	Elevation	Up to 2,515m (Parker 1972)	Mask out areas >2,515m
Y	Soil	Many types; typically found on clay/clay-loam soils (Uva et al. 1997); prefers moist soils (Sharma and Vanden Born 1978)	Clay/clay loam = 5 Loam = 4 Sandy loam = 3 Sandy loam/clay loam = 4
Y	Distance from roads/trails/disturbed areas	Found along roads (Stubbendieck et al. 1992)	0-10m = 5 10-100m = 4 >100m = 3
Y	Proximity to drainage/water source	At SAGU-East there appears to be a strong association with ephemeral washes, particularly sandy washes (D. Backer and D. Foster, pers. comm. 2006).	<50m = 5 >50m = 3

Brassica tournefortii

Included	Factor	Justification	Model Scores
	Elevation	Up to 1,500m; more common below 305m (Minnich and Sanders 2000)	No areas in SAGU <305m Mask out areas >1,500m
Y	Soil	Especially sandy soils (Felger 1990)	Sandy loam = 5 Loam/sandy loam = 4 Loamy sand = 4 Sandy loam/clay loam = 5 Loam = 3
Y	Proximity to drainage/water source	Common near water sources (pers. comm. D. Backer)	<50m = 5 >50m = 3
Y	Distance from roads	Common along roadsides (Epple 1995, California Exotic Pest Plants Council 2002); Well established in natural and disturbed habitats (Felger 1990, Minnich and Sanders 2000)	0-10 m = 5 10-100 m = 4 >100m = 3

N	Fire	No fires fit these criteria	<1 year = 5 1-5 years = 3 >5 years = 0
Y	Distance from trails and disturbed areas	due to tiny seeds, harder to move	0-10 m = 3 10-100 m = 2 >100 m = 1

Bromus rubens

Included	Factor	Justification	Model Scores
Y	Elevation	Below 1,524m (Munz and Keck 1959, Beatley 1966, Crampton 1974); observed up to 8,000 in Saguaro NP (D. Foster, pers. comm.)	Mask out all areas above 2,438m (8,000')
N	Soil	shallow dry/poor textured soil, clayey soil (Sampson et al. 1951, Wu and Jain 1978)	All soils treated same for SAGU; not included in model (no clays or sands)
N	Precipitation	10-25 cm (Hulbert 1955, Bartolome et al. 1980)	All SAGU >25 cm; not included in model
Y	Distance from roads	in deserts and chaparral hillsides, and various places where competition from established herbaceous plants is minimal: along roadsides, waste places, rangelands and cultivated fields (Munz and Keck 1959, Beatley 1966, Crampton 1974); Gelbard and Harrison (2003) used zones of <10m, 10-100m, >100m	0-10m = 5 10-100m = 4 >100m = 3
Y	Proximity to drainage/water source	in deserts and chaparral hillsides, and various places where competition from established herbaceous plants is minimal: waste places, rangelands and cultivated fields (Munz and Keck 1959, Beatley 1966, Crampton 1974); more dense in washes (D. Backer, pers. comm.)	0-50m = 5 >50m = 3

Y	Distance from trails and disturbed areas	grows in undisturbed sites only if bare soil and light is present (Newman 2001); seeds are windborne, carried by animals, etc.	0-10 m = 5 >10 m = 3
Y	Fire	Red brome-fuelled fires result in the loss of native perennial species in invaded areas, resulting in disturbed areas that are ideal for increased growth of red brome (Esque and Schwalbe, 2002)	0-20 yrs = 3 no fire = 0

Bromus tectorum

Included	Factor	Justification	Model Scores
Y	Elevation	To 7,400' (Bowers and McLaughlin 1987, Rondeau et al. 1996); has been found at elevations of 13,100 feet (4,000 m) and above in the United States (Hunter 1991); does not flourish in mature ponderosa pine, Douglas-fir, grand fir, or western redcedar forests of the Intermountain West (Pierson and Mack 1990a, Pierson and Mack 1990b)	Mask areas < 1,219m (4,000')
N	Soil	Will grow in almost any type of soil, but it does best on deep, loamy or coarse-textured soils (e.g. Doescher et al. 1986, Link et al. 1994, Young 2000).	--
Y	Distance from roads	Seeds are transported by vehicles (Carpenter and Murray 1999, Hulbert 1955 in Mosley et al. 1999, Mosley et al. 1999, Rutledge and McLendon 2002, Trainor and Bussan 2001).	0-10 m = 5 10-100 m = 4 >100 m = 3
N	Proximity to drainage/water source	No information available	--
Y	Distance from	Largest infestations found in	0-50 m = 5

	trails, disturbed areas	disturbed areas – overgrazed rangelands, abandoned fields, eroded areas, road verges, waste places (Carpenter and Murray ??); disturbance enhances invasion (Hull and Pechanec 1947, Sowder 1960, Evans and Young 1970, Schlatterer 1972, Evans and Young 1985, Bates et al. 1998, Miller et al. 1999, Rice and Randall 1999, Ogle and Reiners 2002); Disturbance not required for establishment (Goodrich and Gale 1999)	>50 m = 3
Y	Fire	Grows especially well on soils impacted by fire (Mosley et al. 1999)	0-20 yrs = 5

Centaurea melitensis

Included	Factor	Justification	Model Scores
Y	Elevation	Mainly below 1,219m occasionally up to 2,130m (California Dept of Food and Agriculture EncycloWeedia 2002, Parker 1972)	<1,219m = 5 1,219 – 2,130m = 3 Mask out areas >2,130m
Y	Distance from roads/trails and disturbed areas	Common along roadsides (D. Foster, pers. comm.)	0-10m = 5 10-100m = 4 >100m = 3
Y	Proximity to drainage/water source	Common in irrigation ditches (D. Foster, pers. comm.)	0-50m = 5 >50m = 3

Centaurea solstitialis

Included	Factor	Justification	Model Scores
Y	Elevation	To 6,000' (Bowers and McLaughlin 1987, Rondeau et al. 1996); most large infestations are found below 5,000 feet (1,500 m) (Maddox et al. 1985, DiTomaso 2001). Thrives in low elevations	Mask elevations >1,828m (6,000')

		(Callihan et al. 1982)	
N	Soil	relatively dry, fertile soils (DiTomaso and Gerlach 2000); generally associated with deep, well-drained soils; are more likely to dominate in deep silt loam and loam soils with few coarse fragments (Talbot 1987, Larson and Sheley 1994) but they can also establish on shallow, rocky soils (Maddox 1981, Maddox et al. 1985).	--
Y	Distance from roads, trails and disturbed areas	starthistle infestations are nearly always restricted to disturbed sites or open grasslands dominated by annuals; dispersal occurs by human, vehicles, animals, water, or soil movements (California Department of Food and Agriculture, EncycloWeedia 2002; Roché 1992).	0-50 m = 5 50-100 m = 3 >100 m = 1
N	Proximity to drainage/water source	No information available	--

Chenopodium murale

Not enough information to build a model

Included	Factor	Justification	Model Scores
	Elevation	3,400' (Bowers and McLaughlin 1987); 2,600-2,850' (Rondeau et al. 1996); 100-8,000' (Parker 1972)	
	Habitat	Common in waste places – washes, wet soils, disturbed areas, roadsides (Parker 1972, Felger 1990, Holm et al. 1997)	
	Soil	Moist soil; favors soil rich in N (Holm et al. 1997)	--

Cirsium arvense

Not enough information to build a model

Included	Factor	Justification	Model Scores
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	Elevation	To 8,600' (Bowers and McLaughlin 1987, Rondeau et al. 1996)	
	Aspect/Slope	Canada thistle grows best on shallow (9-30%) slopes (Meier and Weaver 1997, Allen and Hansen 1999)	
	Soil	grows on all but waterlogged, poorly aerated soils, including clay, clay loam, silt loam, sandy loam, sandy clay, sand dunes, gravel, limestone, and chalk, but not peat (Rogers 1928, Bakker 1960, Hodgson 1968, Moore 1975).	
	Temperature	Northern limit is 0F mean Jan temp (Moore 1975); Extended periods with temperatures over 90 degrees Fahrenheit (32 °C) reduce plant vigor and generally limit growth (Moore 1975, Morishita 1999)	
	Proximity to drainage/water source	Invades riparian areas in west	

Cirsium vulgare

Included	Factor	Justification	Model Scores
Y	Elevation	To 6,600' (Bowers and McLaughlin 1987, Rondeau et al. 1996)	Mask areas >2,011m (6,600')
N	Aspect	In shade, bull thistle is restricted to south-facing slopes. In dry habitats such as coastal dunes it is confined to north-facing slopes (Klinkhamer and DeJong 1993)	
N	Soil	is found on dry and wet soils, but is most common on soils with intermediate moisture (Randall 1990, Klinkhamer and DeJong 1993); less	--

		common in sand and on soils of >30% humus content, and almost absent from pure clay (Klinkhamer and DeJong 1993)	
N	Proximity to drainage/water source	No information available; terrestrial species	--
Y	Distance roads, trails, and disturbed areas	Most troublesome on recently/repeatedly disturbed areas; promoted by veg removal, soil disturbance (Randall 1990); can also colonize undisturbed grasslands, forest openings (Randall 2000); Disturbance is necessary for its establishment (de Jong and Klinkhamer 1988)	0-10m = 5 10-100m = 4 >100m = 3
Y	Fire	Invades area following fire (Gluesenkamp 2001),	0-5 yrs = 5 5-20 yrs = 3

Cynodon dactylon

Included	Factor	Justification	Model Scores
Y	Elevation	Elevations under 1,829m (Crampton 1974, Humphrey 1977, Burton and Hanna 1985)	Mask out all areas above 6,000' (1,829m)
Y	Soil	tolerates a wide range of soil types and conditions. Growth is greater on heavy clay soils than on light sandy soils in dry regions; this may be due to the greater water holding capacity of the clay (Burton and Hanna 1985)	Loam/clay loam = 5 Loam = 4 Loamy sand = 3 Sandy loam = 3
Y	Distance from roads	Observed more commonly along roadsides – spreads via rhizomes (pers. comm. D. Backer)	0-10m = 5 >10m = 0
Y	Proximity to drainage/water source	In southern Arizona, <i>C. dactylon</i> grows abundantly along sandy washes and near	0-50m = 5 >50m = 2

		alkaline seeps (Gould 1951); In areas of low rainfall it commonly grows along irrigation ditches and streambeds (Crampton 1974, Humphrey 1977, Burton and Hanna 1985).	
Y	Distance from trails and disturbed areas	Observed more commonly close to trails (pers. comm. D. Backer)	0-3 m = 3 >3 m = 1

Eragrostis lehmanniana* and *E. curvula

Included	Factor	Justification	Model Scores
Y	Elevation	1,000 to 1,460 m (Cox et al. 1987, Cox et al. 1988); as low as 670 m and as high as 1,700 m (D. Foster and D. Backer, pers. comms.)	Mask areas <670 m and >1,700 m
Y	Soil	Seedlings of <i>E. lehmanniana</i> generally do not emerge from seed planted on silt loam, loam, or clay loam soils regardless of planting depth (Cox et al. 1987); growing best on sites with sandy- to sandy loam-textured soils (Cox et al. 1987, Cox et al. 1988); <i>E. curvula</i> is best adapted to and most persistent on sandy and sandy loam soils (Atkins and Smith 1967, Cox et al. 1987, Dahl and Cotter 1984).	Sandy loam = 5 Loamy sand = 5 Loam = 4 Clay loam/clay = 3
Y	Distance from roads, trails, and disturbed areas		0-10 m = 5 10-100 m = 4 >100 m = 1
N	Proximity to drainage/water source	This species is an upland, terrestrial species	--
Y	Fire	Following fire, soil-stored seeds germinate when moisture conditions become favorable. Within a few months after fire seedling	<5 yrs = 5 >5 yrs = 4 no fire = 0

		establishment is typically abundant, resulting in replacement stands even after hot fires that kill mature plants. Fire promotes germination because (1) heat from the fire scarifies the hard seed coat and (2) removing the grass canopy results in greater soil temperature fluctuations and greater irradiance of red light, which increase germination (Sumrall et al. 1991, Roundy et al. 1992)	
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Erodium cicutarium

Included	Factor	Justification	Model Scores
Y	Elevation	below 2,134 m (Kearney et al. 1960)	Mask areas >2,134m
Y	Slope	Old-field specific	Mask areas >10% slope
N	Soil	grows in well-drained, clayey, loamy, or sandy soil (Biswell and Gilman 1961, Brotherson et al. 1987)	All soils treated same for SAGU; not included in model (no clays or sands)
Y	Distance from roads, trails, and disturbed areas	pioneer on disturbed sites (Wagner et al. 1978)	0-10 m = 5 >10 m = 3
Y	Proximity to drainage/water source	Observed closer to drainages and standing water in Saguaro NP (D. Backer, pers. comm.)	0-10 m = 5 >10 m = 3

Euphorbia esula

Not enough information to build a model

Included	Factor	Justification	Model Scores
	Elevation		
	Soil	Rich, damp soils to extremely nutrient-poor, dry soils; tends to grow most rapidly in coarse-textured soils (Selleck et al. 1962)	
	Distance from roads	No information available	

	Proximity to drainage/water source	No information available	
	Distance from trails and disturbed areas	This species can establish independent of any known natural or anthropogenic disturbance (Rabie 2002).	

Hordeum murinum

Included	Factor	Justification	Model Scores
Y	Elevation	In Saguaro NP, has been observed up to 4,500' (D. Backer, pers. comm.)	Mask areas >1,524m (5,000')
Y	Distance from roads	Common along roadsides (Davison 1971);	0-50 m = 5 >50 m = 2
Y	Proximity to drainage/water source	Common along wet and dry drainages in Saguaro NP (D. Backer, pers. comm.)	0-50 m = 5 >50 m = 2
Y	Distance from trails and disturbed areas	Often colonizes bare soils (Davison 1971)	<10 m = 3 10-100 m = 2 >100 m = 1

Lamium amplexicaule

No information available.

Marrubium vulgare

Included	Factor	Justification	Model Scores
Y	Elevation	To 8,000' (Bowers and McLaughlin 1987, Rondeau et al. 1996); it occurs from 100-8500 ft. in Arizona (Parker 1972)	Mask areas >2,590m (8,500')
N	Proximity to drainage/water source	particularly on dry upland soils (Muenscher 1980	--
Y	Distance from roads, trails, and disturbed areas	It is a common weed of old agricultural fields, waste places, roadsides, and ranges (Muenscher 1980, Parker 1972); establishes on infertile soils and is often the first	0-10m = 5 10-50m = 4 >50m = 2

		colonizer in eroded areas (Lippai et al. 1996); seeds spread via humans and vehicles, through recreation and agricultural machinery (Weiss et al. 2000)	
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Pennisetum ciliare

Included	Factor	Justification	Model Scores
	Elevation	To 4,640 (Saguaro NP); To 2,800' (Rondeau et al. 1996)	Mask areas > 1,524m (5,000')
	Soil	Clay soils less associated with Buffelgrass (Ward 2003) Coarse-textured soils required for establishment (Mutz and Scrifes, Cox et al. 1988, Hanselka 1988, Ibarra et al. 1995)	Loam/sandy loam = 5 Sandy loam/clay loam = 3 Sandy loam = 5 Loamy sand = 5 Loam = 5 Loam/clay loam = 3
	Distance from roads	In West district, distance from roads an important predicting factor, but areas far from roads also likely to host buffelgrass (Ward 2003)	0-10m = 5 10-100m = 4 >100m = 3
	Aspect	South- and south-west facing slopes associated with buffelgrass presence (Ward 2003)	S, SW slopes = 5 Rest = 3

Pennisetum setaceum

Included	Factor	Justification	Model Scores
Y	Elevation	Most common below 100m, can be found up to 610m (Lovich 2000), still expanding; has been observed up to 5,000' at Saguaro NP	Mask areas >1,524m (5,000')
Y	Soil	Prefers drier, sandy soils (Chambers and Hawkins 2002)	Sandy loam = 5 Sandy loam/clay loam = 5 Loamy sand = 4 Loam = 4 Loam/clay loam = 3
Y	Temperature	Cannot tolerate long periods	Mask out areas with

		of freezing temperatures (California Dept of Food and Agriculture EncycloWeedia 2002)	winter low temperature <0C
Y	Distance from roads	Common along roads (California Dept of Food and Agriculture EncycloWeedia 2002, Chambers and Hawkins 2002); not observed along trails in Saguaro NP (D. Backer, pers. comm.)	0-50 m = 5 50-100 m = 4 >100 m = 3
Y	Proximity to drainage/water source	Prefers riparian areas and washes (Chambers and Hawkins 2002; D. Backer, pers. comm.)	0-100 m = 5 >100 m = 3
N	Distance from trails or disturbed areas	Not observed near trails in Saguaro NP (pers. comm. D. Backer)	--

Poa pratense

Not enough information to build a model

Included	Factor	Justification	Model Scores
	Elevation	5,900-7,400' (Bowers and McLaughlin 1987, Rondeau et al. 1996)	
	Soil	high frequency on drier sites of Ontario old fields on shallow circumneutral soils overlying gravel (Maycock and Guzikowa 1983), low frequency on sandy soils in Wisconsin (Kline pers. comm.), and absence from sandy soils in Nebraska (Steuter pers. comm. in Sather 1996); grows on a wide variety of soils, but thrives on well-drained loams or clay loams rich in humus (USDA 1937). It also thrives on soils derived from limestone (USDA 1937, Smoliak et al. 1981, Hardy 1989).	
	Fire	burning may enhance seed germination of Kentucky	

		bluegrass	
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Rhus lancea

No information available.

Rumex acetosella

Not enough information to build a model

Included	Factor	Justification	Model Scores
	Elevation	7,300-8,400' (Bowers and McLaughlin 1987, Rondeau et al. 1996); Arizona 5,500-8,000 (FEIS)	
	Habitat	commonly found in old fields; generally found in open, unshaded areas on disturbed sites (Voss 1985, Great Plains Flora Association 1986, Welsh et al. 1987); Sheep sorrel invades disturbed sites and may move onto undisturbed sites when growing conditions are ideal (Schramm 1966, Agee 1988, Escarre et al. 1994, Lackschewitz 1991). It is commonly found on clearcut, burned, and flood-disturbed riparian sites (Agee 1988, Weaver et al. 1990, DeFerrari and Naiman 1994, Granstrom 1982).	
	Soil	Is adapted to a variety of soil types (Fitzsimmons and Burrill 1993, Great Plains Flora Association 1986, Wilson and Tilman 1991). Sheep sorrel is commonly found on sandy loam, fine sandy, silty, and gravelly soils (Biswell 1956, Blewett 1978, Del Tredici 1977, MacLean and Wein 1977, Zimmerman and Neuenschwander 1984).	

Rumex crispus**Not enough information to build a model**

Included	Factor	Justification	Model Scores
	Elevation	3,700-5,300' (Bowers and McLaughlin 1987, Rondeau et al. 1996); 100-8000 ft. (30-2440 m) (Parker 1972)	
	Habitat	In Arizona, it is a weed in permanent pastures, irrigation ditches, and in cultivated crops throughout the state (Parker 1972)	
	Soil	deep, moist soils (Parker 1972); found on most soils, including well and poorly drained, clay, loamy clay, fertile, and slightly acid soils (Holm et al. 1991); it is rarely found on acidic soils (Holm et al. 1991, Rutledge and McLendon 2002). It grows vigorously on moist soils, and grows best on nutrient-rich sandy and loam soils (Oregon State University, Weed Science Program 1998, Parker 1972).	

Salsola kali/tragus

Included	Factor	Justification	Model Scores
Y	Elevation	Below sea level to 2,134m in AZ (Kearney and Peebles 1960)	Mask areas >2,134 m
Y	Slope	Frequently observed in flat, open, disturbed areas (D. Backer, pers. comm.)	Mask areas >10% slope
N	Soil	Any type; prefers sandy to loamy soils that are well-drained (Stubbendieck et al. 1992, Wallace et al. 1968, Holm et al. 1997); does not prefer compacted soils (Holm et al. 1997, Rutledge and McLendon 2002); cannot	Does not seem to be as important in limiting its spread (D. Backer, pers. comm.)

		tolerate saturated soils (Young 1991)	
Y	Distance from roads	Observed along highways in Arizona (D. Backer, pers. comm.)	0-50 m = 5 50-100 m = 4 >100m = 3
Y	Proximity to drainage/water source	Common along waterways (Kearney and Peebles 1960); Can tolerate a wide range – along edge of water to dry, open spaces (Holm et al. 1997)	0-50m = 3 >50m = 0
Y	Distance from trails and disturbed areas	Does well on disturbed sites (Rutledge and McLendon 2002); Common along trails (Kearney and Peebles 1960)	0-10 m = 3 >10 m = 1

Schismus arabicus* and *S. barbatus

Included	Factor	Justification	Model Scores
Y	Elevation	<i>S. arabicus</i> : 305-1,220 m (Kearney and Peebles 1960, Parker 1972); <i>S. barbatus</i> : 30-1,220m (Esque and Schwalbe 2002, Kearney and Peebles 1960, Parker 1972)	Mask areas >1,220 m
N	Soils	occurs on sandy soils on flats, washes, and dunes (Kearney and Peebles 1960, Felger 1990)	No soils classified as “sand” in soils layer for Saguaro NP
N	Distance from roads, trails, and disturbed areas	Common along roads; common in disturbed and undisturbed areas (Chambers and Hawkins 2002); Abundant in disturbed soils (Brooks 2000)	
Y	Proximity to drainage/water source	Observed in drainages at Saguaro NP (D. Backer, pers. comm.)	0-50 m = 5 >50 m = 3

Sonchus asper* and *S. oleraceus

Included	Factor	Justification	Model Scores
Y	Elevation	46-2,438 m (Parker 1972)	Mask areas >2,438 m
N	Soil	Wide variety, preferring well-	--

		drained soils (Hutchinson et al. 1984)	
Y	Distance from roads, trails, and disturbed areas	Common on disturbed sites (Parker 1972, Hutchinson et al. 1984)	0-50 m = 3 >50 m = 1
Y	Proximity to drainage/water source	Riparian zone species (Felger 1990, Van Devender et al. 1997); common in washes at Saguaro NP (D. Backer, pers. comm.)	0-50 m = 3 >50 m = 1

Sorghum halepense

Included	Factor	Justification	Model Scores
Y	Elevation	Common below 6,000' (Kearney et al. 1960)	Mask areas >1,828m (6,000')
Y	Slope	Observed mainly in pits, agricultural fields (D. Backer, pers. comm.); Found in ditches, cultivated fields, wastelands (Gould 1951)	Mask areas >10% slope
N	Soil	Adapted to wide variety of soils; fertile porous soils support larger plants than poorly drained clay soils (Warwick and Black 1983); occurs on all soil textures (Hauser and Arle 1958) best growth on silty bottomlands (Allen 1990, Hauser and Arle 1958)	Not applicable to Saguaro NP
Y	Distance from roads, trails, disturbed areas	Common in ditches along roads, borrow pits near washes at Saguaro NP (D. Backer, pers. comm.); Thrives in disturbed soils (Newman 1993)	0-50 m = 3 >50 m = 1
Y	Proximity to drainage/water source	Found in ditches; flooded bottom lands esp susceptible (McWhorter 1981); extensive along canals (Holm et al. 1977); in arid sites such as Organ Pipe Cactus National Monument, Arizona, Johnson	0-50 m = 5 >50 m = 2

		grass establishes mostly in wet locations such as washes, drainages, and stream edges (Felger 1990, Stromberg and Chew 1997)	
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Tamarix aphylla, T. chinensis, T. parviflora, T. ramosissima

Included	Factor	Justification	Model Scores
Y	Elevation	Up to 2,100 m (Hoddenbach 1990)	Mask areas >2,100 m
N	Soil	Mostly on fine-textured soils (Everitt 1980)	--
Y	Proximity to drainage/water source	Facultative phreatophyte (Turner 1974); occurs in areas where roots can reach water table such as floodplains and along irrigation ditches; depth to groundwater 3-5m (Horton et al. 1960); common along irrigation ditches (Benson and Darrow 1981)	0-50 m = 5 >50 m = 2
N	Disturbance	Seems to require disturbance of native vegetation (Brotherson and Winkel 1986)	Difficult to assign scores for recent disturbance

Taraxicum officinale

Included	Factor	Justification	Model Scores
Y	Elevation	7,200-7,400' (Bowers and McLaughlin 1987, Rondeau et al. 1996); Common dandelion occurs on flat to rolling topography or moderate to steep slopes (Cole and Hall 1992, Dittberner and Olson 1983)	Mask areas >2,438m (8,000')
N	Soil	Occurs on soils that vary from thin layers above permafrost in the subarctic to deep loams in the western United States (Dittberner and Olson 1983, Stainforth and Scott 1991). Soil texture ranges from clays and clayey loams to sandy	--

		loams. Does poorly on dense clay soils, saline soils, and acidic soils (Dittberner and Olson 1983)	
Y	Distance from roads, trails, and disturbed areas	Most commonly occurs in disturbed areas such as cut-over or burned forests, avalanche areas, overgrazed ranges, and marshy floodplains (Holloway and Alexander 1990, Weaver et al. 1990); also occurs sites on highway and railroad rights-of-way, waste places, old fields, pastures, and lawns (Stainforth and Scott 1991, ARS 1991).	0-10m = 5 10-50m = 4 >50m = 2

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Appendix B: Index Modeling Details – ArcGIS 9.0

Appendix B: Index Modeling Details – ArcGIS 9.0

This document describes in detail how to build index models as described in the Saguaro National Park Exotic Plant Early Detection Predictive Modeling Report. These instructions are specific to ArcGIS 9.0. Please refer to the report text for information on how environmental layers were selected and for more information on index modeling.

Preparing input raster layers

NOTE: All raster layers used to construct models must be the same extent and resolution. The easiest way to accomplish this is to have one layer which reflects the extent and resolution you would like the models to follow (in this case, the 10m DEM). Then, as you create new grid layers, you can specify that they match up with this layer.

Creating a raster layer from a vector (polygon) layer

Typically, model input layers need to be created. Some input environmental factors are polygon layers which need to be converted to raster layers. This can be accomplished using the “Feature to Raster” command (Arc Toolbox → Conversion Tools → To Raster → Feature to Raster). Select the polygon layer of interest for “Input features”, select the field you wish to have the grid be classified with, and specify the output location for the grid. Finally, select the grid you determined above which reflects the extent and resolution of interest (ie, DEM) under “Output cell size (optional)”. This will ensure that your new layer will match up with it.

Calculating distance from a feature

If you wish to create zones of distance from a feature type (ie, trails, roads, or washes), use the “Euclidian Distance” command (Arc Toolbox → Spatial Analyst Tools → Distance → Euclidian Distance). Input the feature layer of interest (ie, trails layer) in the “Input raster or feature source data”, specify the new grid name and location in the “Output distance raster” window, then select the grid you determined above which reflects the extent and resolution of interest (ie, DEM) under “Output cell size (optional)”. This will ensure that your new layer will match up with it.

Reclassifying values

To change the values associated with classes in raster files, use the “Reclassify” command (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify). Select the values field you wish the grid to be classified on, then type new values into the “New values” column in the table.

This is the way scores were applied for each layer for each species model based on the scores specified in Appendix A. For example, for *Avena fatua*, the soils layer was reclassified and assigned the scores specified in the *A. fatua* table (Appendix A), the distance from roads/trails/disturbed areas layer was reclassified and assigned the scores

specified in the *A. fatua* table (Appendix A), and the proximity to washes layer was also reclassified and assigned the scores specified in the *A. fatua* table (Appendix A). These reclassified grids were stored in an *A. fatua* folder (V:\SAGU_exotics\Data\Spatial_Data\Processed_Data\SAGU_grids\avefat).

Generating model output

Once all input environmental grids were created and then scored for a particular species, the model was created. This simply involved summing the input grids. In the case of *A. fatua*, this meant summing the scored soils, distance from roads/trails/disturbed areas, and distance from washes grids. This was accomplished using the Raster Calculator (go to “Spatial Analyst” pull-down menu, select “Raster Calculator”. Construct the equation, ie:

avefat_soils + avefat_dist + avefat_hydro

and press “Evaluate”. This will create a temporary raster layer titled “Calculation”. If you wish to save this Calculation grid as a raster layer for reference in the future, right-click on the grid and select “Make Permanent”. Then specify a grid name and file location. You will have to add that grid layer into the view, it will not automatically load after this operation.

Masking out inappropriate areas

To mask out areas which should not be included in the final model output, such as certain elevations, create a masking layer and then “Extract by Mask”. To create a mask, such as “do not include elevations above 2,500m”, reclassify the DEM layer (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify). Select the “Classify” button and specify 2 classes. Modify the elevations in the “Old values” field to reflect the cut-off (xxx – 2,500 and 2,500 – xxx). Under “New values”, leave a “1” for <2,500m, then type NoData for values >2,500m. This will create a grid with the value of “1” only for regions within the park <2,500m.

To extract the model calculation output using this elevation mask, use the “Extract by Mask” tool (Arc Toolbox → Spatial Analyst Tools → Extraction → Extract by Mask). Select your model calculation grid for the “Input raster” and the elevation mask layer for the “Input raster or feature mask data”. Specify an output raster name and location.

Scaling model output values

Depending on the number of environmental grids used to create a species model and the range of scores assigned to the grids, model output will cover a range of values. In order to compare individual species models to each other, the output values must be scaled to the same range (ie, 1 to 3). This can be accomplished by determining the number of classes encompassed by the lowest and highest values in the range (ie, a range of 4 -11

has 7 classes). The range from 1 to 3 must then be split into 7 classes. To calculate what this interval is, create the following ratio:

$$\frac{7}{2} = \frac{1}{x}$$

where 7 is the number of classes in the range, 2 is the difference between 1 and 3, and x is the interval to be solved for. In this case, $x = 0.29$. Therefore, the range from 4 – 11 can be scaled to 1 – 3 in the following manner:

Old value	New value
4	1.0
5	1.29
6	1.58
7	1.87
8	2.16
9	2.45
10	2.74
11	3.0

Once these new values have been calculated, the grid can be reclassified to reflect them. However, an integer grid (which is likely what the model output is) cannot be reclassified to reflect decimals. Instead, the grid must be converted to a floating point grid (Arc Toolbox → Spatial Analyst Tools → Math → Float). Once this floating point grid has been created, you can reclassify it (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify) to reflect the scaled classes.

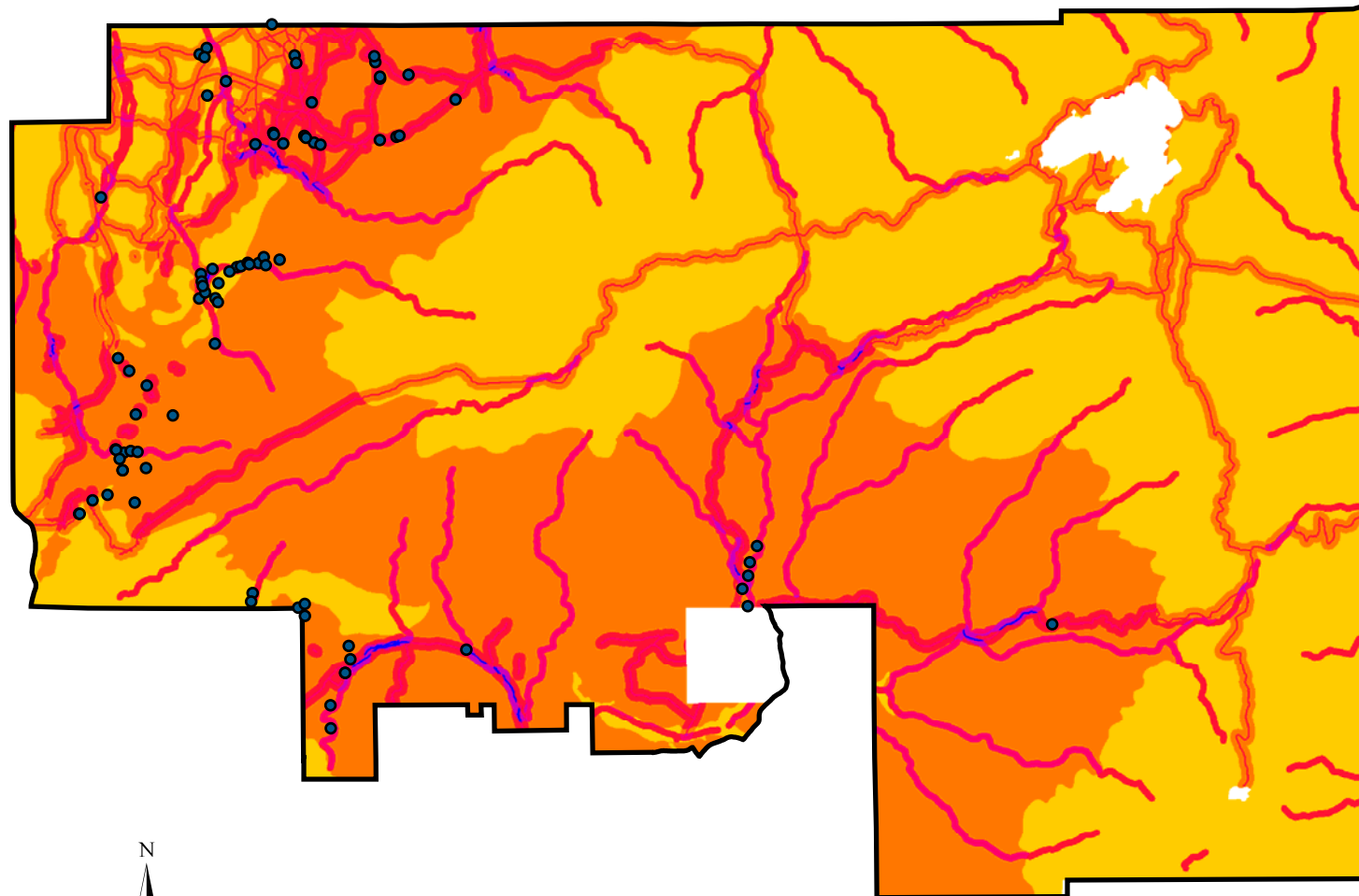
Summing multiple species model grids

Before species model grids can be summed to generate a composite map, areas which currently show “no data” (areas which were masked out) must be converted to “0”. This can be accomplished using the “Reclassify” command (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify). Once this has been done for all species models, they can be summed using the Raster Calculator (go to “Spatial Analyst” pull-down menu, select “Raster Calculator”. You may wish to scale the output of this resultant calculation using the directions above (ie, scale to 0.5 – 1, to use as input for the RRQRR tool).

Appendix C: Individual Species Predictive Models



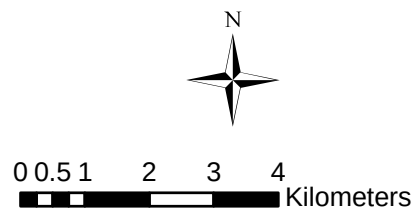
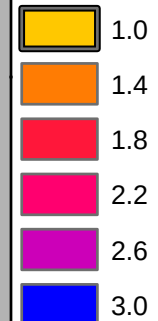
Avena fatua wild oats



Legend

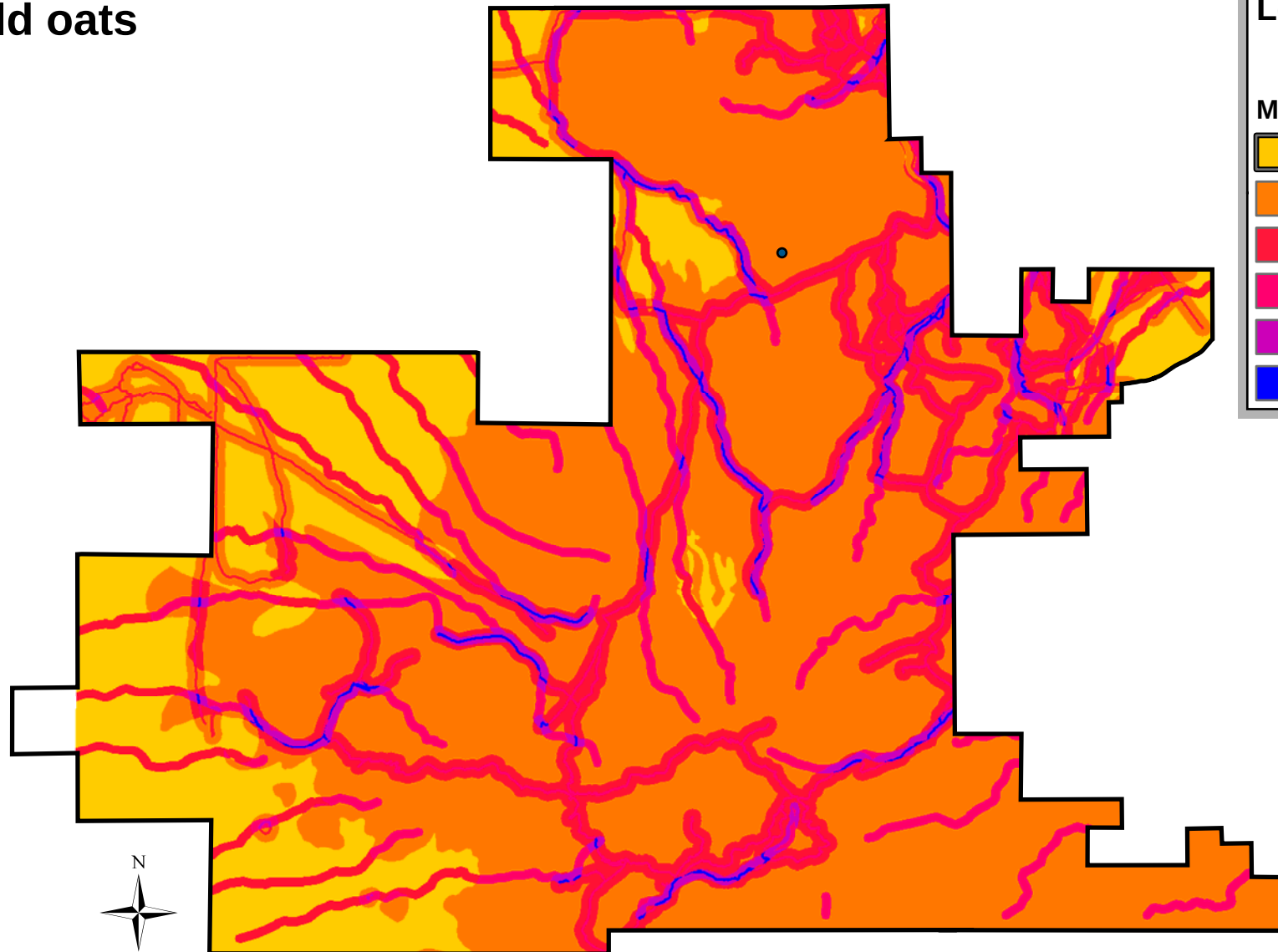
- A. fatua observations

Model Score





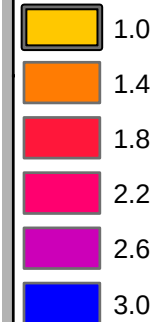
Avena fatua wild oats



Legend

- A. fatua observations

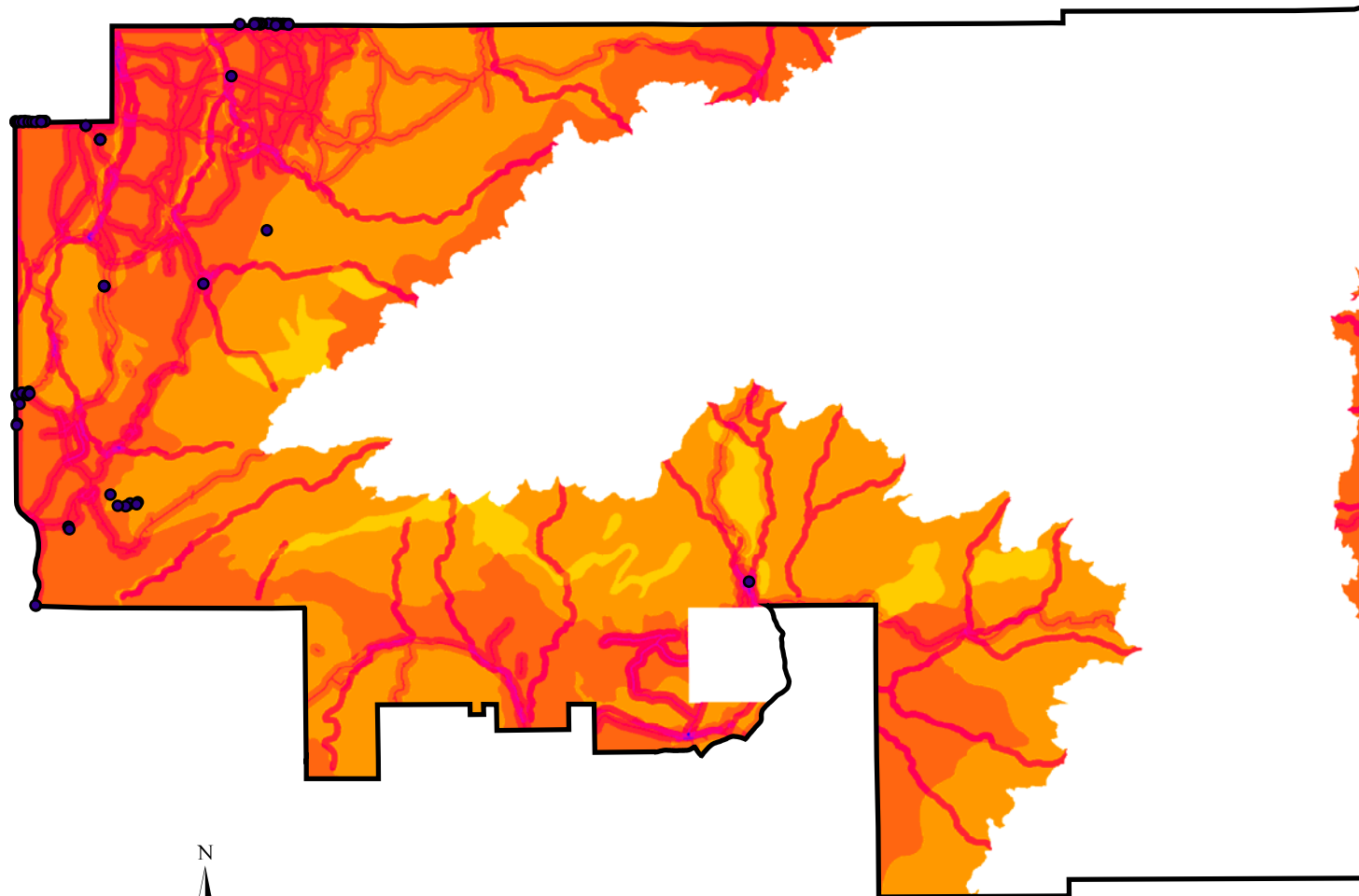
Model Score



0 0.35 0.7 1.4 2.1 2.8
Kilometers



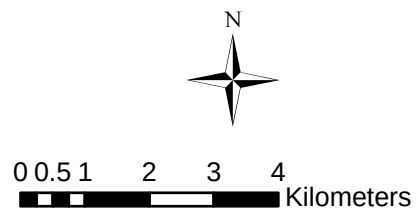
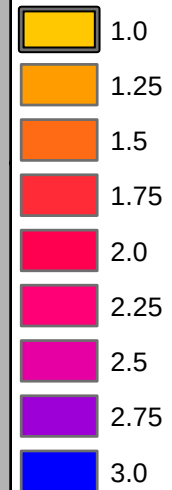
Brassica tournefortii Sahara mustard



Legend

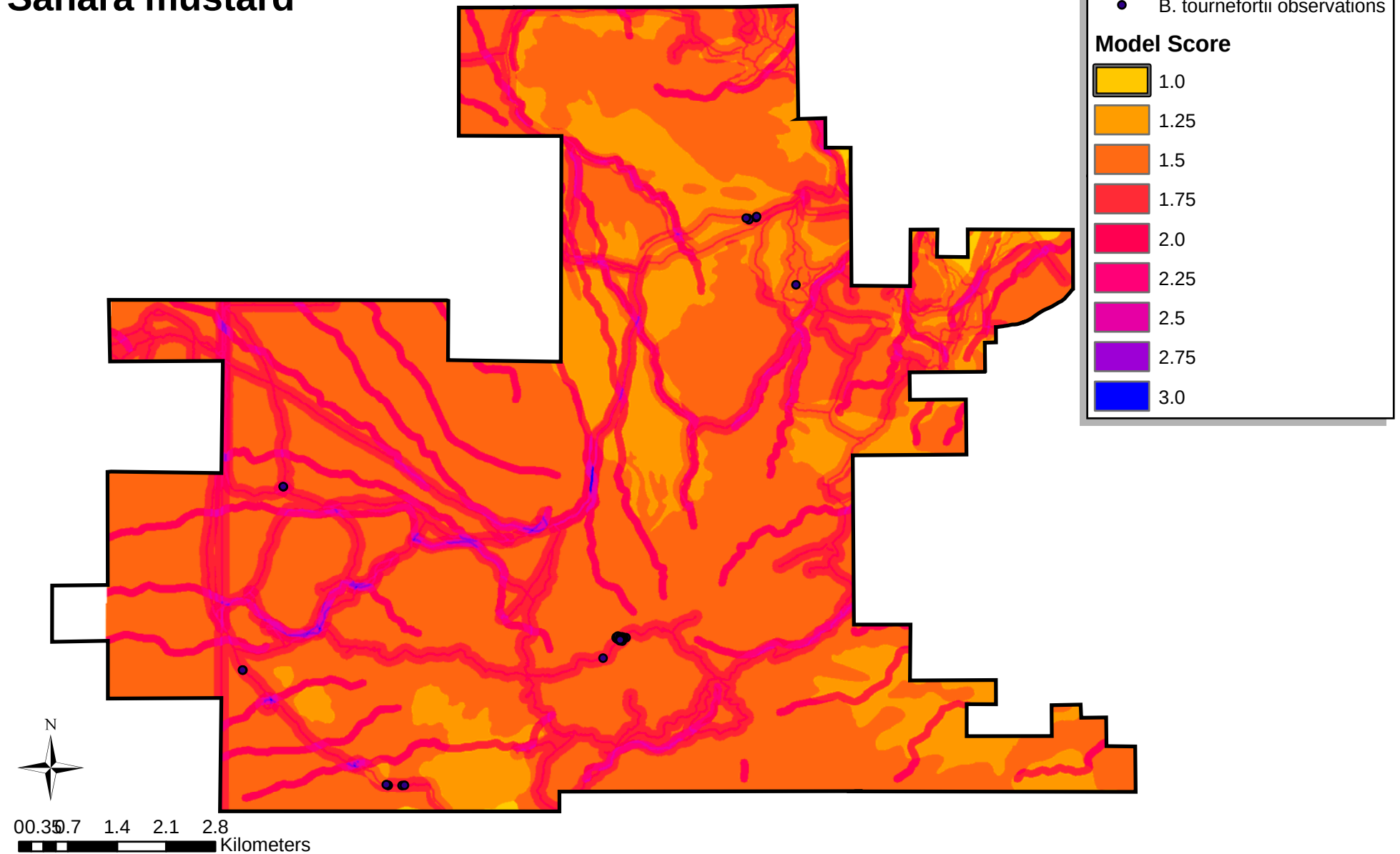
- B. tournefortii observations

Model Score



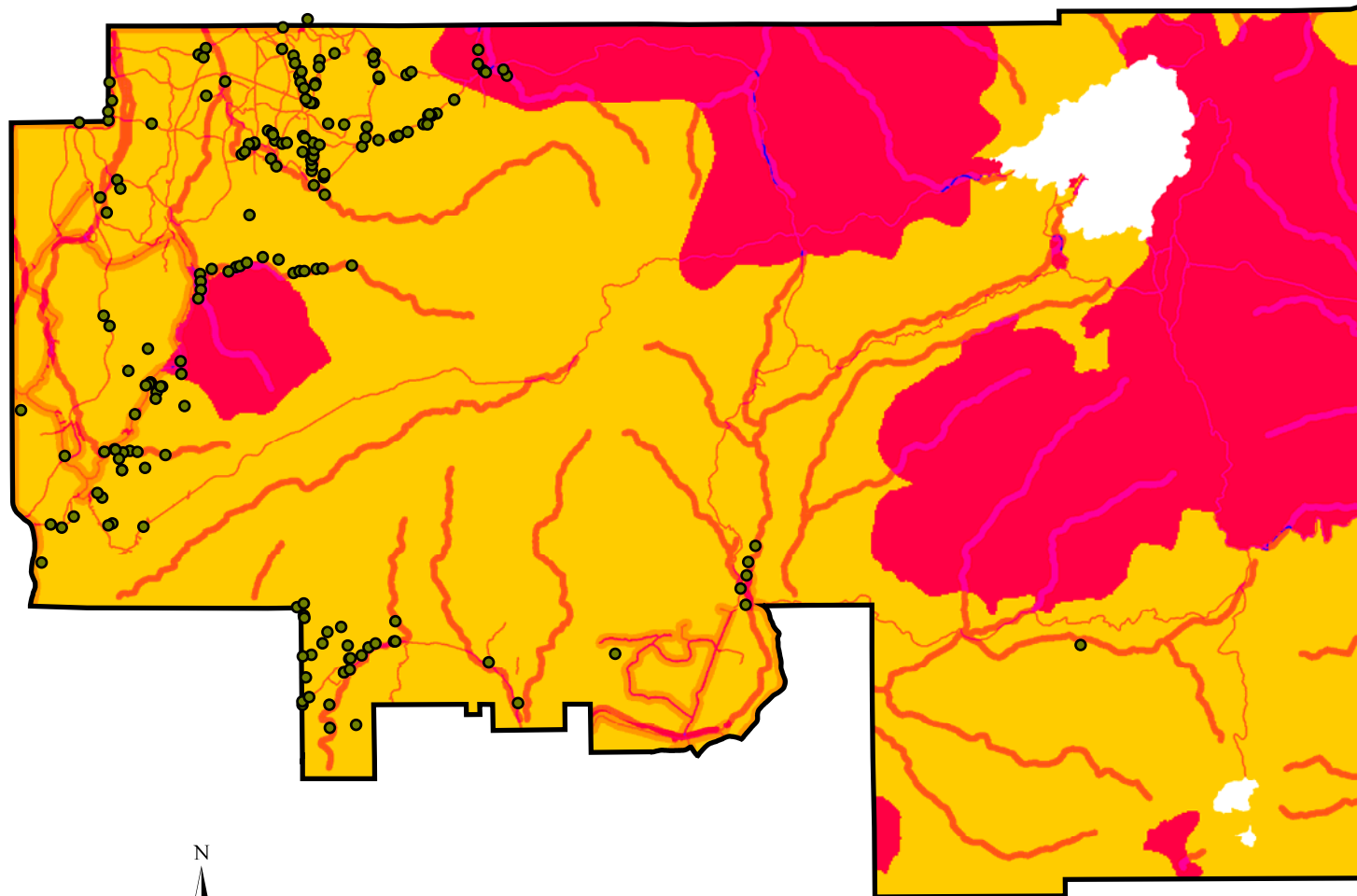


Brassica tournefortii Sahara mustard





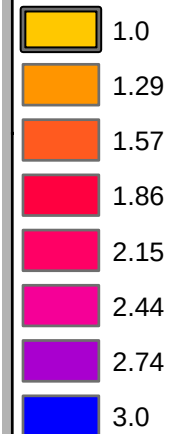
Bromus rubens red brome



Legend

● B. rubens observations

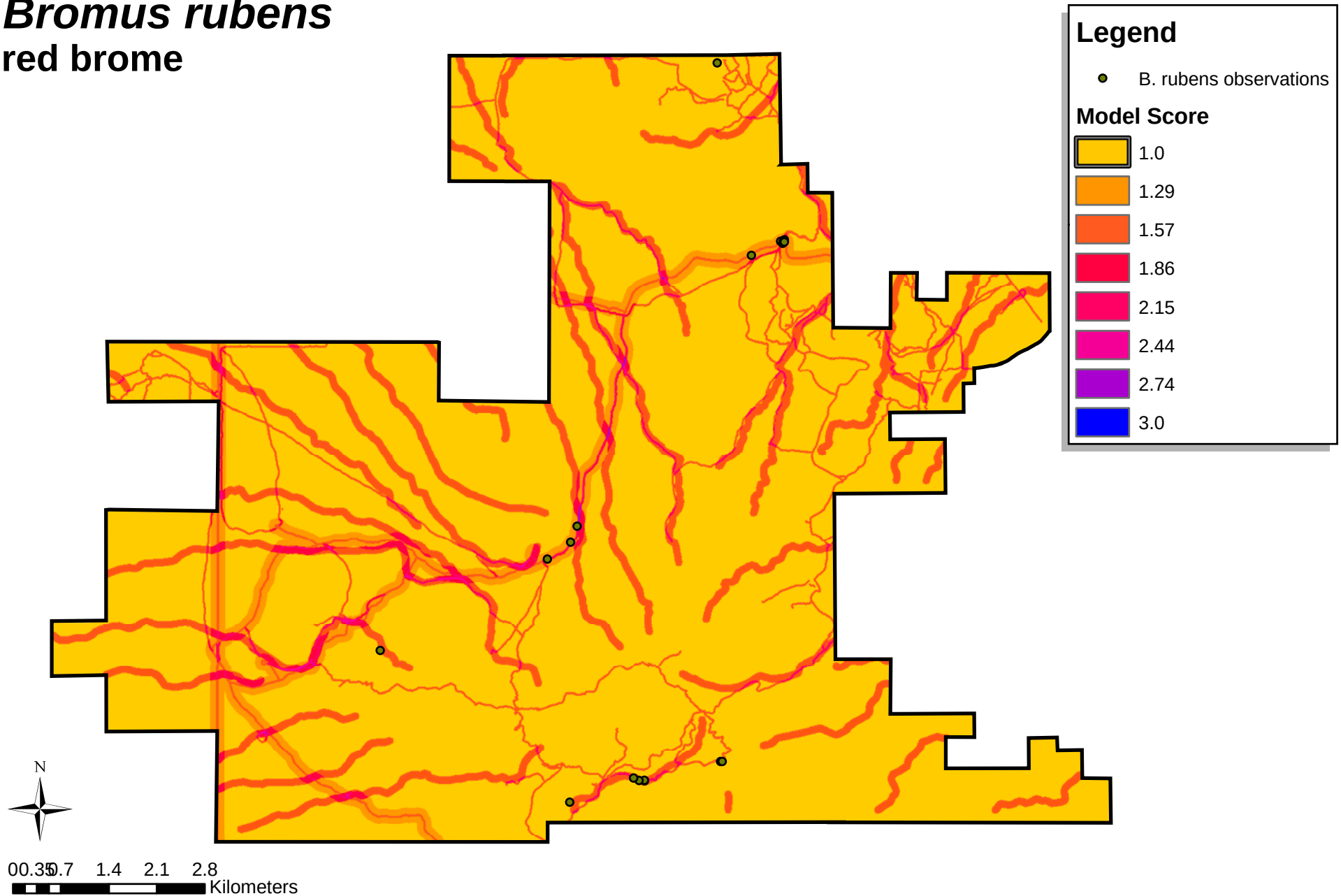
Model Score



0 0.5 1 2 3 4
Kilometers

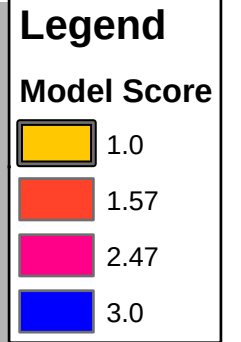
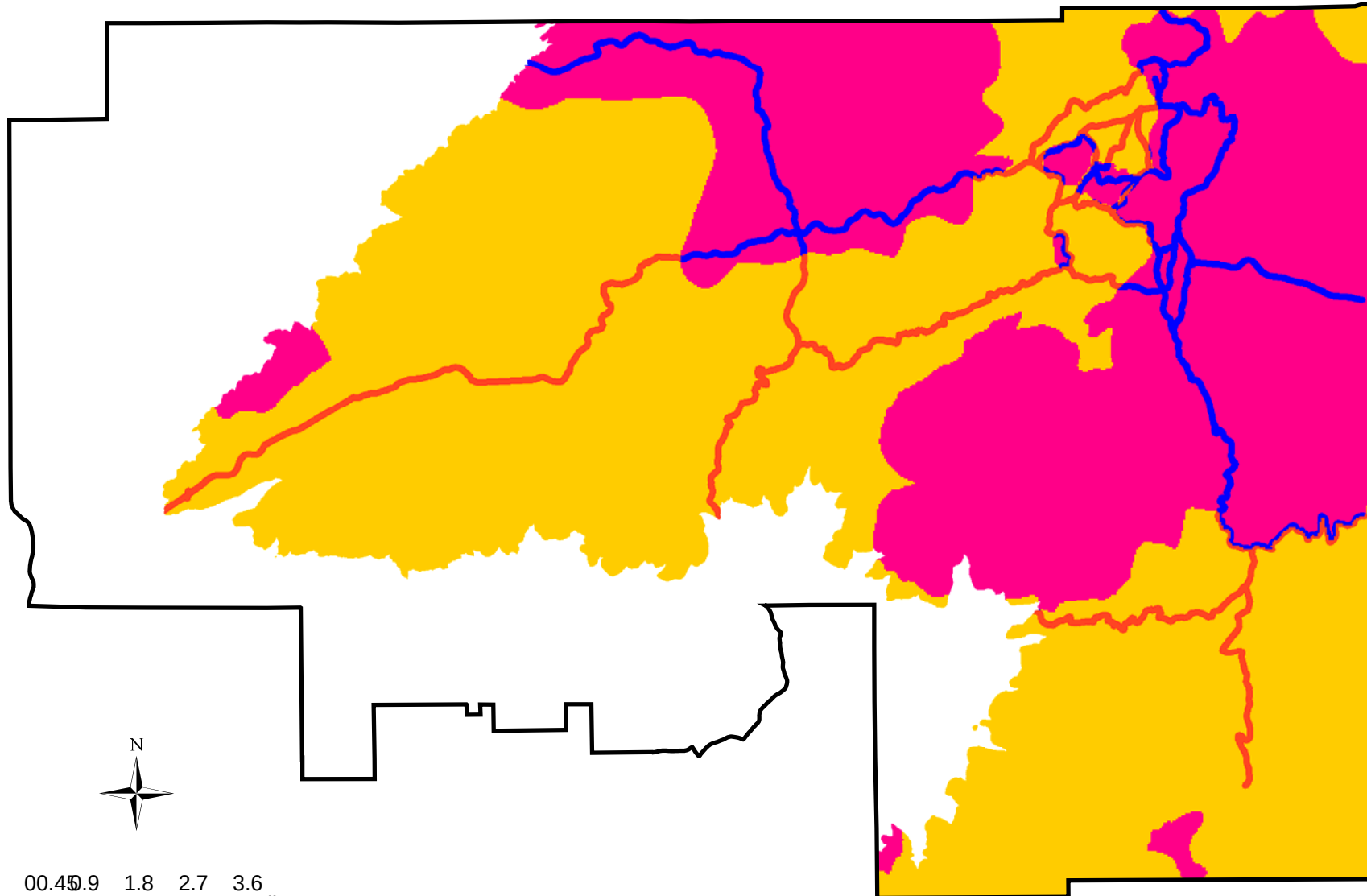


Bromus rubens red brome





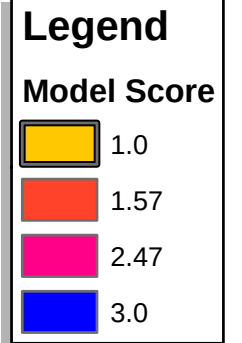
Bromus tectorum cheatgrass



0 0.4 0.9 1.8 2.7 3.6
Kilometers



Bromus tectorum cheatgrass

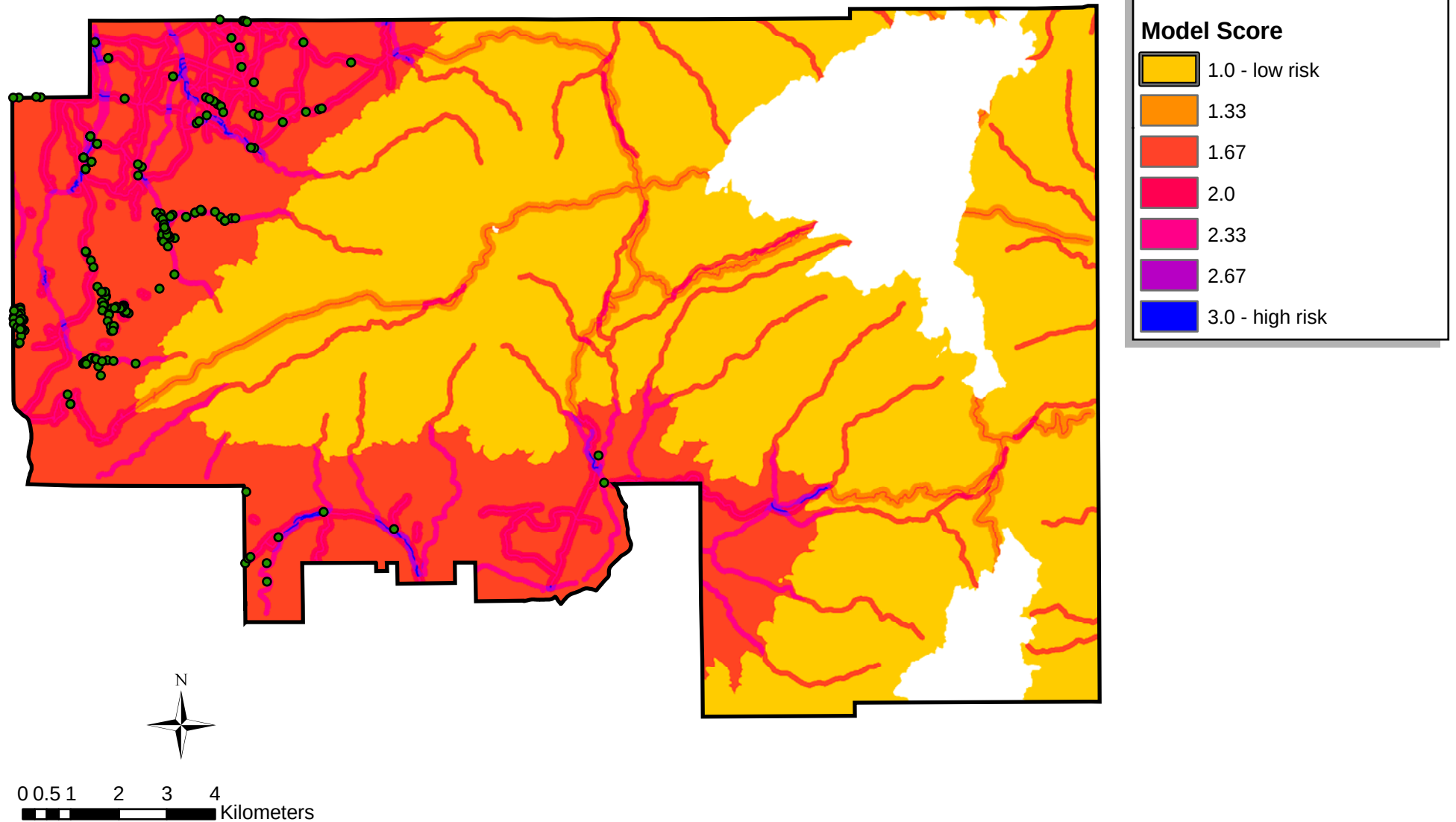


0 0.6 1.2 1.8 2.4
Kilometers



Centaurea melitensis

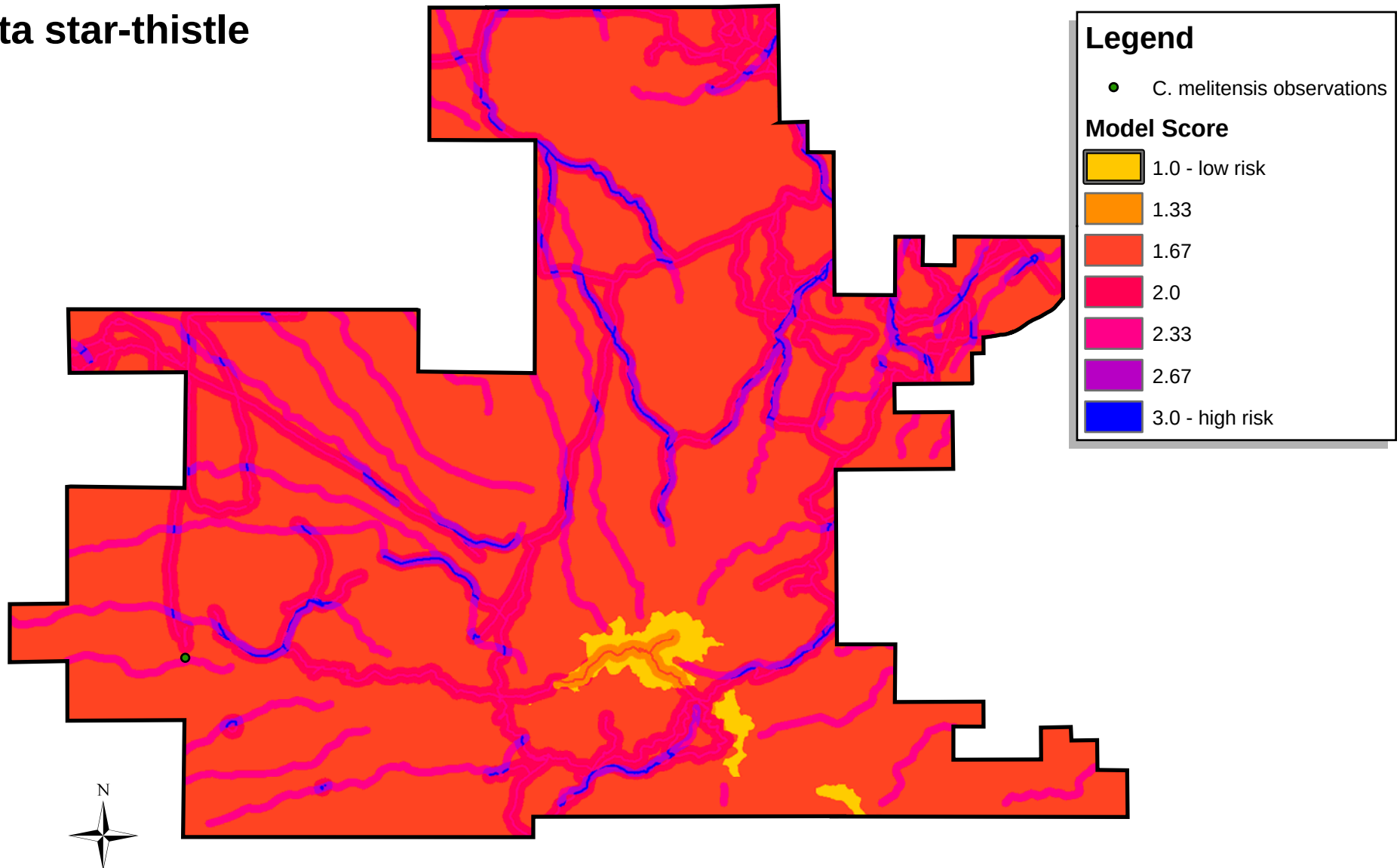
Malta star-thistle





Centaurea melitensis

Malta star-thistle

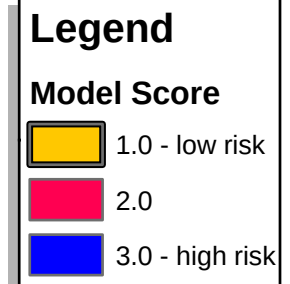
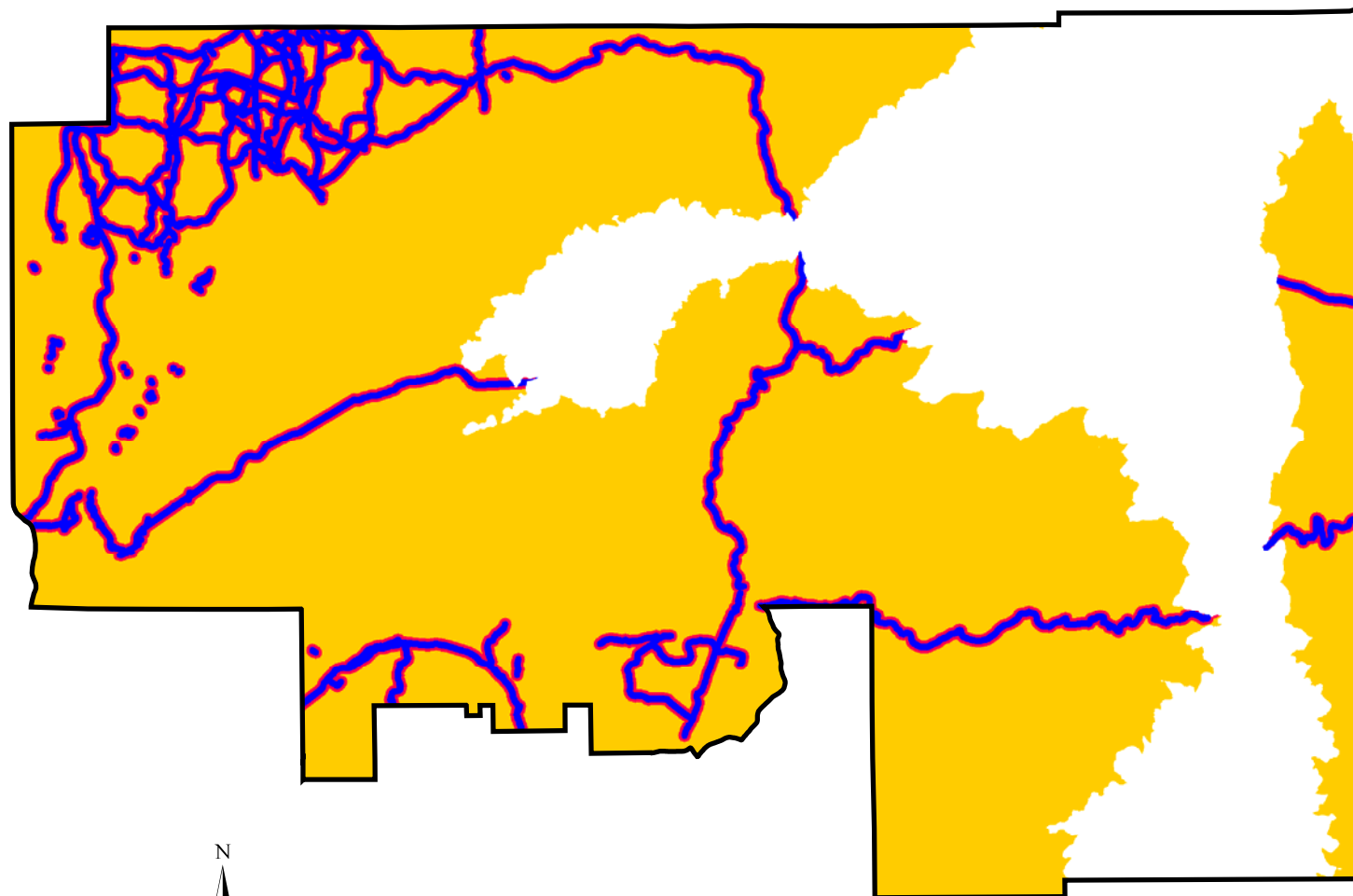


0.375 1.5 2.25 3
Kilometers



Centaurea solstitialis

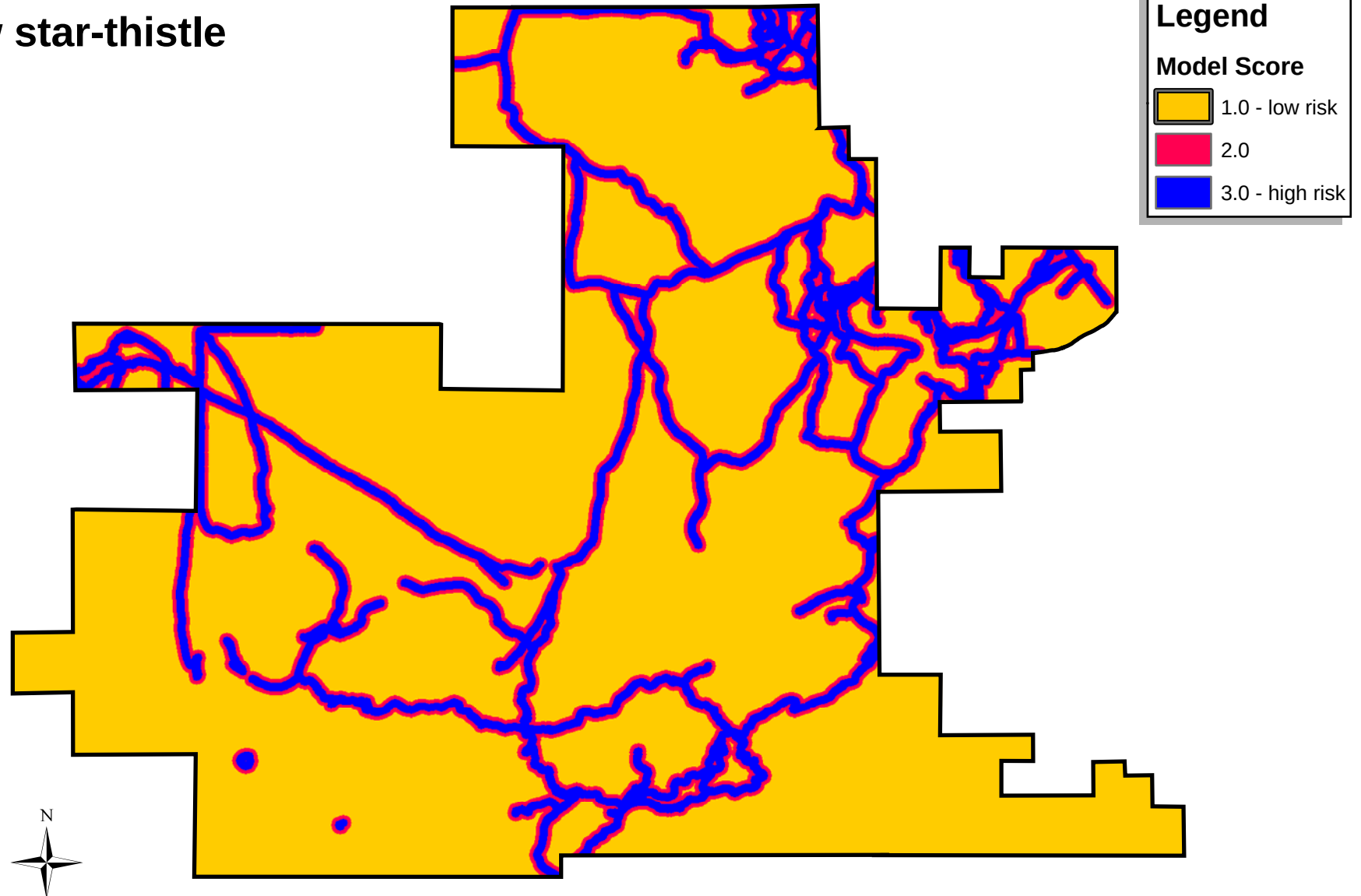
Yellow star-thistle



0 0.5 1 2 3 4
Kilometers



Centaurea solstitialis Yellow star-thistle



Legend

Model Score

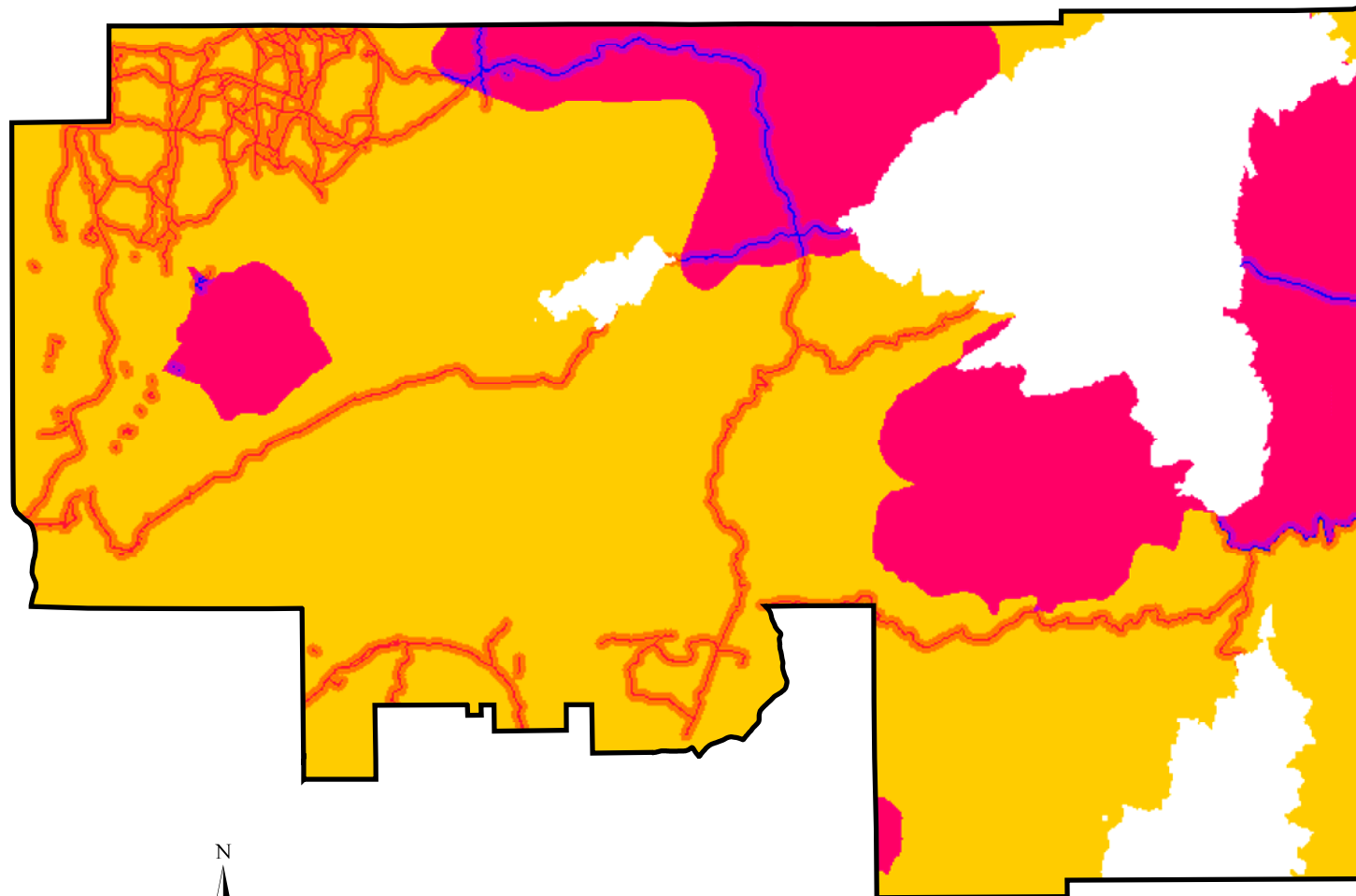
- 1.0 - low risk
- 2.0
- 3.0 - high risk



0 0.375 1.5 2.25 3
Kilometers

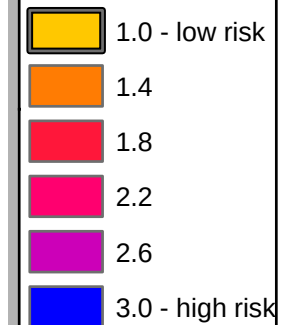


Cirsium vulgare bull thistle



Legend

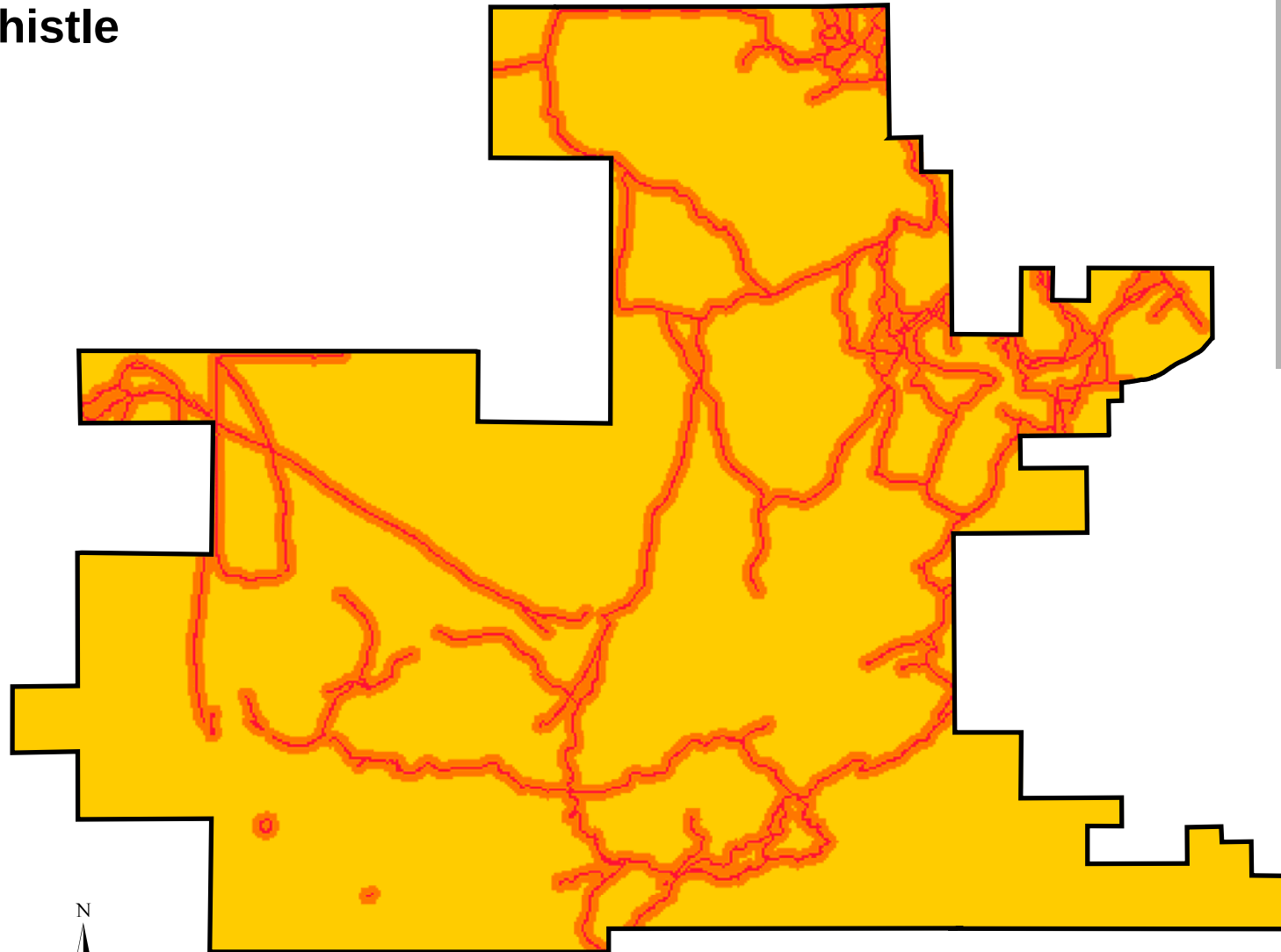
Model Score



0 0.5 1 2 3 4
Kilometers

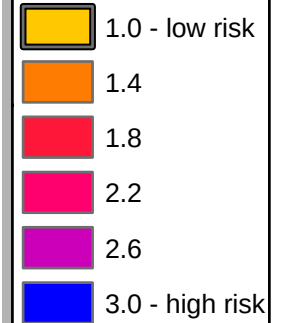


Cirsium vulgare bull thistle



Legend

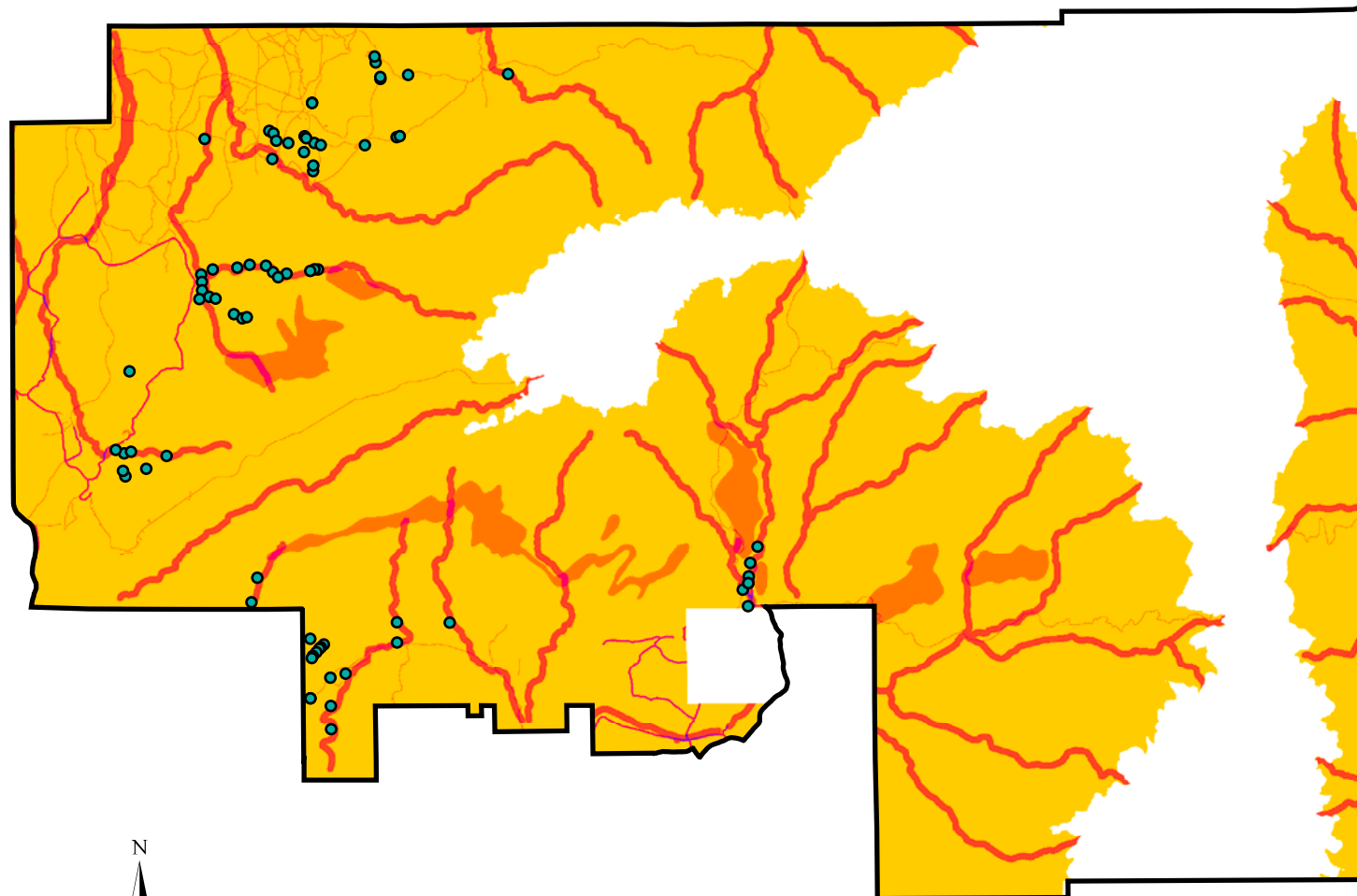
Model Score



0.375 1.5 2.25 3
Kilometers



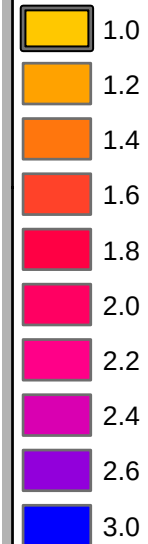
Cynodon dactylon Bermuda grass



Legend

• C. dactylon observations

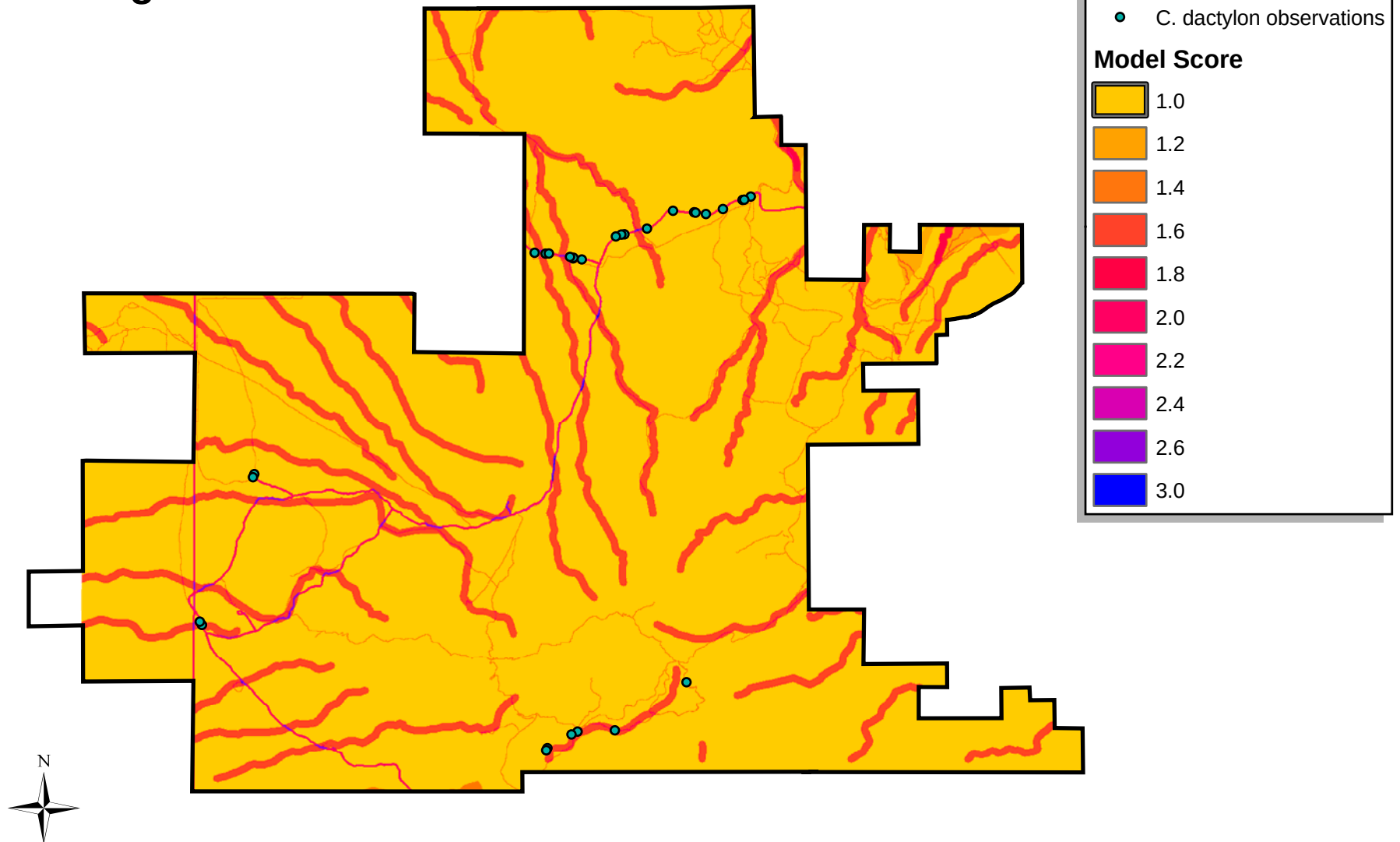
Model Score



0 0.5 1 2 3 4
Kilometers



Cynodon dactylon Bermuda grass

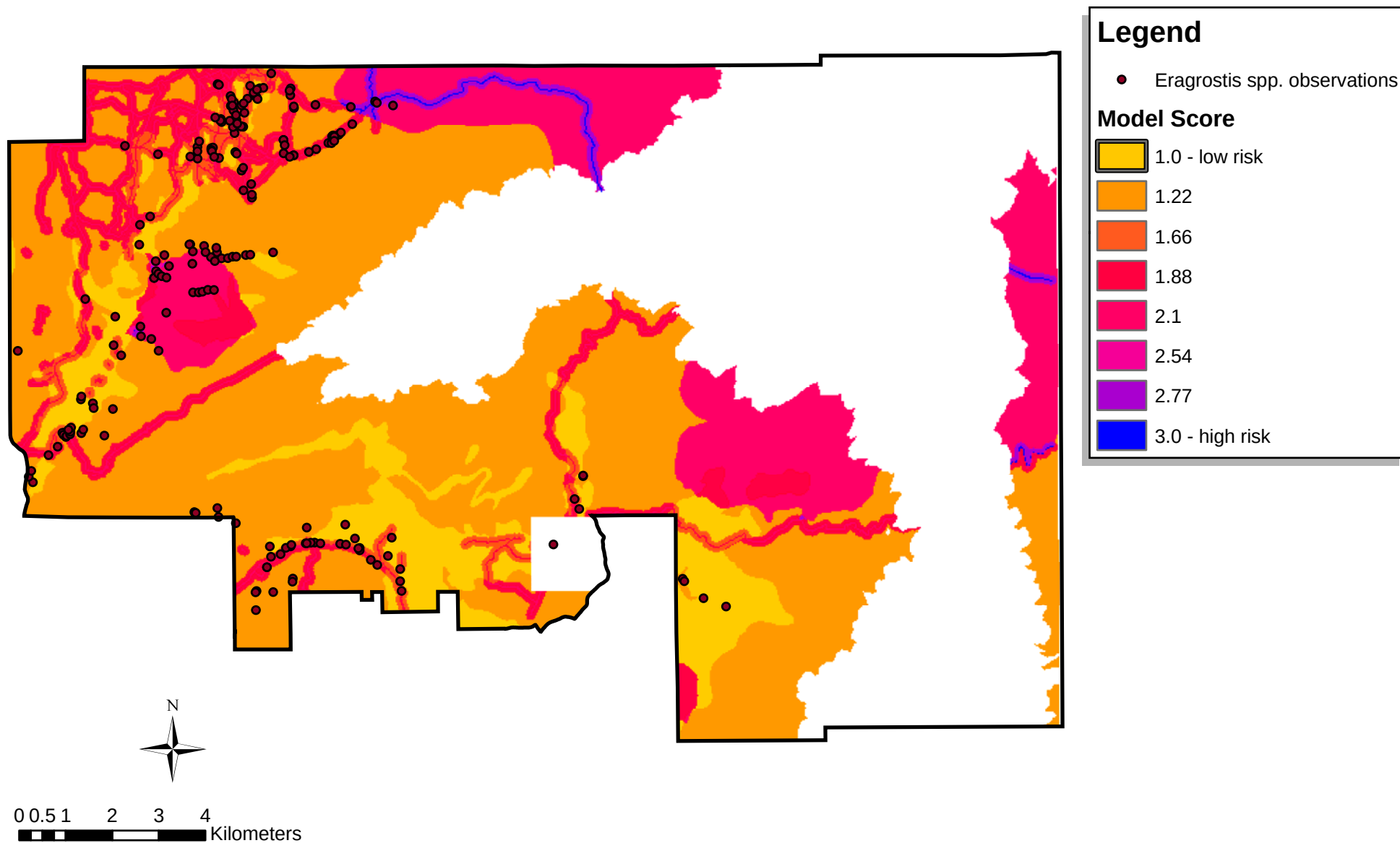


0 0.4 0.8 1.6 2.4 3.2
Kilometers



Eragrostis lehmanniana and *E. curvula*

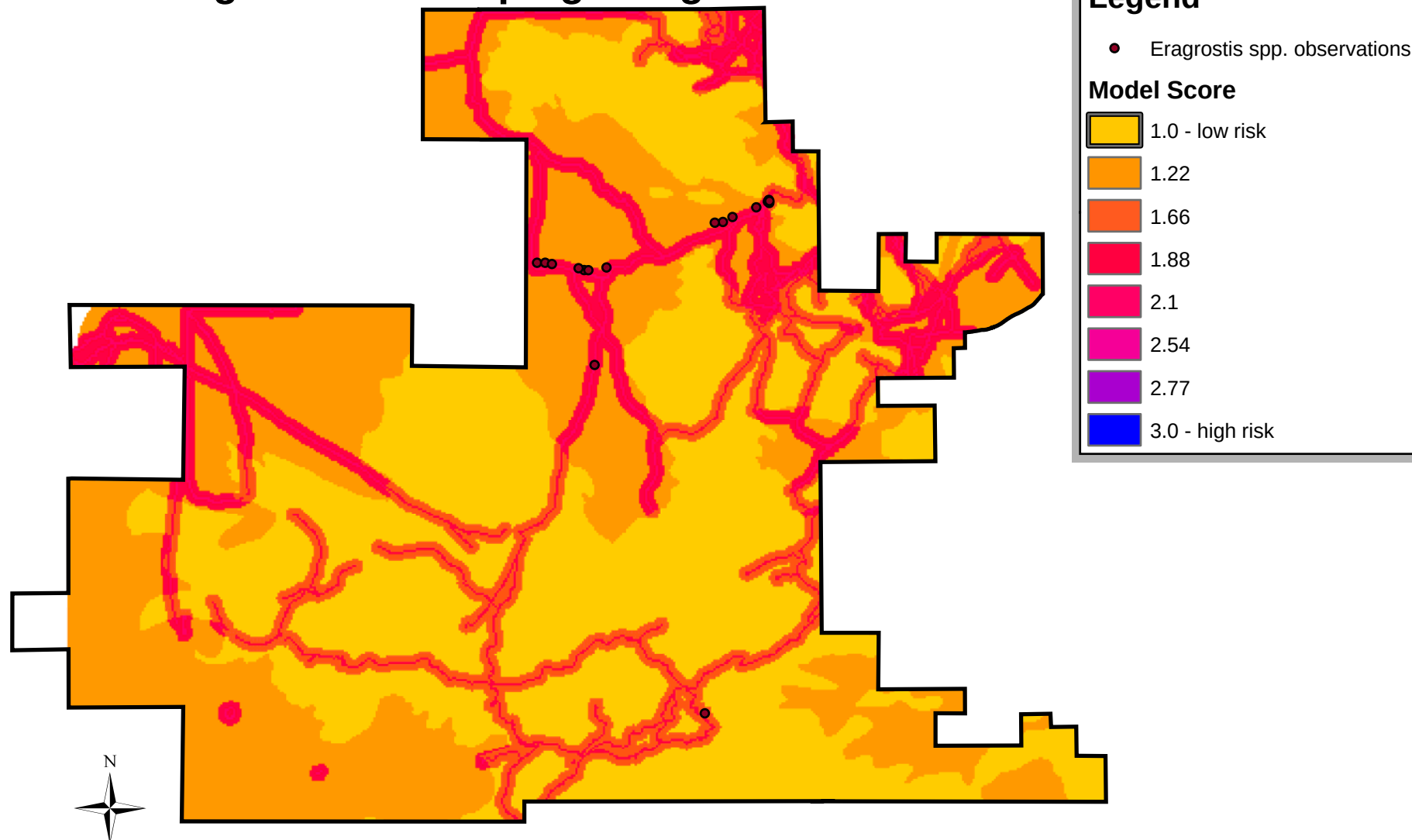
Lehmann lovegrass and weeping lovegrass





Eragrostis lehmanniana and *E. curvula*

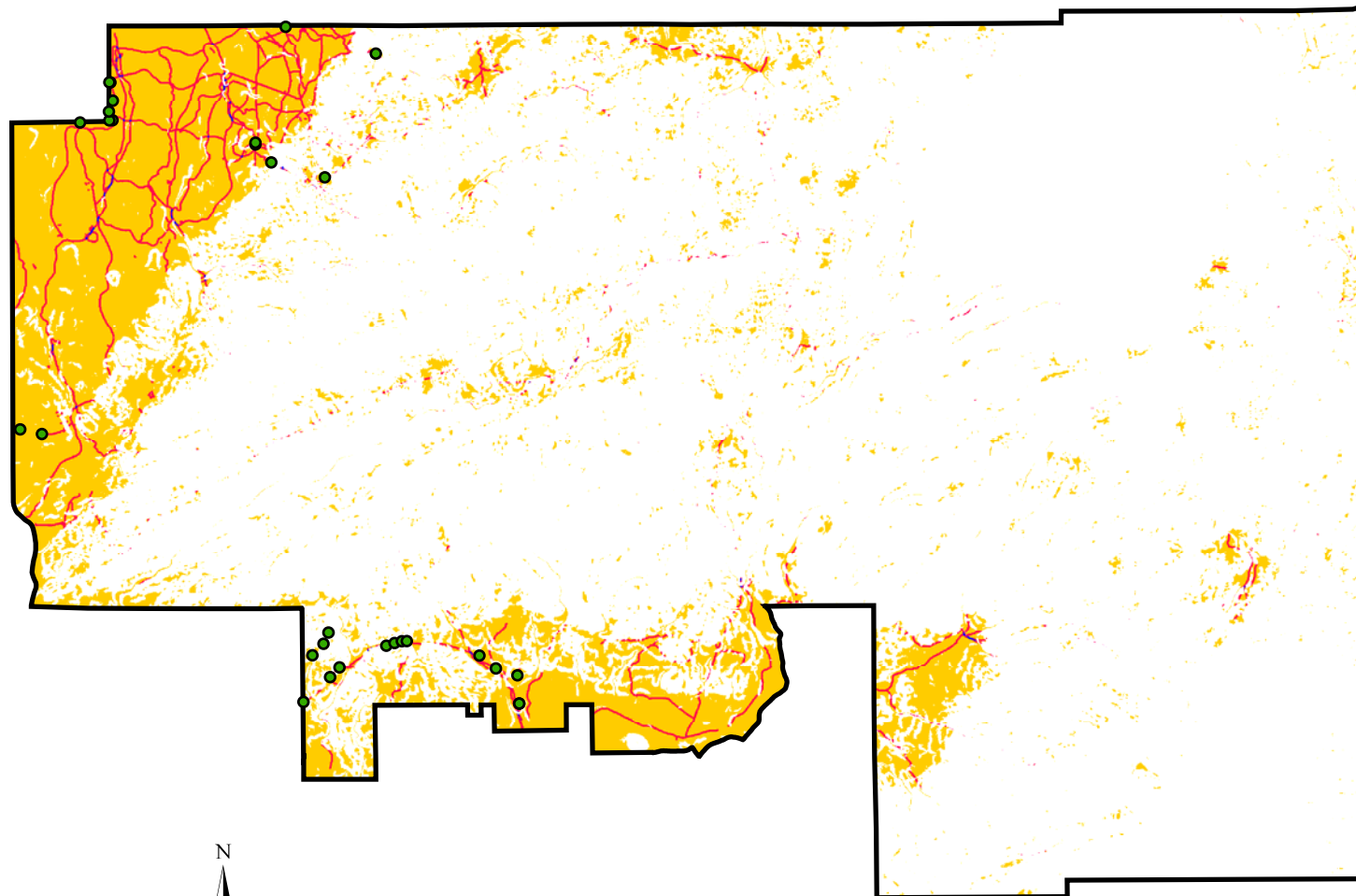
Lehmann lovegrass and weeping lovegrass



0.375 1.5 2.25 3
Kilometers



Erodium cicutarium redstem filaree



Legend

● E. cicutarium observations

Model Score

1.0 - low risk

2.0

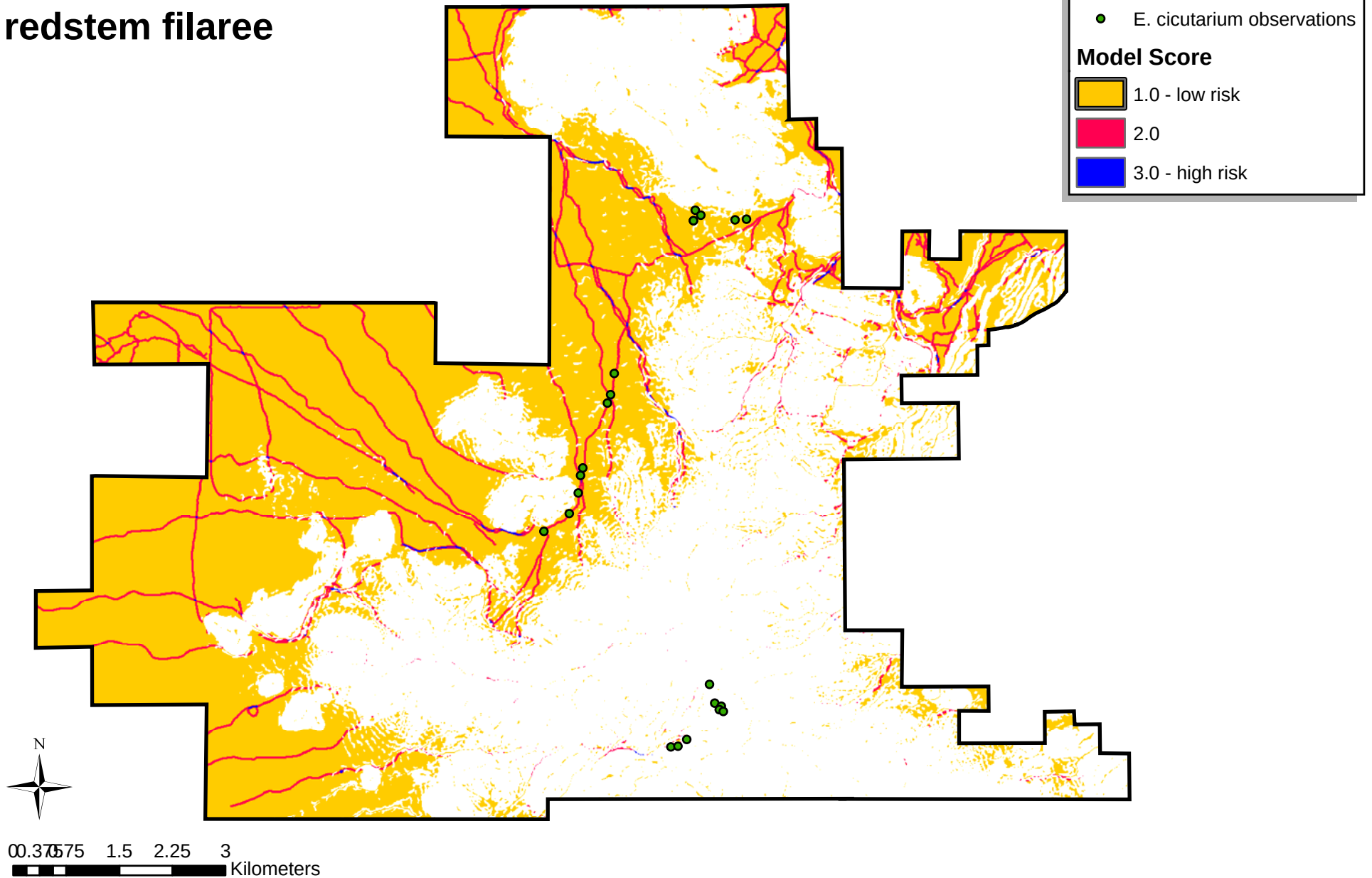
3.0 - high risk



0 0.5 1 2 3 4
Kilometers

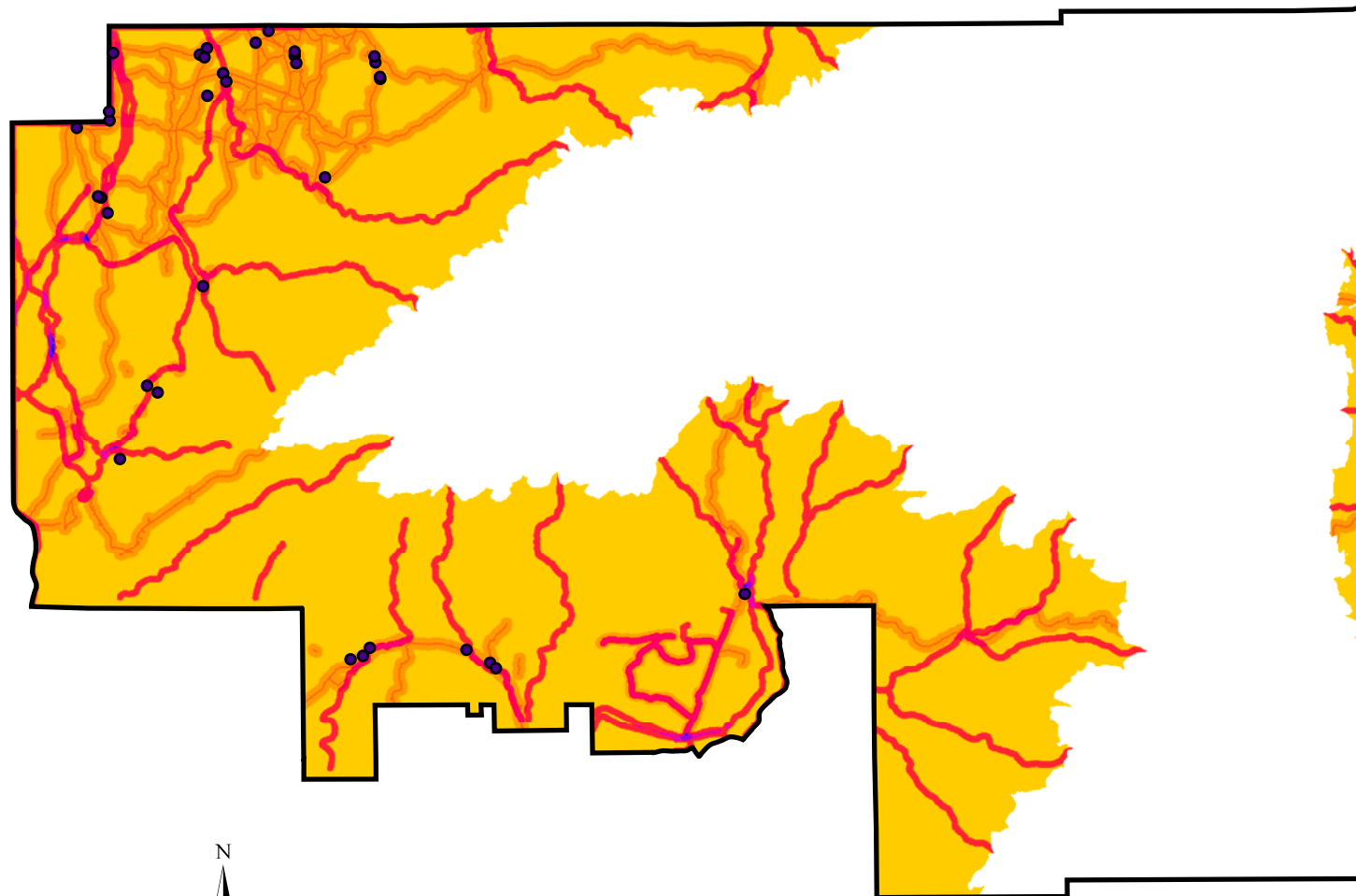


Erodium cicutarium redstem filaree





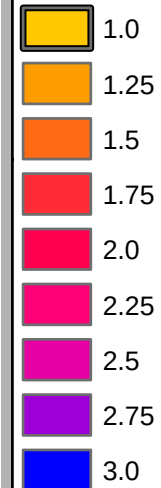
Hordeum murinum mouse barley



Legend

- *H. murinum* observations

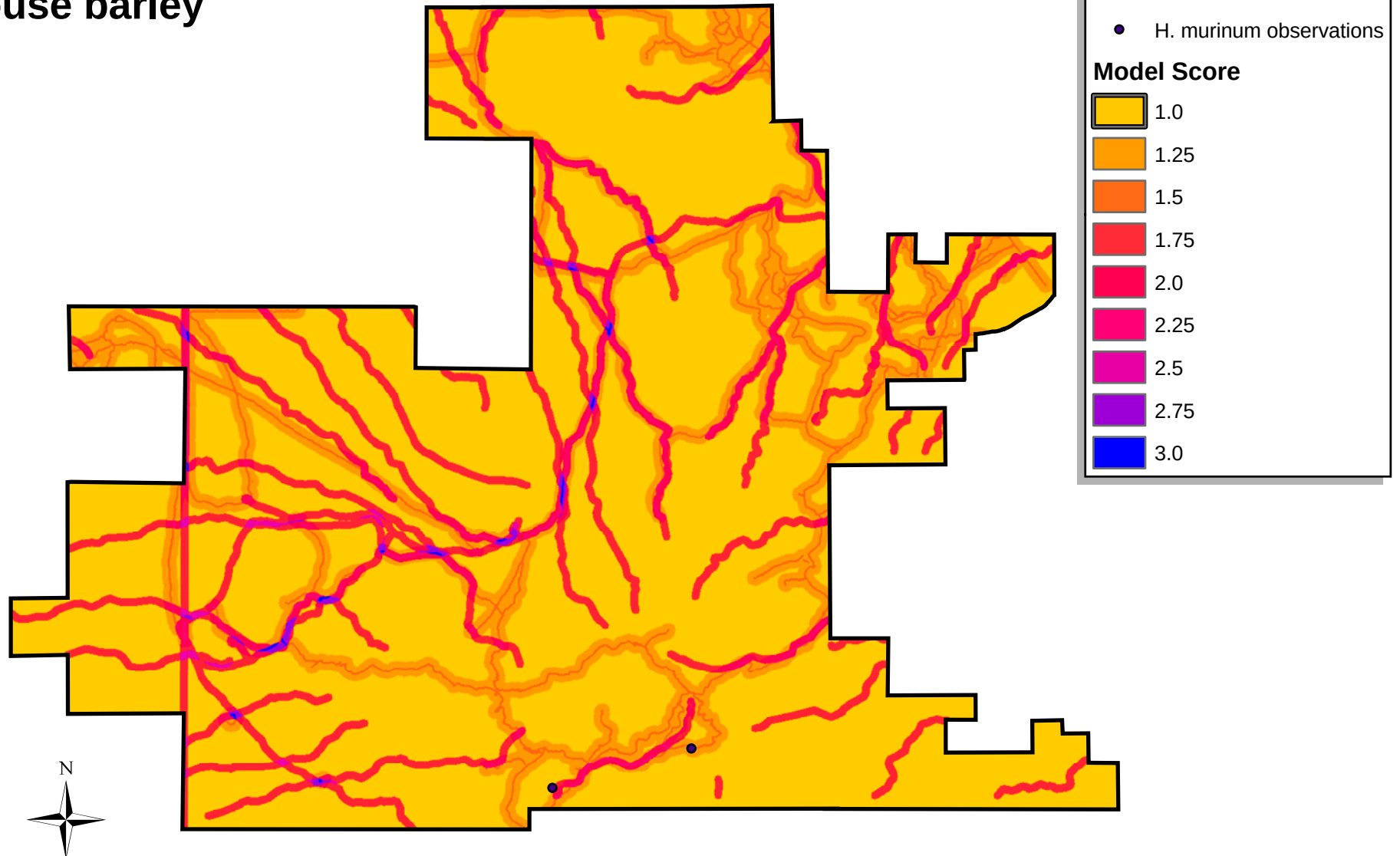
Model Score



0 0.5 1 2 3 4
Kilometers



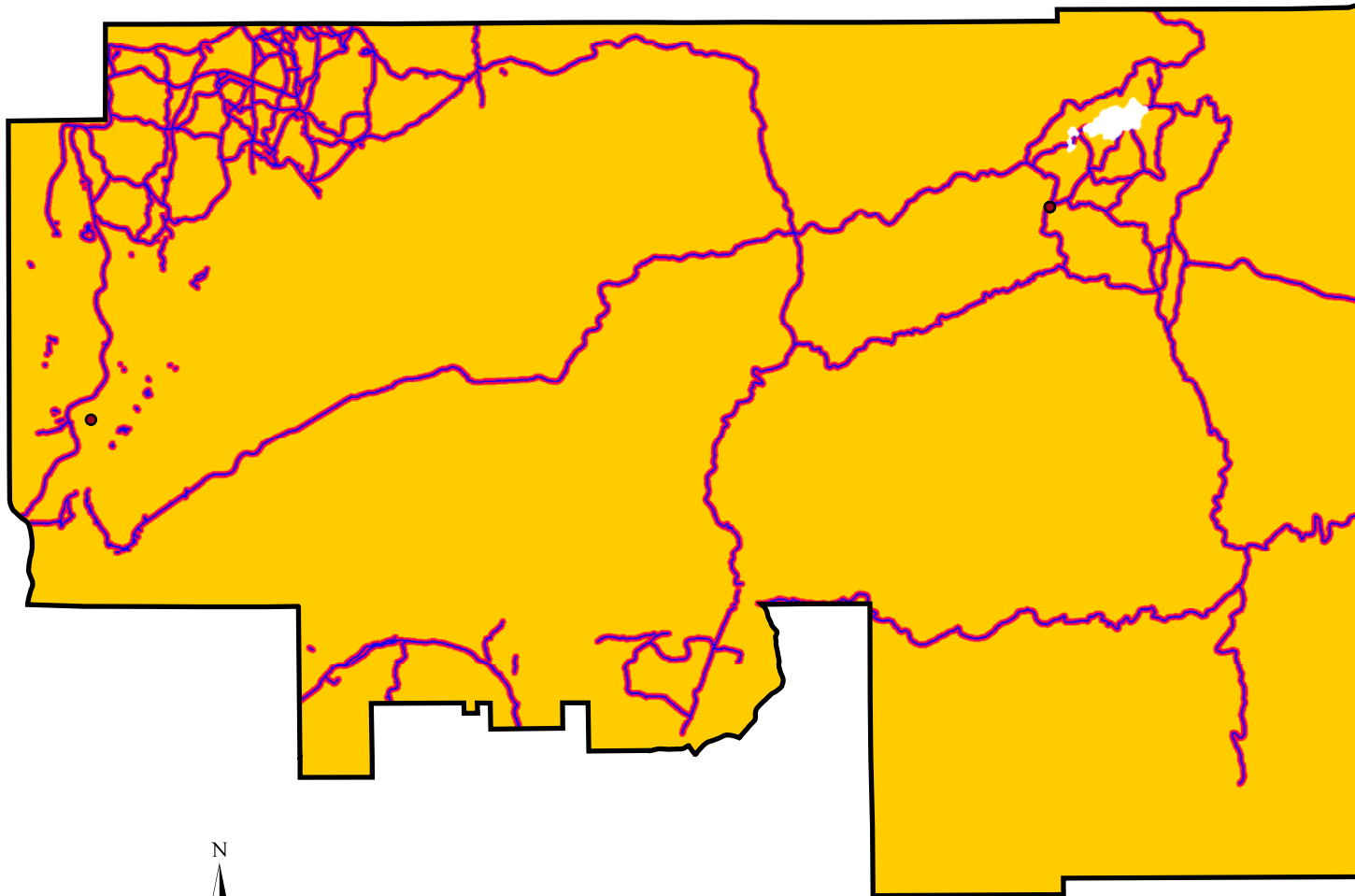
Hordeum murinum mouse barley



0 0.450.9 1.8 2.7 3.6
Kilometers



Marrubium vulgare horehound



Legend

- M. vulgare observations

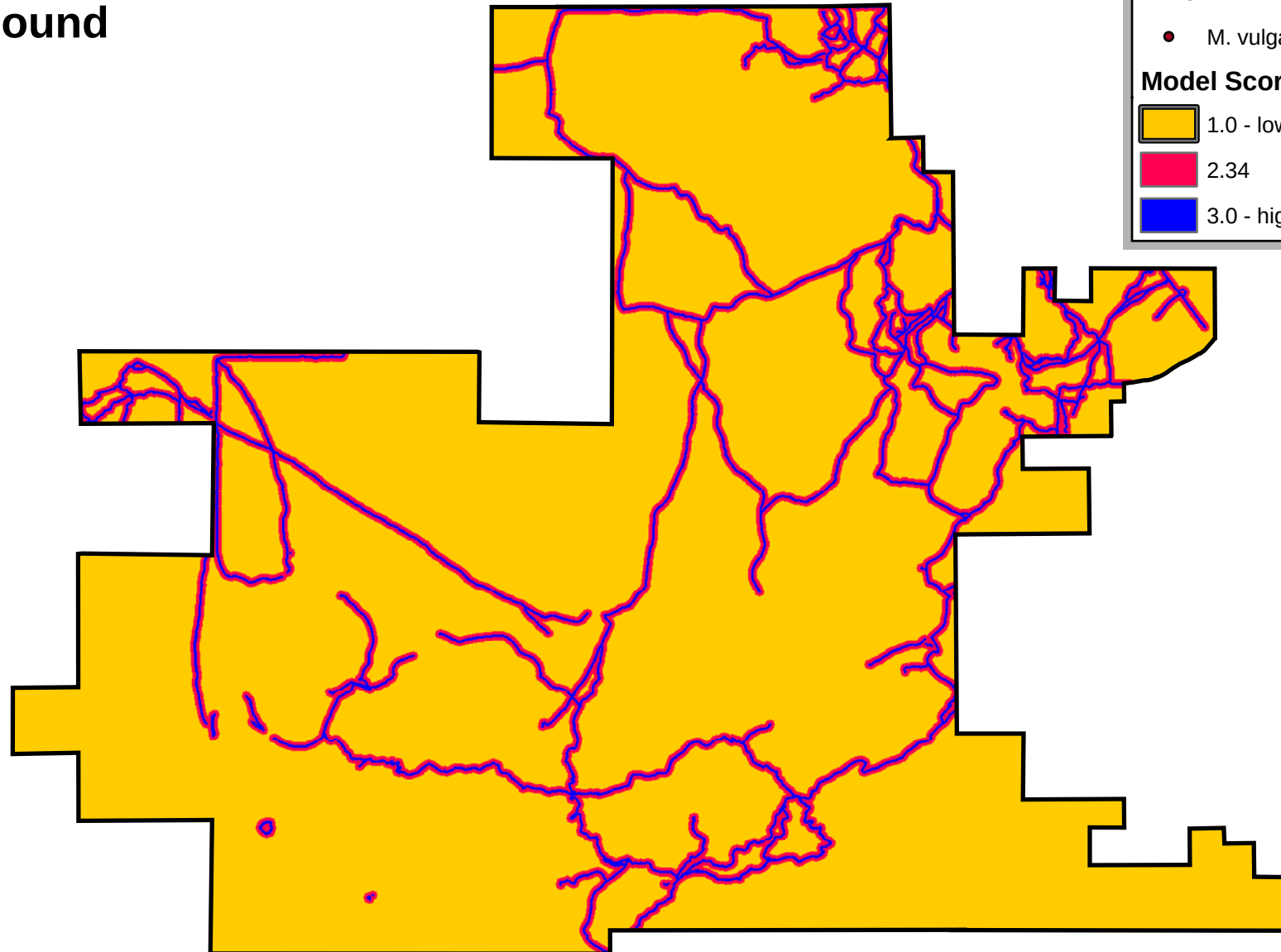
Model Score

- 1.0 - low risk
- 2.34
- 3.0 - high risk

0 0.5 1 2 3 4
Kilometers



Marrubium vulgare horehound



Legend

- M. vulgare observations

Model Score

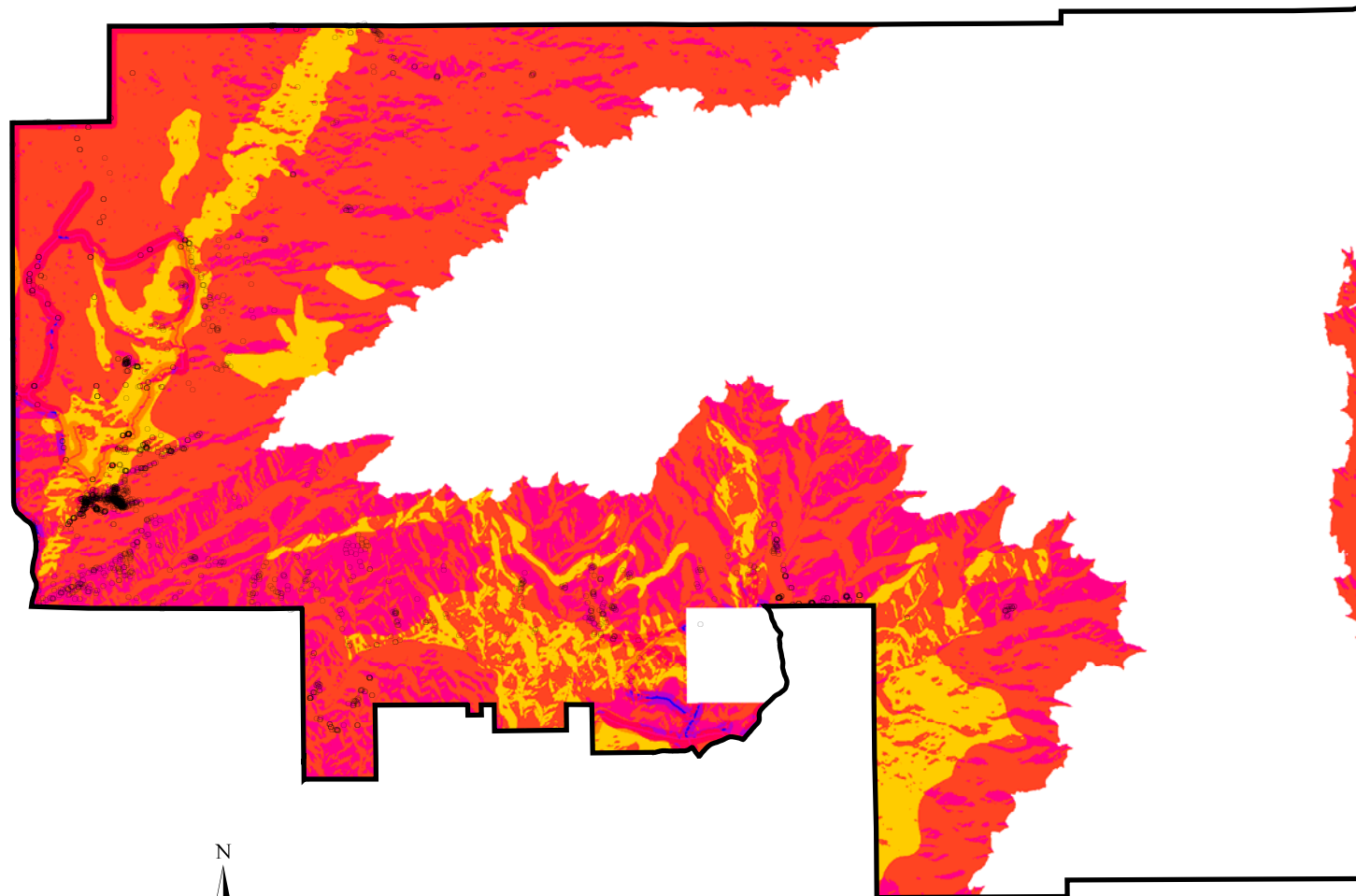
- 1.0 - low risk
- 2.34
- 3.0 - high risk



0 0.3 0.7 1.4 2.1 2.8
Kilometers



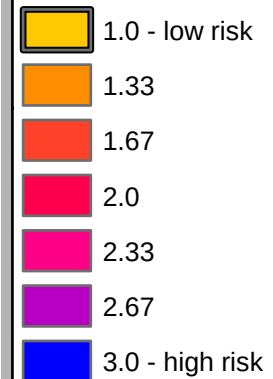
Pennisetum ciliare buffelgrass



Legend

○ *P. ciliare* observations

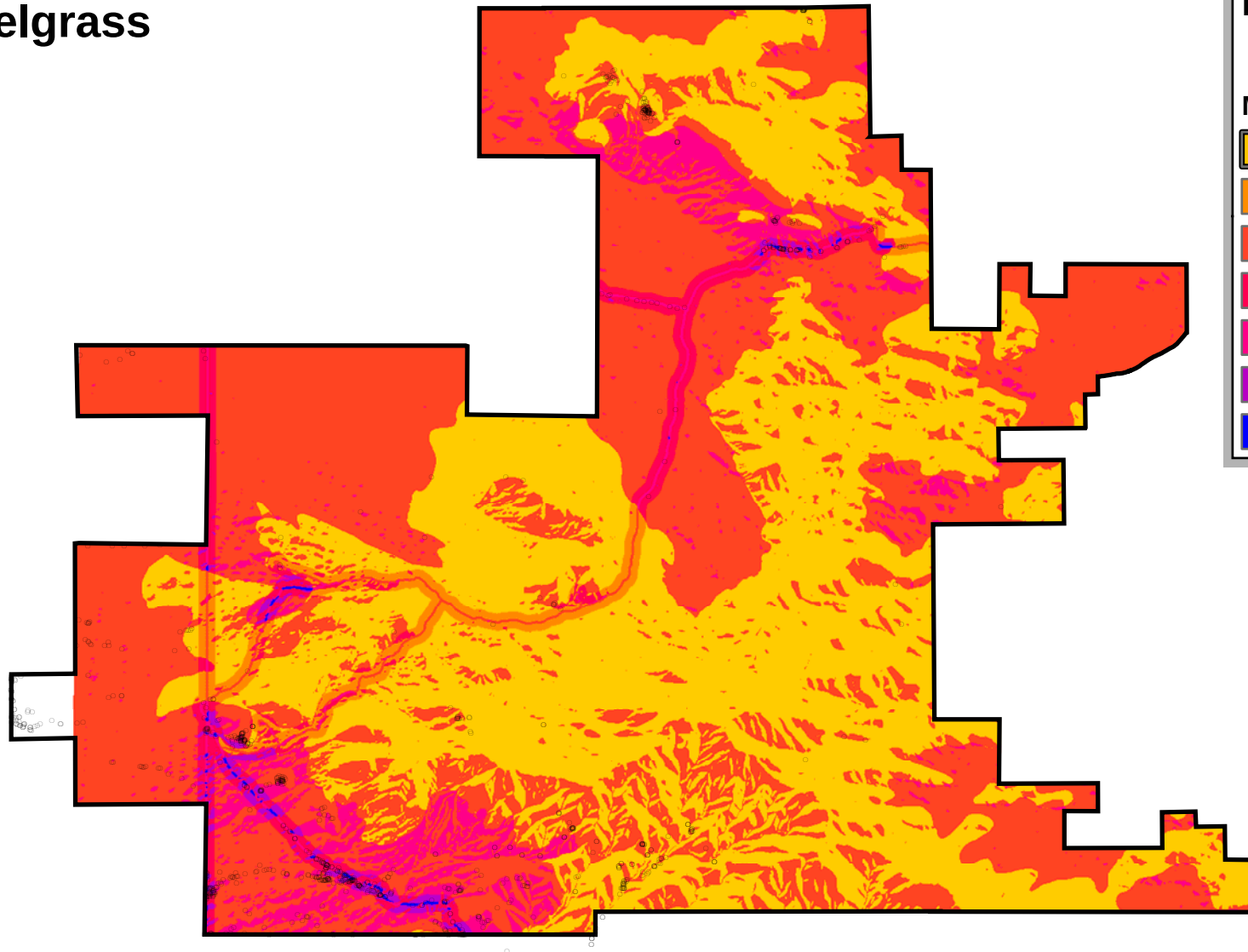
Model Score



0 0.5 1 2 3 4
Kilometers



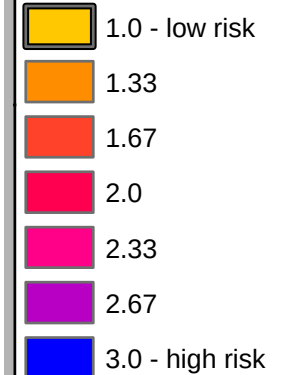
Pennisetum ciliare buffelgrass



Legend

○ *P. ciliare* observations

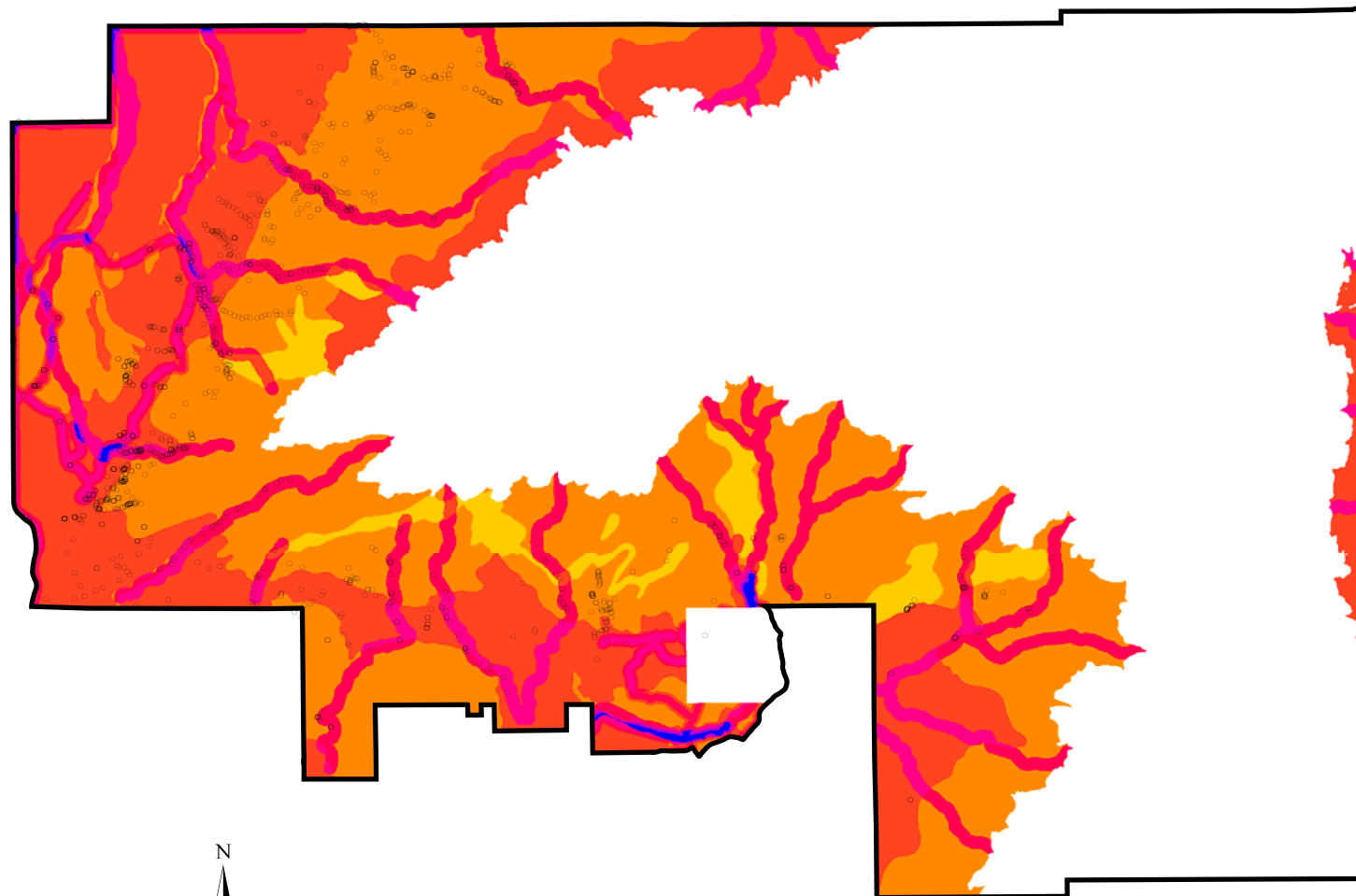
Model Score



0.375 1.5 2.25 3
Kilometers



Pennisetum setaceum fountain grass



Legend

Model Score

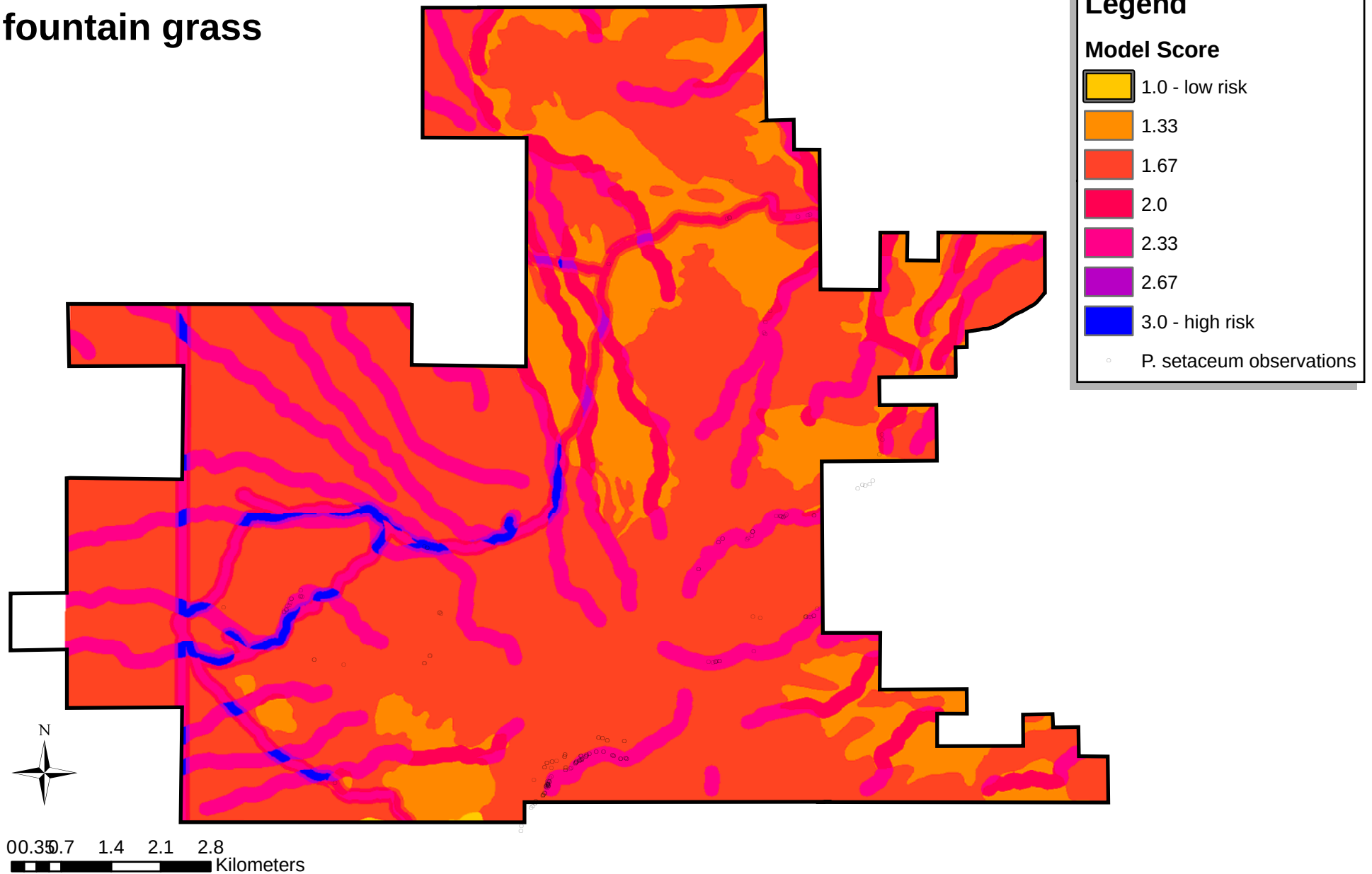
- 1.0 - low risk
- 1.33
- 1.67
- 2.0
- 2.33
- 2.67
- 3.0 - high risk
- P. setaceum observations



0 0.5 1 2 3 4
Kilometers

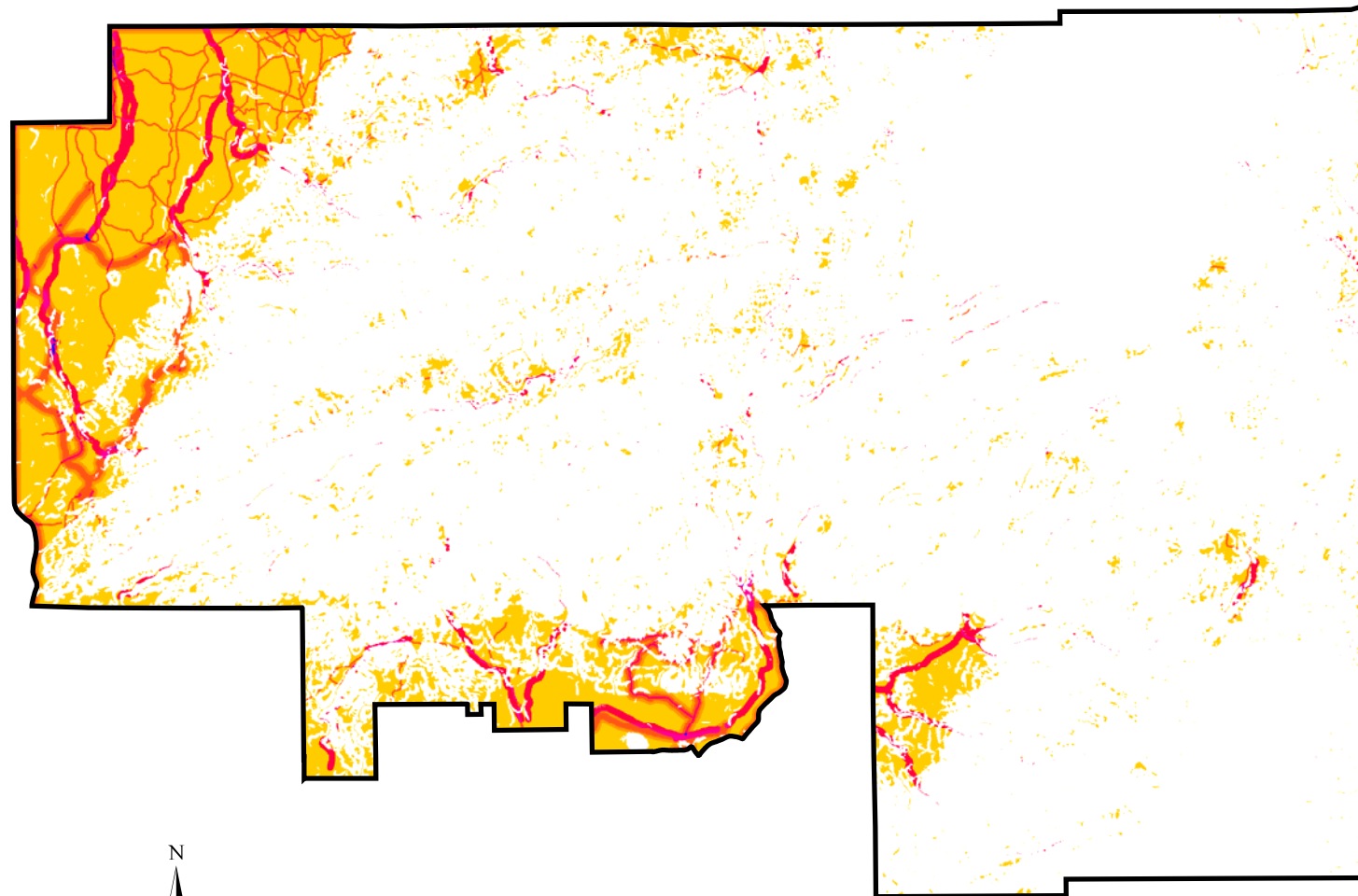


Pennisetum setaceum fountain grass



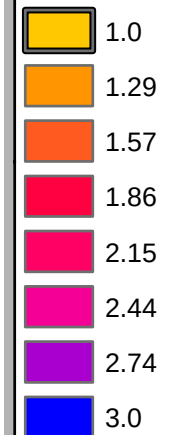


Salsola kali, *S. tragus* Russian thistle



Legend

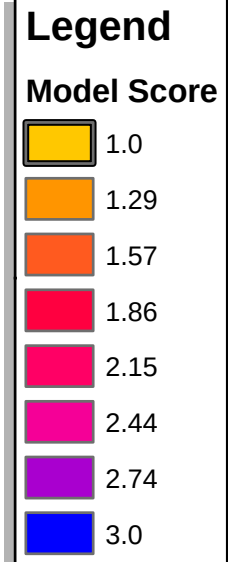
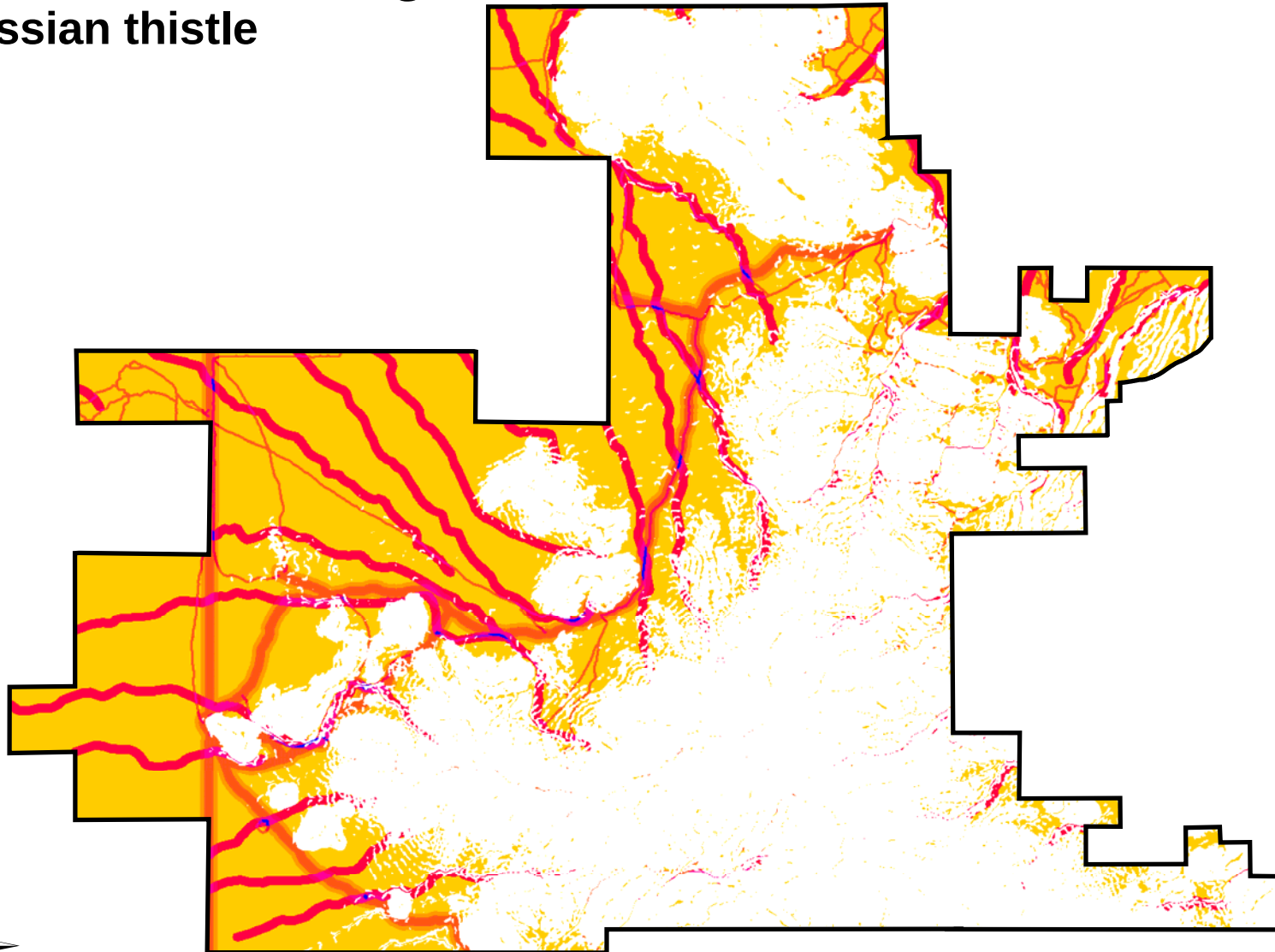
Model Score



0 0.5 1 2 3 4
Kilometers



Salsola kali, *S. tragus* Russian thistle

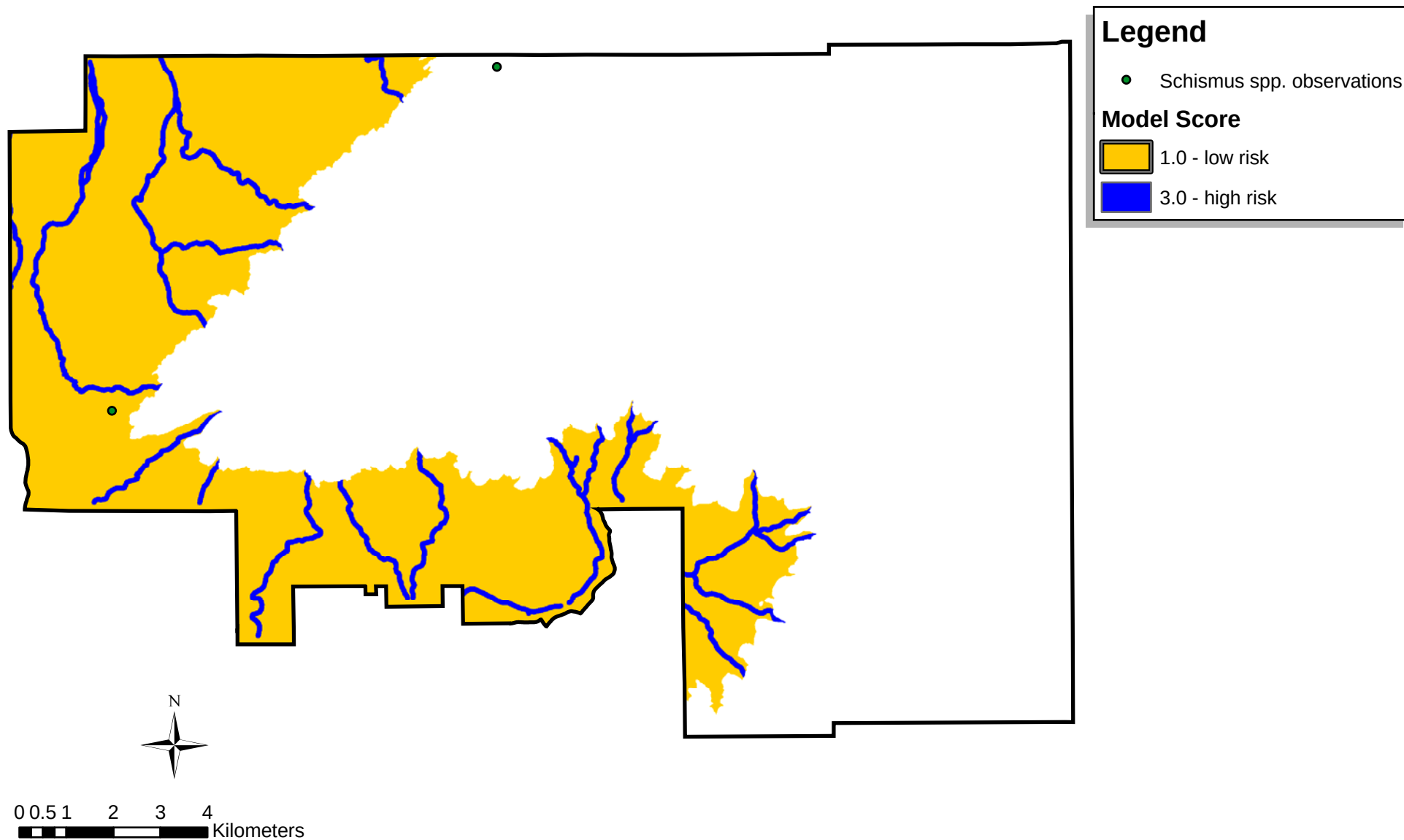


0 0.35 0.7 1.4 2.1 2.8
Kilometers



Schismus arabicus and *S. barbatus*

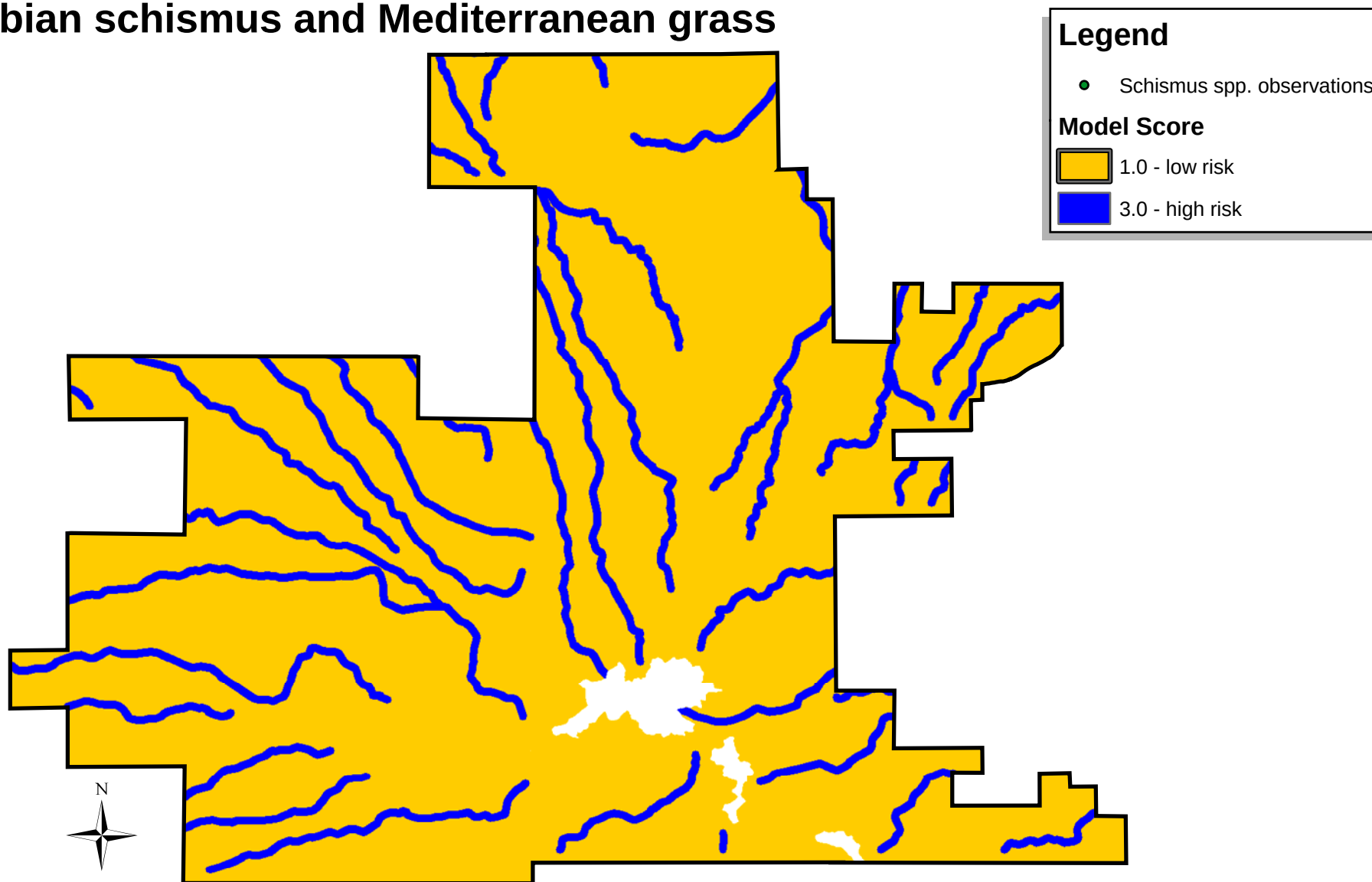
Arabian schismus and Mediterranean grass





Schismus arabicus and *S. barbatus*

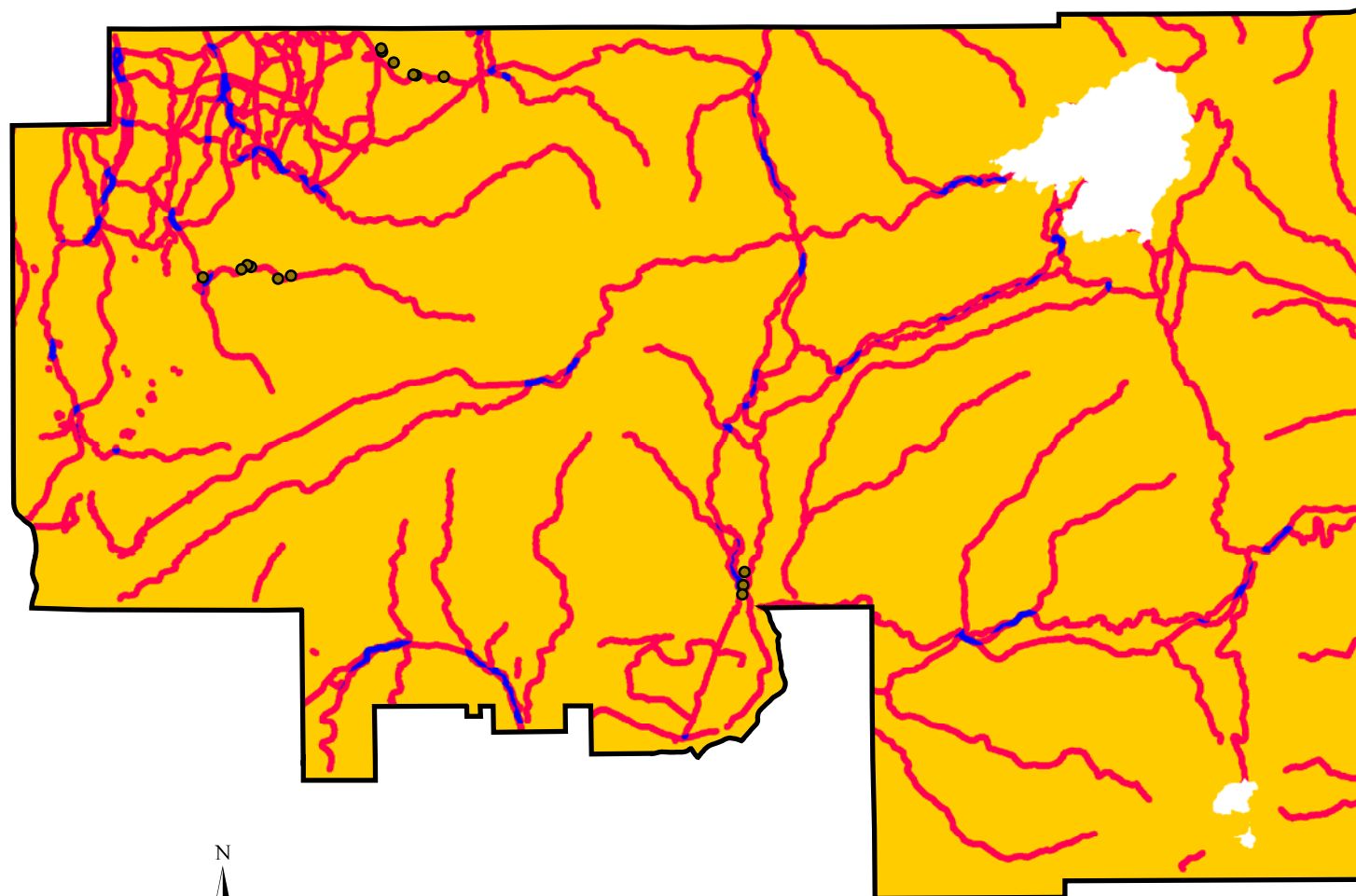
Arabian schismus and Mediterranean grass



0.375 1.5 2.25 3
Kilometers



Sonchus asper and *S. oleraceus* spiny sowthistle and common sowthistle



Legend

Model Score

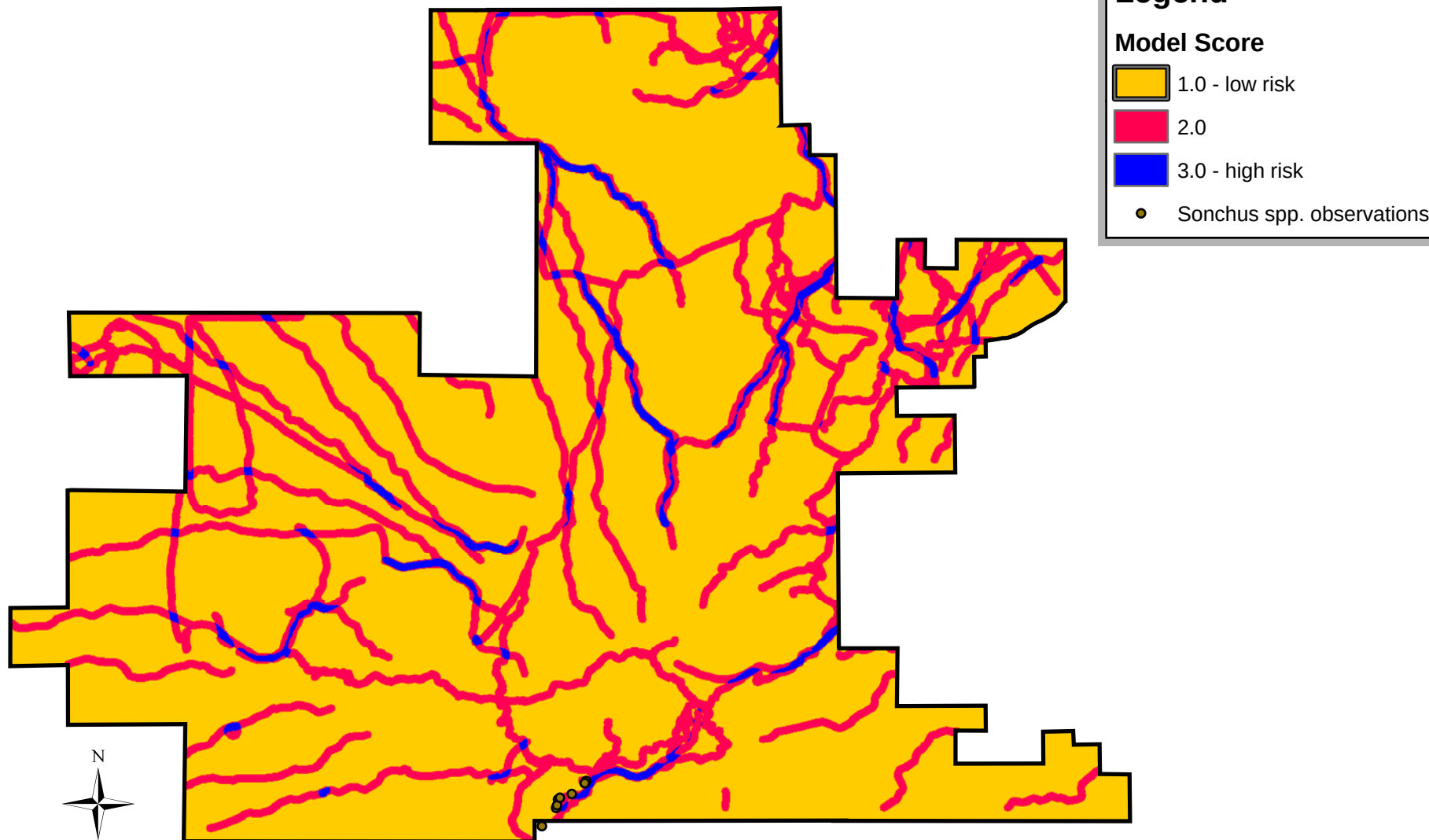
-  1.0 - low risk
-  2.0
-  3.0 - high risk
-  *Sonchus* spp. observations



0 0.5 1 2 3 4
Kilometers



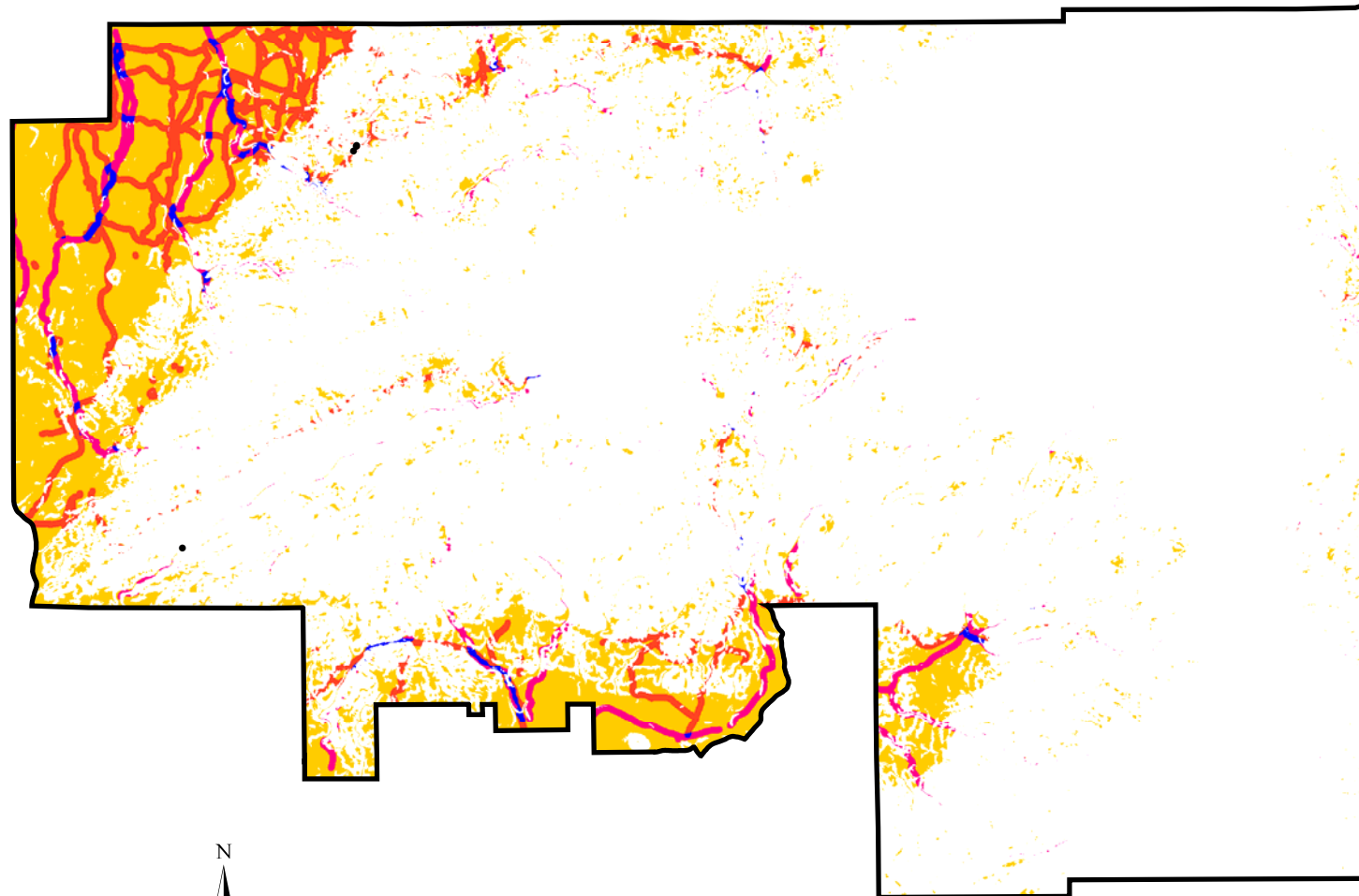
Sonchus asper and *S. oleraceus* spiny sowthistle and common sowthistle



0.375 1.5 2.25 3
Kilometers



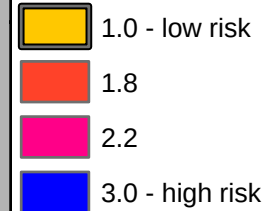
Sorghum halepense Johnsongrass



Legend

- *S. halepense* observations

Model Score



0 0.5 1 2 3 4
Kilometers



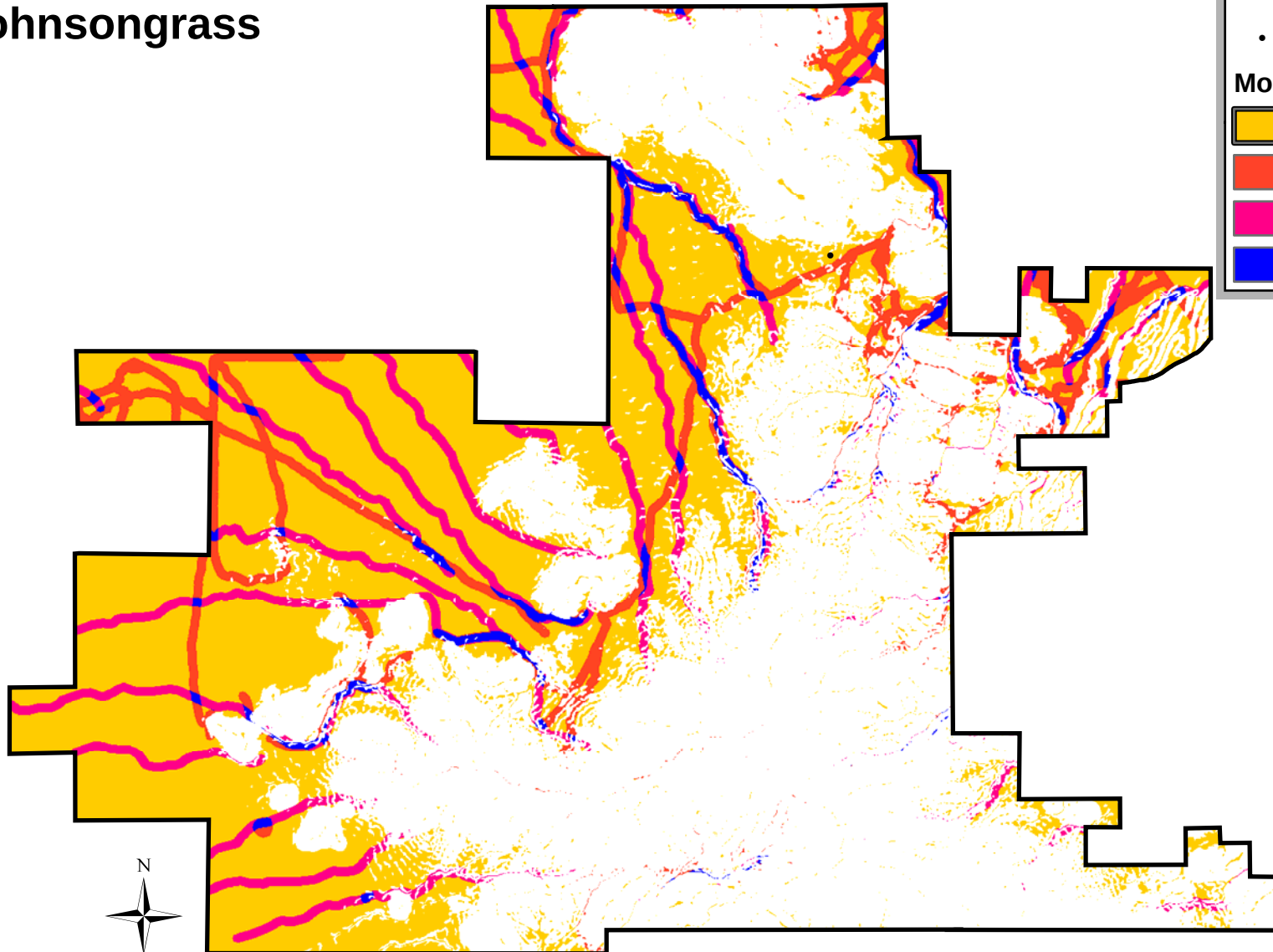
Sorghum halepense Johnsongrass

Legend

- S. halepense observations

Model Score

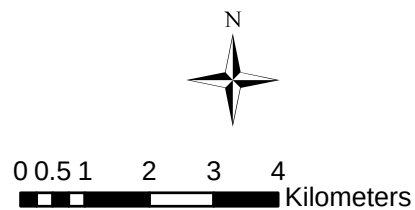
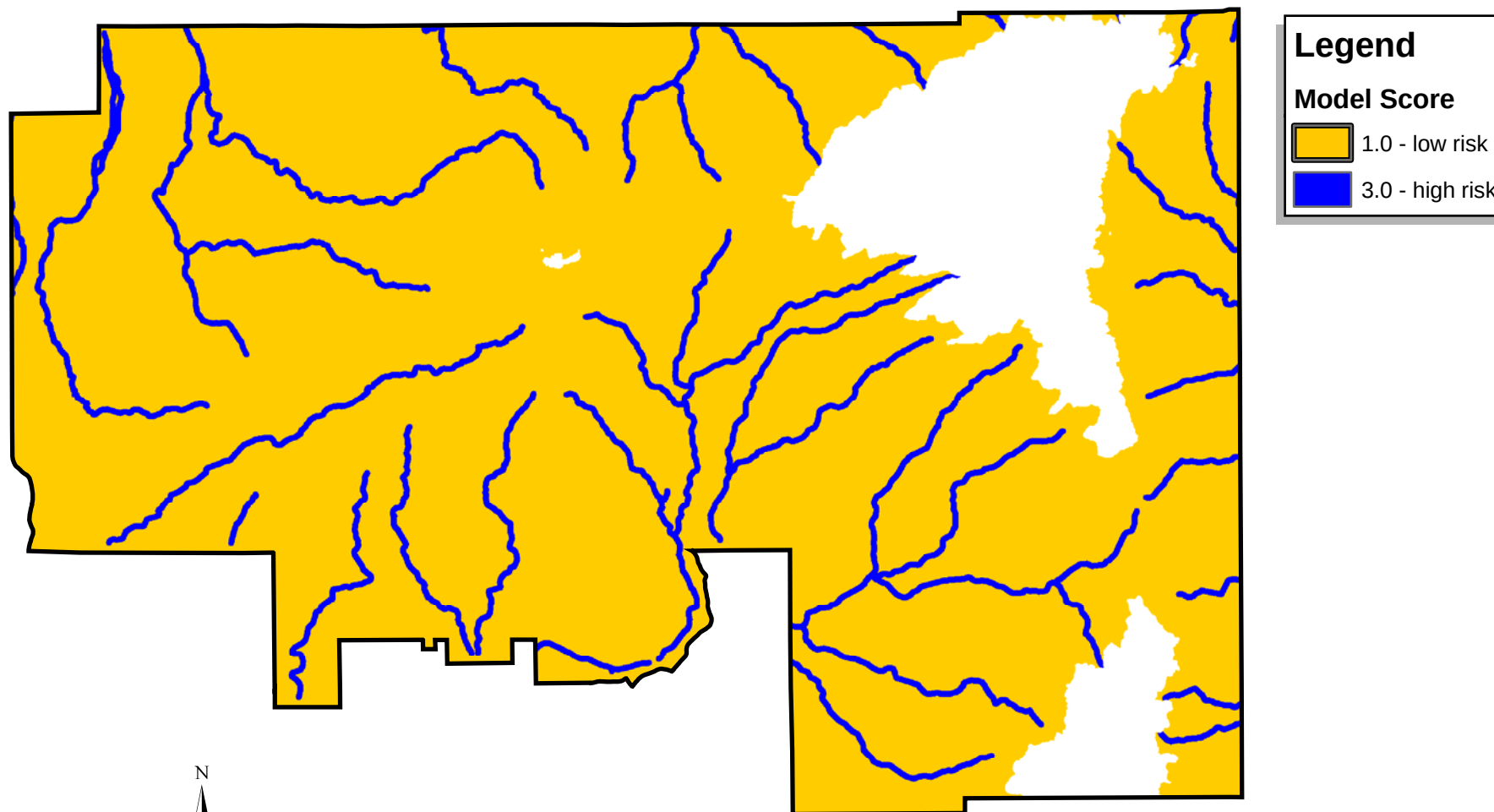
- 1.0 - low risk
- 1.8
- 2.2
- 3.0 - high risk



0 0.35 0.7 1.4 2.1 2.8
Kilometers

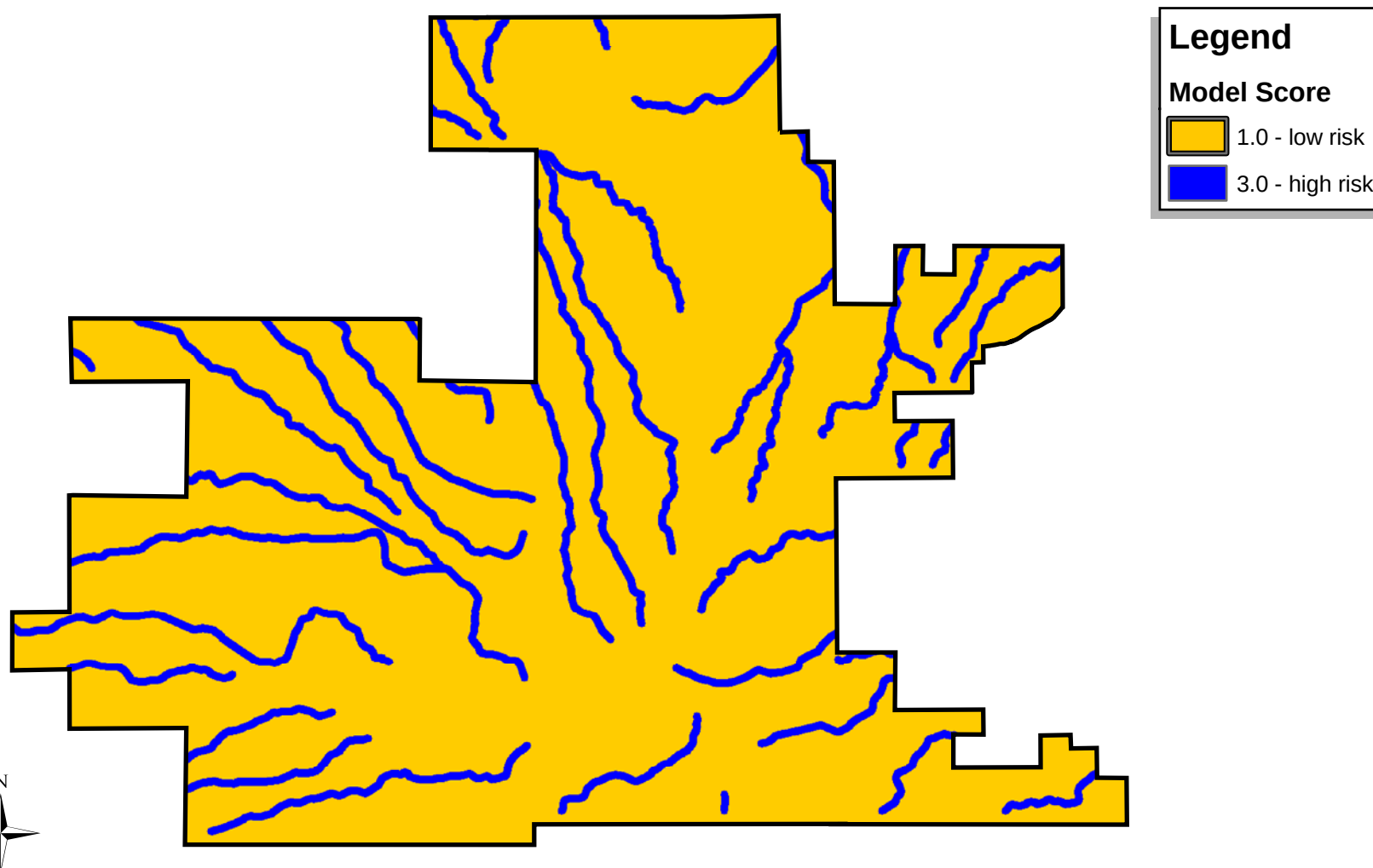


Tamarix aphylla*, *T. chinensis*, *T. parviflora*, *T. ramosissima
atheltree, five-stamen tamarisk, smallflower tamarisk, saltcedar





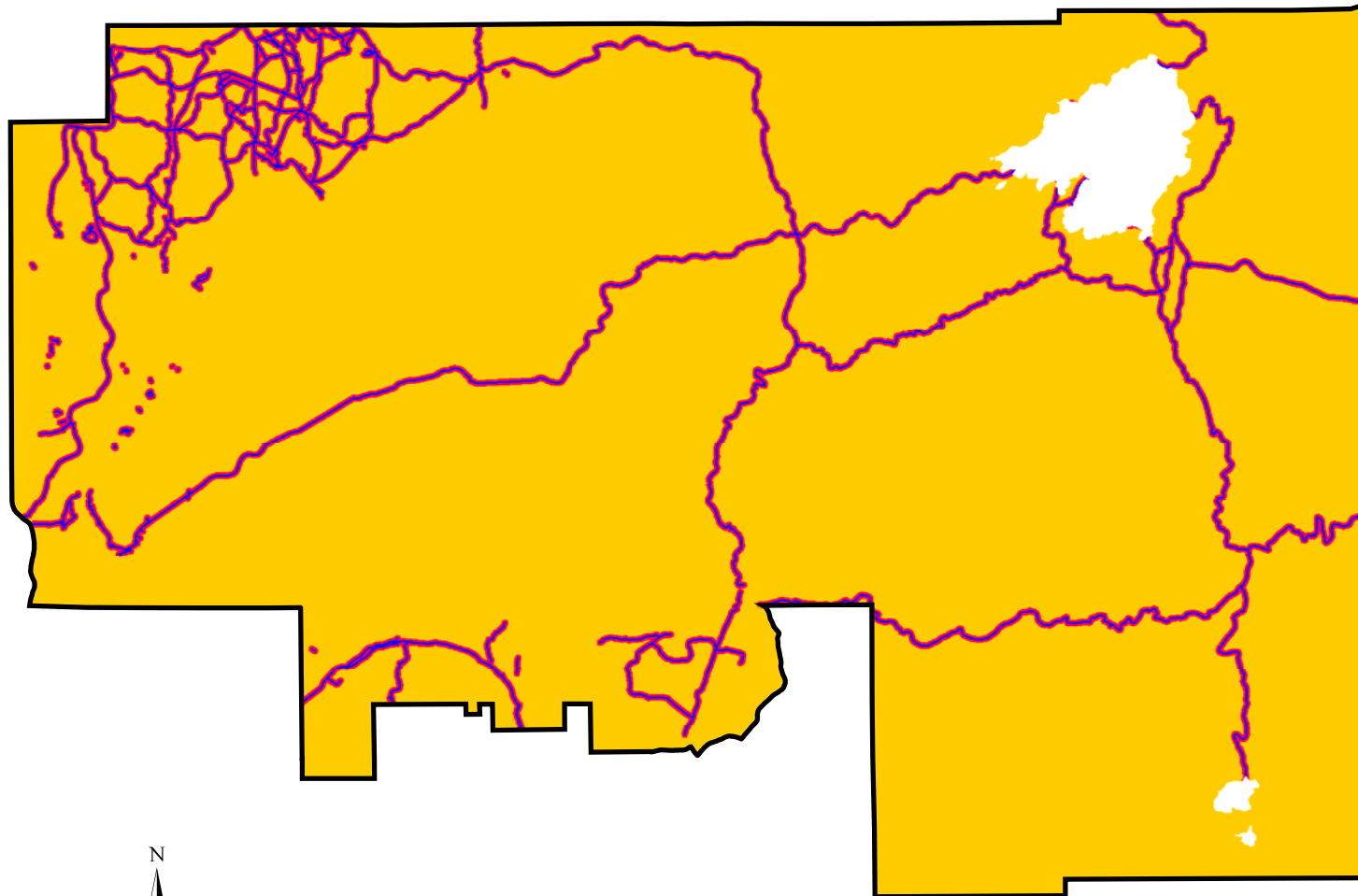
Tamarix aphylla*, *T. chinensis*, *T. parviflora*, *T. ramosissima
atheltree, five-stamen tamarisk, smallflower tamarisk, saltcedar



0 0.40.8 1.6 2.4 3.2
Kilometers

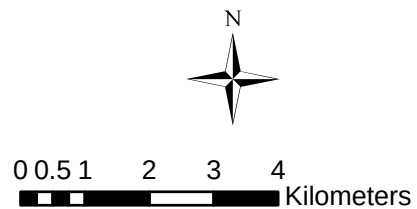


Taraxacum officinale common dandelion



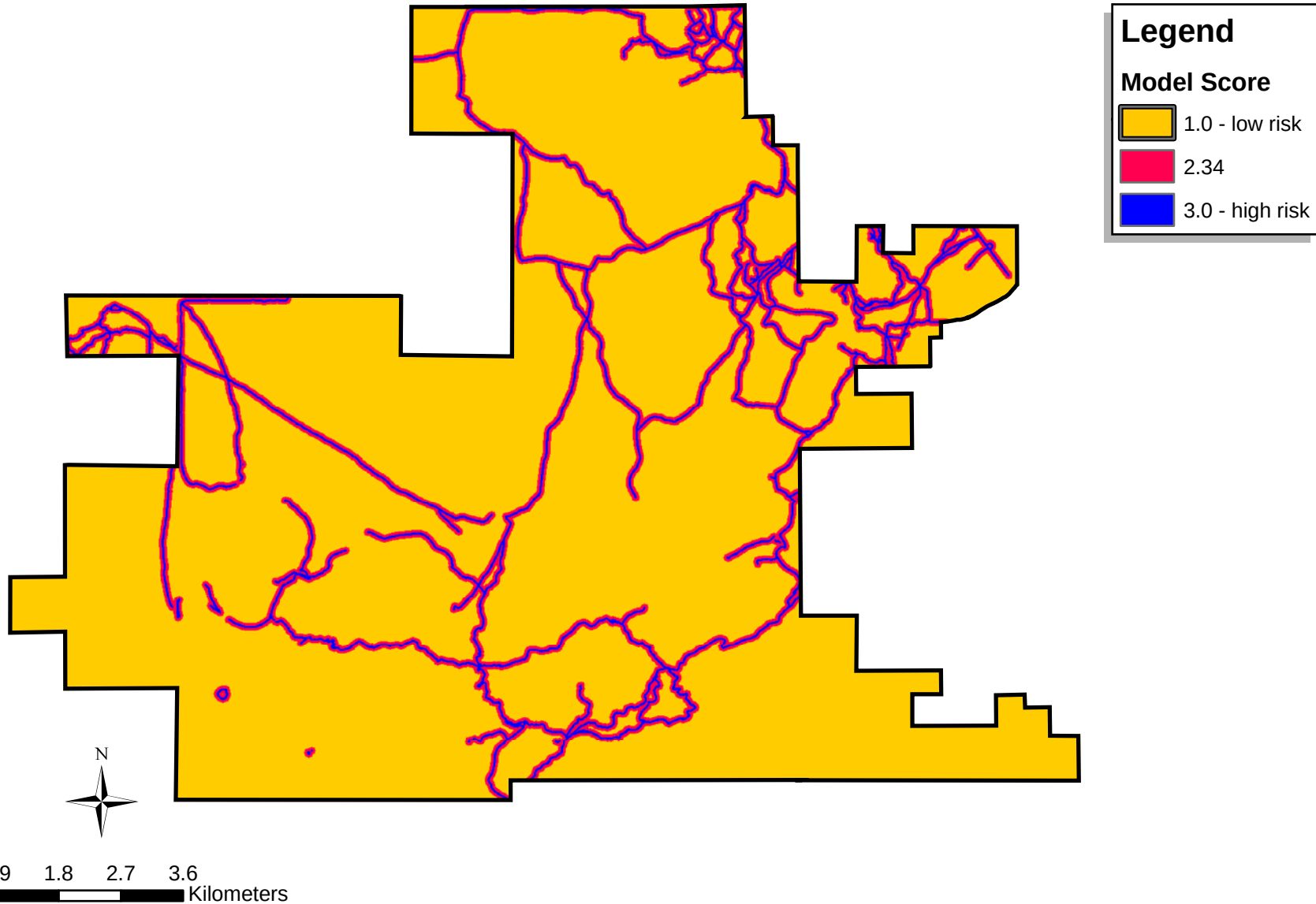
Legend

Model Score





Taraxacum officinale common dandelion



Appendix D: Using RRQRR Spatial Sampling Tool for ArcGIS 9

Appendix D: Using RRQRR Spatial Sampling Tool for ArcGIS 9 (Theobald et al. 2005)

This document briefly describes how to implement the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm to draw a spatially balanced sample. This algorithm is similar to the Generalized Random Tessellation Stratified (GRTS), as they both based on a hierarchical quadrant-recursive ordering using Morton order. The primary difference between the RRQRR tool and the R stats code developed for drawing a GRTS-based sample is that GRTS is feature-based (point, line, or area) and the RRQRR algorithm runs on raster grids within a GIS environment. Technical details on the RRQRR algorithm can be found in Theobald et al. (2005).

The main requirements to run the RRQRR tool are as follows:

- ArcGIS 9
- Service Pack 3 loaded (if not, download from <http://support.esri.com/index.cfm?fa=downloads.patchesServicePacks.gateway>)
- Add in Spatial Analyst extension (Tools → Extensions, put check mark next to Spatial Analyst)
- Add in STARMAP Spatial Sampling toolbox (located on the N: server [Apps Drive]):
 - o Right click in the ArcToolbox, select “Add Toolbox”, then navigate to where the toolbox is stored
- Set project workspace (Tools → Options → Geoprocessing... Environments → General Settings... Current Workspace)

Drawing a Spatially-balanced Sample

The major input is a raster surface where the bounds of the grid represent the sampling frame (areas which could potentially be included in the sample) and where the values of the grid cells represent inclusion probabilities (probabilities of likelihood of being selected as a sampling point – higher values represent a higher likelihood of being selected and lower values represent lower likelihood of being selected. A score of zero represents no possibility of that pixel being selected as a sampling point).

This input raster must range from 0 to 1. If your input raster does not, you will need to scale it so that it does. This can be accomplished using the Reclassify function (Spatial Analyst Tools → Reclass → Reclassify) in combination with converting the integer grid to a floating point grid. One approach is:

- Reclass grid values into classes 1 – 9
- Convert the integer grid (with values 1 – 9) to a floating point grid using Math → Trigonometric → Float
- Divide the floating point grid by 10 to result in values that range from 0.1 – 0.9 using Math → Trigonometric → Divide

To run the tool and generate a spatially balanced random sample, select the “spatially balanced sample” tool from the STARMAP Spatial Sampling toolbox. The help documentation describes the process well. Load your inclusion probability raster into the first window (Sampling frame & inclusion probability raster). It is fine to leave the number of runs at 1. If you have sampling locations that already exist that you would like to include in the new sample, load these as a layer in the 3rd window (Existing sample locations).

The output will be located in a time and date-stamped folder located within the project workspace. The point file, sbs_samples1.shp, will be a point file of your ordered sampling points. Use the field “PointID” as the order to visit the sampling locations. The “FID” field is a top-down, left to right ordering of the points and is not the field to use to order sampling locations.

Refer to the powerpoint “V:\SAGU_exotics\Presentations\SBSNotes_20050524.ppt” for a description of the grids generated through running the tool that appear in the time and date-stamped folder, these grids are intermediate files generated through the Morton ordering as part of the RRQRR algorithm. The sbs_1 raster is a raster of the final sample order that passed through the inclusion probability filter; it is from this subset of points that the final sample was drawn. Automatically, the top 0.1% of locations is selected from the sbs_1 raster and are presented in the sbs_samples1.shp file. If a larger or smaller sample is desired than was drawn, this can be accomplished by adding the sbs_1 layer into the project view, then selecting Spatial Analyst Tools → Map Algebra → Single Output Map Algebra. In dialogue box, type:

Con (sbs_1 <= XXX, sbs_1), where XXX refers to the ceiling of the value that can be selected from the sbs_1 raster grid.

However, Theobald et al. (2005) recommend that the sample size not be larger than 0.1%.

Point selection

Many more points than you expect to sample should be drawn using the RRQRR tool, as several of the points may be inappropriate for sampling when visited in the field. By selecting extra points, you allow some to be discarded. Selection of extra points also allows additional sampling locations to be added if the sample is increased in the future. Under such conditions, one would simply add the next point on the list.

Use of sampling points in the field

To increase efficiency in the field, plots would not need to be visited in the *exact* order specified by the RRQRR algorithm. Plots located in close proximity and likely to be included in the sample (say, plots numbered 22, 35, and 72 if a sample of 50 plots was desired) may all be visited in one field outing if a trip could be planned to easily include them all. Data from plot 72 may not actually be used in the final analysis, if 50 plots could be covered before plot 72 was reached, but the tradeoff should be considered: is it

more efficient to send the crew out to plot 72 later in the field if it is found to be necessary, or collect the data when they are out there, risking that it may not get used?

References

Theobald, D.M., D.L. Stevens, Jr., D. White, N.S. Urquhart, and A.R. Olsen. 2005. Using GIS to generate spatially-balanced random survey designs for natural resource applications. Manuscript submitted to *Environmental Management*. Available online: www.nrel.colostate.edu/projects/starmap/download/rrqrr/theobald_etal_RRQRR20050706.pdf.