Interim Performance Report:

Determining prescribed fire and fuel treatment compatibility with semidesert grassland habitat rehabilitation for the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*)

Project ID: 13-1-06-16

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Table of Contents

I. Project objectives

This project is focused on determining fire-effects on habitat conditions for the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*) whose historical range inside the U.S. overlaps with Buenos Aires National Wildlife Refuge (BANWR). The principle objectives of this project are to 1) Improve field sampling methods to efficiently monitor long- and short-term fire treatment effects on semidesert grassland fine-fuel loads, vegetation composition and structure important to masked bobwhite quail survival and reproduction, 2) Compare field plots, masked bobwhite habitat conditions, and habitat suitability index (HSI) outputs according to fire management histories summarized from the USFWS fire atlas, 3) Assess how fire frequency and spatial and temporal pattern of burn can most likely achieve masked bobwhite habitat rehabilitation, and 4) Determine how other interacting site biophysical factors such as annual variation in rainfall, soil substrates, terrain variability, and other edaphic factors may positively or adversely impact habitat conditions modified by fire. To the degree possible, grazing history prior to refuge establishment in 1985 and other land use factors will also be considered. In addition, this project seeks to combine a field study of long-term fire effects on a semidesert grasslands with other geospatial data to characterize habitat conditions at fine- to landscape-scales.

Previously developed expert-based HSI functions will be used for this project because an established population of mask bobwhite quail does not currently exist on BANWR study site or for any other location within the U.S. (LaRoche and Conway 2012, **Appendix A**).

II. Changes to the project

We have completed the third year of this 3-year project. JFSP funding was awarded in July of 2013 to US Fish and Wildlife Service Southwest Region. Our Grants Contracts Office was only able to complete a cooperative agreement and sub-award to research partners at the Northern Arizona University (NAU) Lab of Landscape Ecology and Conservation Biology by February of 2014. This caused delays to the project, and adjustments were made to the timing of field sampling. We had originally planned to complete all fieldwork in 2014, but have conducted a second full season of fieldwork in 2015. Because of some initial delays at the beginning of the project, we were also granted a one-year extension of the project until June of 2017. Nevertheless, we were able to collect destructively sampled herbaceous plant biomass (fine-fuels) together with Decagon AccuPAR LP-80 ceptometer Leaf Area Index (LAI) measurements in 2013 as part of another USFWS funded project on BANWR. A dry weight biomass regression tree model was developed from oven dried and weighed biomass collected in 2013. The model performed well when tested with quadrat samples left out of model training (r^2 = 0.87). We applied this model to non-destructive samples collected on 2014 and 2015 vegetation plots. Despite adjustments to the project timeline, the LAI-based biomass model allowed us to increase the number of plots sampled during 2014 and 2015 field seasons.

III. Project progress

The following project milestones and deliverables have been completed or nearly completed during the first to third years of the project (**details on pages 5 - 11**):

Project Milestones	**Dates**
Fine fuel biomass data field collection protocol and processing	Aug. – Nov. 2013
Fine fuel biomass model completed	Dec. – Jan. 2014
MS graduate student recruited	Jan. 2014
Sub-award to project cooperator, Northern Arizona University, Lab of Conservation Biology and Landscape Ecology	Feb. 2014
Project kick-off meeting at with BANWR staff, fire managers, cooperators and stakeholders	Jun. 2014
Field stratification and protocol development using fire history and topoedaphic GIS data layers	Jul. 2014
1st field study of masked bobwhite habitat conditions, measuring vegetation composition and structure, soil and fine fuels	Aug. – Nov. 2014
Multivariate analysis of previous years (2012 – 2013) vegetation data	Sept. 2014
Soil sample processing	Jan. – Jun. 2015
Data processing and preliminary analyses of 2014 vegetation data	May – Jul. 2015
2nd field study of masked bobwhite habitat conditions, measuring vegetation composition and structure, soil and fine fuels	Aug. – Oct. 2015
Conference presentation at the Biennial Conference of Science & Management of the Colorado Plateau & SW Region in Flagstaff, AZ	Oct. 2015
JFSP project presentation to masked bobwhite endangered species	May 2016

recovery team in Tucson, Arizona	
Final field data processing of 2015 vegetation and soils data	May 2016
JFSP project presentation to masked bobwhite recovery team and Mexican collaborators, Benjamin Hill, Mexico	July 2016
Development of an R statistics package "MBQhsi" to compute masked bobwhite quail habitat suitability from expert derived model functions	June 2016
Data processing and preliminary analyses of 2014 - 2015 vegetation data	May – August 2016
Conference presentation at Beyond hazardous fuels: managing fire for social, economic, and ecological benefits. Tucson, AZ.	Nov. 2016

This interim report focuses on new work completed or work in progress for 2016. Project progress and preliminary results from previous work can be viewed in prior interim reports for 2014 and 2015. We have made several advances with respect to project deliverables in addition to developing landscape-scale fine-fuels and quail habitat data from vegetation plots measured between 2012 and 2015 using National Park Service sampling protocols (Hubbard et al. 2012). We have presented preliminary data and results to the Masked Bobwhite Quail Endangered Species Recovery Team and BANWR refuge managers on two separate occasions as well as helping to develop future management priorities for establishing quail populations in Arizona and Sonora, Mexico. This year's activities have involved regular interaction with refuge managers and recovery team members to preset project details and results during key discussion about future management and research priorities for masked bobwhite in Arizona and Mexico. Below, we briefly describe each element of the project developed to analyze fire and other effects on masked bobwhite habitat to determine current landscape conditions on BANWR and help guide future fire and quail management activities.

a. Field data development

To date, all field sampling has been completed, entered into a project database, and summarized for analyses. In addition, laboratory analyses of soil sample chemical and physical properties have been completed for a total of 239 plots (**Figure 1**). Additional plots from 2012 and 2013 (*n* = 207) provide supplementary data from across the refuge for a total of 446 plots, however the majority of analyses to determine fire effects on vegetation use only 2014 and 2015 data from a stratified random sample within the masked bobwhite management zone (**Figure 1**). Data summary scripts in the R statistics package (R Development Core Team 2016) were also developed to create plot-scale variables to estimate masked bobwhite habitat suitability from HSI (Laroche and Conway 2012). Plots were further summarized using multivariate and other techniques to develop training data for remote sensing-based models of fine-fuel biomass, vegetation classes, and other vegetation parameters (e.g. percent woody and herbaceous plant cover) important to masked bobwhite quail.

b. Fire effects on vegetation

Preliminary analyses using permutational multivariate analyses of variance (PERMANOVA) resulted in a significant relationship between fire frequency and vegetation composition on BANWR. However, a primary focus for this research is to determine important fire and biophysical factors influencing habitat conditions essential to masked bobwhite. A cursory investigation of the vegetation and environmental data using hierarchical clustering and ordination of plots revealed multiple factors are potentially related to plant distributions on BANWR (**Figure 2A-C**). As most fires on BANWR are intentional prescribed burns and, at times, used to mitigate hazardous fuels, fire frequency was highly correlated with ordination axis 1 in the direction of plots dominated by non-native invasive grass species *Eragrostis lehmanniana* (**Figure 2C)**. *E. lehmanniana* develops a more continuous fuelbed layer and has 2 to 4 times the amount of biomass as native plant dominated sites (Anable et al. 1992, Van Devender et al. 1997, *see also* 2015 interim project report). A moderate precipitation gradient was also shown as increased growing season precipitation in the southern portion of BANWR where *E. lehmanniana* cover is high (**Figure 2A**). A mantel correlogram of plant species, soil texture and fire further indicated that a moderate environmental and disturbance gradient exists within the masked bobwhite management zone (**Figure 3**).

To better understand relationships among factors driving plant composition, we chose a structural equation modeling (SEM) approach that was suitable for investigating complex ecological relationships (Grace et al. 2010). We are currently developing multilevel SEM models to determine general plant composition differences on plots with respect to environmental and disturbance factors, in addition to those related to specific plant life forms such as native shrub, grass, and forb cover and diversity. Each of these habitat constituents has been previously identified as important to maintaining masked bobwhite populations in Sonoran Desert grasslands (Tomlinson 1972, Hernandez et al. 2006). To construct preliminary SEMs, we used non-metric multidimensional scaling (NMDS) ordination axes 1 scores as a dependent variable that was highly correlated with native (Pearson r = -0.72) and non-native (Pearson r = 0.92) vegetation cover. Ordination axis 2 scores were a second dependent variable that was related to a topoepahic gradient and principally grasses and forbs inhabiting low areas that are occasionally inundated during summer monsoon rainfall and flooding (**Figure 2B**).

We have preliminarily developed SEM for general plant composition conditions; however this approach was promising to help address complex hypotheses about factors driving habitat conditions for the masked bobwhite. Results from SEM to date indicated that fire frequency and warm-season rainfall had a significant and positive effect on grass cover that was strongly correlated with NMDS axis 1 (**Table 1, Figure 4**). These results were consistent with recent investigations southwestern semidesert grasslands identifying soil texture and precipitation as important driving factors of fire occurrence and frequency (Levi and Bestelmayer 2016). As we had anticipated, time since last burn had a significantly negative effect on forb cover as greater forb cover is often associated with recently burned areas correlated with NMDS axis 2. Further work will develop multilevel SEM for desired masked bobwhite habitat characteristics outlined in the BANWR 2010 Habitat Management Plan such as cover and diversity by plant life forms observed on plots.

We originally proposed to determine fire and other effects on masked bobwhite habitat using expert derived habitat suitability (HSI) values (LaRoche and Conway 2012). Our desired approach was to calculate HSI from plot measurements (**Appendix A**), and then develop probabilistic models of habitat suitability from disturbance and biophysical variables. We anticipated using a multi-model inference approach to compare *a-prior* defined candidate models (Anderson 2008). To improve this aspect of the research we developed the “MBQhsi” R statistics package to estimate habitat suitability at the individual plot-scale with help of project collaborator, Dominic LaRoche. However, there were 9 separate expert HSI models that include a literature-based model, each with a unique set of model variables and empirical functions. Our initial comparisons of HSI derived from vegetation plots yielded strongly different habitat suitability outcomes. For example, models developed by experts Goodwin and Tomlinson were poorly correlated with one another (Pearson r = 0.06). Tomlinson habitat suitability values were far lower than Goodwin HSI using the same plot data and covered a narrower range of values (**Figure 5**).

While a single preferred HSI model can feasibly be used, additional verification of model outputs will be required to use these values as a response to fire management practices and biophysical variables. In contrast, the SEM approach can be used to estimate fire impacts on individual habitat constituents without specific suitability thresholds for the masked bobwhite. Thus, factors influencing cover by leguminous shrubs and forbs preferred by masked bobwhite as a source of winter food and thermal protection will be explored using multilevel SEMs. Final SEMs are anticipated to highlight disturbance and biophysical relationships for each aspect of habitat suitability related to masked bobwhite food resources, cover and reproduction that are critical to recovering populations (LaRoche and Conway 2012).

c. Landscape-scale models of vegetation

An objective of this project was to scale-up plot measurements to assess habitat conditions for the masked bobwhite and fine-fuel biomass as it relates to habitat rehabilitation and potentially hazardous fuel conditions. Landscape-scale habitat and fuels information were developed by combining BANWR plots with multispectral and multitemporal data from 2015 high spatial resolution Worldview-3 and Landsat-8 OLI satellite imagery. We used plot data summaries to predict vegetation classes, fine-fuel biomass (Kg/ha), and percent cover for woody and herbaceous plants and bare ground (**Figure 6 A-D**). Random forest classification and regression tree models were used to predict vegetation parameters and evaluate model performance from Landsat- and Worldview-based predictions (Breiman 2001). Models using Worldview-3, 8-band imagery resampled to a 10m pixel size performed only slightly better than Landsat models. We used two Worldview-3 image dates from 2015 representing a "peak-green" date in September and an image from November that represented a "brown date" or point when most vegetation was non-photosynthetically active or senesced. Visible and near infrared bands (NIR) as well as spectral vegetation indices (VI) that are sensitive to plant biomass and Leaf Area Index (LAI; Huete et al. 2002) were used to predict vegetation parameters from plots to un-sampled areas. Vegetation classes were predicted at an overall accuracy of 80% and cover models explained between 41% and 55% of the variation with regression tree methods.

We further developed regression tree models of masked bobwhite habitat suitability using HSI values predicted from Worldview-3 spectral bands and VI, however results were poor

(<15% variation explained). A number of vegetation parameters for the masked bobwhite are structural conditions such as vegetation height, density, and cover by life form. Other airborne remotely sensed data such as discrete return laser altimetry (LiDAR) to characterize 3-dimentional structure may help to better predict habitat suitability. A LiDAR data acquisition for BANWR has been targeted for 2017 by the USGS 3D Elevation Program (3DEP). Nevertheless, selecting an appropriate HSI model or combination of models is needed to refine these approaches.

d. Data synthesis

Spatial data developed from plots and satellite imagery are being used to identify important habitat areas for releasing captive raised masked bobwhite and estimating potential fire behavior across the refuge.

First, to help determine the current status of fire and habitat management units on the refuge and potential masked bobwhite release sites, we used our vegetation map to group units with similar landscape conditions. We performed an ordination of management units overlaying them with principal groups identified from hierarchical cluster analysis and landscape conditions contributing to differences among units (**Figure 7A, B**). We estimated an optimal number of management unit groups from k-means clustering and observing changes in the within group sums of squares at sequentially smaller group sizes (data not shown). Management units grouped by landscape conditions highlighted important habitat differences between units located in the northern and southern portions of the refuge (**Figure 7A, B**). The southern portion of the refuge is characterized by medium to high fire frequency while the northern portion is characterized by low to medium fire frequency (**Figure 1**). Locations identified as potential sites for masked bobwhite releases by refuge managers and recovery team experts corresponded with management units labeled as 1c and 1b (**Figure 7B**), in the northern portion of the refuge that have greater cover by of native grasses and mixed vegetation. Further analyses within specific management units will use plot data to help determine existing habitat conditions important to the masked bobwhite.

We also used the fine-fuel and vegetation class data layers developed from 2015 Worldview-3 imagery to refine standard fuel model types for estimating potential fire behavior on BANWR following Scott and Burgan (2005). Fuel models were visually compared to 2001 and 2014 LANDFIRE fuel types indicating differences particularly grass (GR) and grass-shrub (GS) fuel type distributions (**Figure 8A-C**). Assumptions made for disturbance areas and refreshed LANDFIRE fuel models is that burned areas return to a grassland fuel type, however this is not always the case for semidesert grasslands with dominant cover by velvet mesquite (*Prosopis velutina)* and non-native grasses (Kupfer and Miller 2005, Geiger and McPherson 2005). Previous grazing history, fuel-bed characteristics and fire behavior (e.g. fire-line intensity and scorch height) play a key role in post-fire vegetation structure and composition. Our future work will compare: 1) 2015 Worldview-3/Landsat-8 OLI, 2) LANDFIRE 2001 (baseline), and 3) 2014 fuel types using FlamMap (Finney 2006) model outputs (e.g. fireline intensity and burn probability) to assess potential fire behavior within important habitat areas and release sites for masked bobwhite quail.

e. Next steps

This project is providing modern fire and habitat monitoring tools important to improving masked bobwhite quail recovery efforts. We anticipate frequent interaction with the masked bobwhite recovery team and BANWR managers to share results over the remainder of this project, and in the future.

Further work will fully develop SEM models to characterize fire and biophysical impacts on vegetation important to rehabilitating masked bobwhite quail habitat on BANWR. SEMs will also include latent variables such as soil impacts from an intensive grazing history measured using soil bulk density estimates for plots. Other factors such as solar radiation on a site and soil fertility will be compared to assess site-scale biophysical variables potentially important to vegetation responses in addition to fire-effects. Fire behavior modeling with both Worldview-3/Landsat-8 and LANDFIRE fuel models will also be used to develop estimates of hazardous fuels on BANWR and where they may or may not overlap with perspective quail release sites. We anticipate two main publications to be developed from this work. One publication will focus on SEMs to determine fire and biophysical factors important to rehabilitating desired masked bobwhite habitat conditions. A second publication will identify and test field sampling and remote sensing techniques that can be used to improve inputs for fire behavior models and help prioritize fire management activities for achieving desired ecological conditions on BANWR.

Further work is needed to more fully explore and validate expert derived HSI to obtain reliable habitat suitability estimates. We have not explored HSI by all experts and, in particular, the literature-based model which may provide a baseline for comparing expert models. Further efforts are also needed to reduce spatial bias derived from individual plots used to obtain suitability estimates. For example, plot-scale suitability does not effectively represent quail home range conditions that are important to sustaining individuals in a population. An iterative selection of plots and vegetation attributes within a potential home range size (~10 ha) can potentially be used to reduce spatial biases and improve habitat data to determine priority release sites for captive raised birds.

Various aspects of fire effects monitoring and data development techniques from this project are anticipated to be transferable to other parts of the Southwest National Wildlife Refuge System. In addition, sampling protocols and remote sensing techniques are currently being transferred to priority sampling locations within the historical masked bobwhite range in Sonora, Mexico where wild populations may still exist.

f. Presentations

Yurcich, E., S.E. Sesnie, and T.D. Sisk. 2016. Estimating prescribed fire effects on semidesert vegetation composition and structure using 30-year Landsat derived fire history data. Beyond hazardous fuels: managing fire for social, economic, and ecological benefits. Tucson, AZ. November 28 – December 2

Sesnie, S.E., E. Yurcich, H.E. Eagleston, and L. Johnson. 2016 Determining prescribed fire and fuel treatment compatibility with semidesert grassland habitat rehabilitation for the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*)**.** Masked Bobwhite Endangered Species Recovery Team meeting. May 20, Benjamin Hill, Mexico.

Sesnie, S.E., E. Yurcich, H.E. Eagleston, and L. Johnson. 2016. Determining prescribed fire and fuel treatment compatibility with semidesert grassland habitat rehabilitation for the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*. Masked Bobwhite Endangered Species Recovery Team meeting. March 3, Tucson, AZ.

Yurcich, E., S.E. Sesnie, and T.D. Sisk. 2015. Estimating prescribed fire effects on semidesert vegetation composition and structure using 30-year Landsat derived fire history data. Biennial Conference of Science and Management on the Colorado Plateau & Southwest Region. October 5 – 8, Flagstaff, AZ

Sesnie, S.E., L.J. Zachmann, B.G. Dickson, E. Yurcich, J.M. Rundall, and L. Johnson. 2015. Multiscaled approaches to southwestern arid lands vegetation monitoring, modeling, and management. Biennial Conference of Science and Management on the Colorado Plateau & Southwest Region. October 5 – 8, Flagstaff, AZ

Sesnie, S.E., M. M. Altemus, and L. Johnson. 2014. Field ceptometer LAI measurements for monitoring semidesert grassland biomass, fuel loads, and wildlife habitat conditions with remotely sensed data. ASPRS Rio Grande Chapter Annual Spring Meeting, April 5th, 2014. University of New Mexico, Albuquerque, NM.

Sesnie, S.E. 2015. Presentation to the masked bobwhite quail recovery team: Mapping habitat suitability for masked bobwhite quail (*Colinus virginianus ridgwayi*) using MODIS phenology products. February 18th, Tucson, AZ.

g. Related publications and reports

Sesnie, S.E. and H. Eagleston. (*Submitted*). DOI Remote Sensing Activities Worldview-3 derived vegetation products for masked bobwhite quail habitat management and re-introduction. DOI Remote Sensing Working Group. On-line report.

Sesnie, S.E. 2015. DOI Remote Sensing Activities 2015. Estimating prescribed fire effects on semidesert vegetation composition and structure using 30-year Landsat derived fire history data. DOI Remote Sensing Working Group. On-line report.

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Tables

Table 1. SEM maximum likelihood estimate, regression weights and standardized regression weights. Explanatory variables are time since burn (Tsb), percent clay (clay), topographic wetness index (twi), fire frequency (freq), combined sand that is the total percentage of all sand particles sizes, and amount of precipitation for the warmest month (Bio_18) from Worldclim bioclimatic data layers.

Variables	**Estimate**	**S.E.**	**C.R.**	**P-value**	**Std. Estimate**
Forb cover <--- Tsb	-0.574	0.133	-4.32	<0.001***	-0.244
Forb cover <--- clay	3.621	0.706	5.126	<0.001***	0.293
Forb cover <--- twi	1.26	0.371	3.4	<0.001***	0.194
Graminoid cover <--- Tsb	0.078	0.189	0.415	0.678	0.024
Forb cover <--- freq	-2.085	0.567	-3.678	<0.001***	-0.207
Graminoid cover <--- freq	3.375	0.805	4.193	<0.001***	0.24
Graminoid cover <--- combined sand	0.241	0.099	2.437	0.015**	0.139
Graminoid cover <--- Bio_18	1.322	0.2	6.616	<0.001***	0.379
NMDS2 <--- Forb cover	0.008	0	19.687	<0.001***	0.787
NMDS1 <--- Graminoid cover	0.006	0	16.932	<0.001***	0.739

*significant at the <0.05 level, **significant at the <0.01 level, ***significant at the <0.001 level

Figures

Figure 1. BANWR study area (left figure) and masked bobwhite management zone (pink area). Fire frequency and terrain strata sampled on plots (black dots) during the 2014 and 2015 field seasons are shown in the middle and right figures.

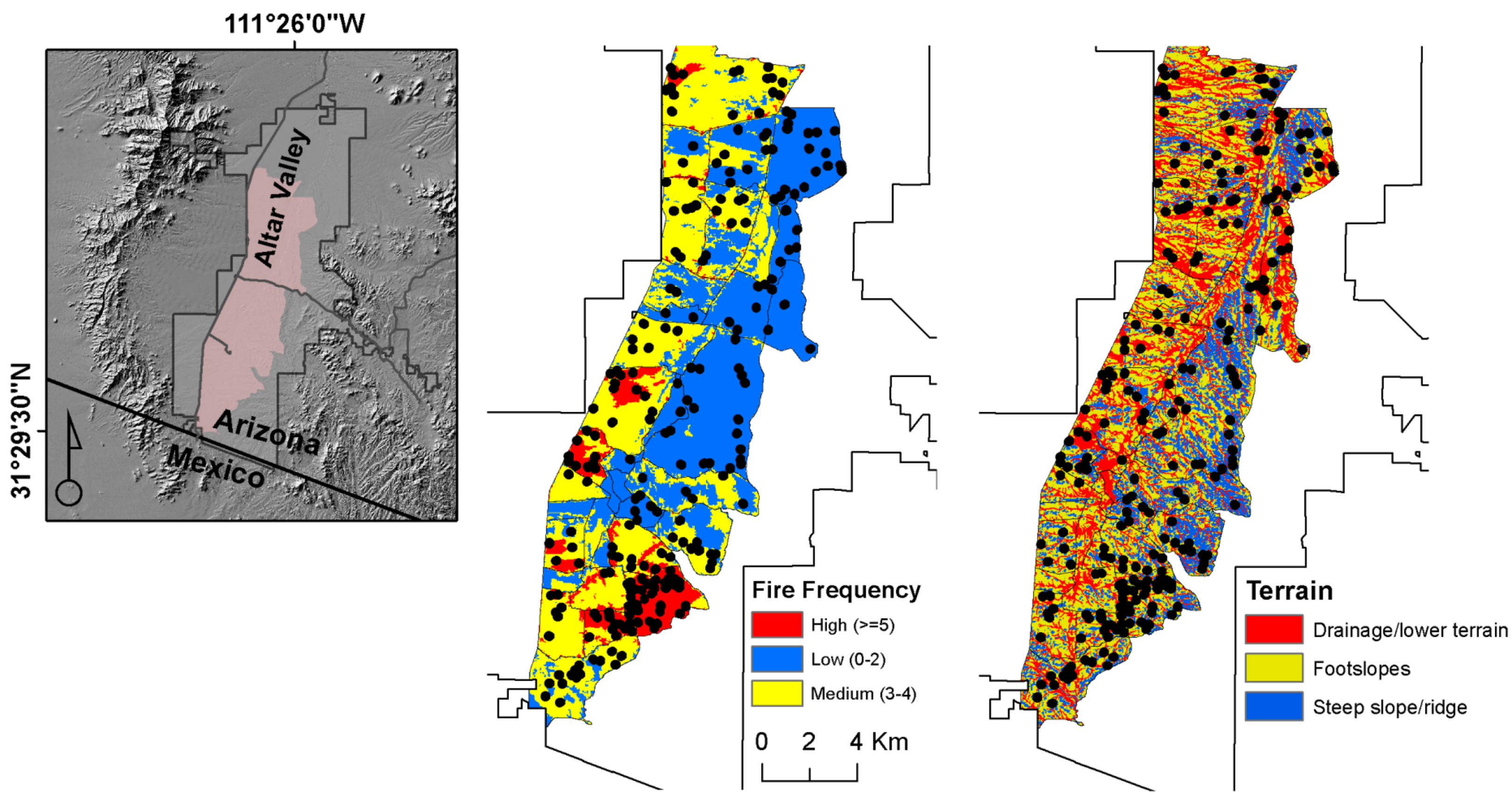


Figure 2. Ordination of a plot (2014 and 2015) by plant species dissimilarity (Bray-Curtis) matrix rotated on non-native grass *E. lehmanniana* which can achieve as much as 70% canopy cover on BANWR. Blue vector overlays represent a significant correlation with ordination axes by **A**) Worldclim bioclimatic variables (http://www.worldclim.org/) representing temperature (pointing left) and precipitation (pointing right), **B**) soil texture and topographic variables (twi = topographic wetness index), and **C**) fire frequency (Freq) and a corrected time since last burn (Tsbc). Red vectors show the magnitude and direction of canopy cover and dominance by native and non-native plants, principally *E. lehmanniana*.

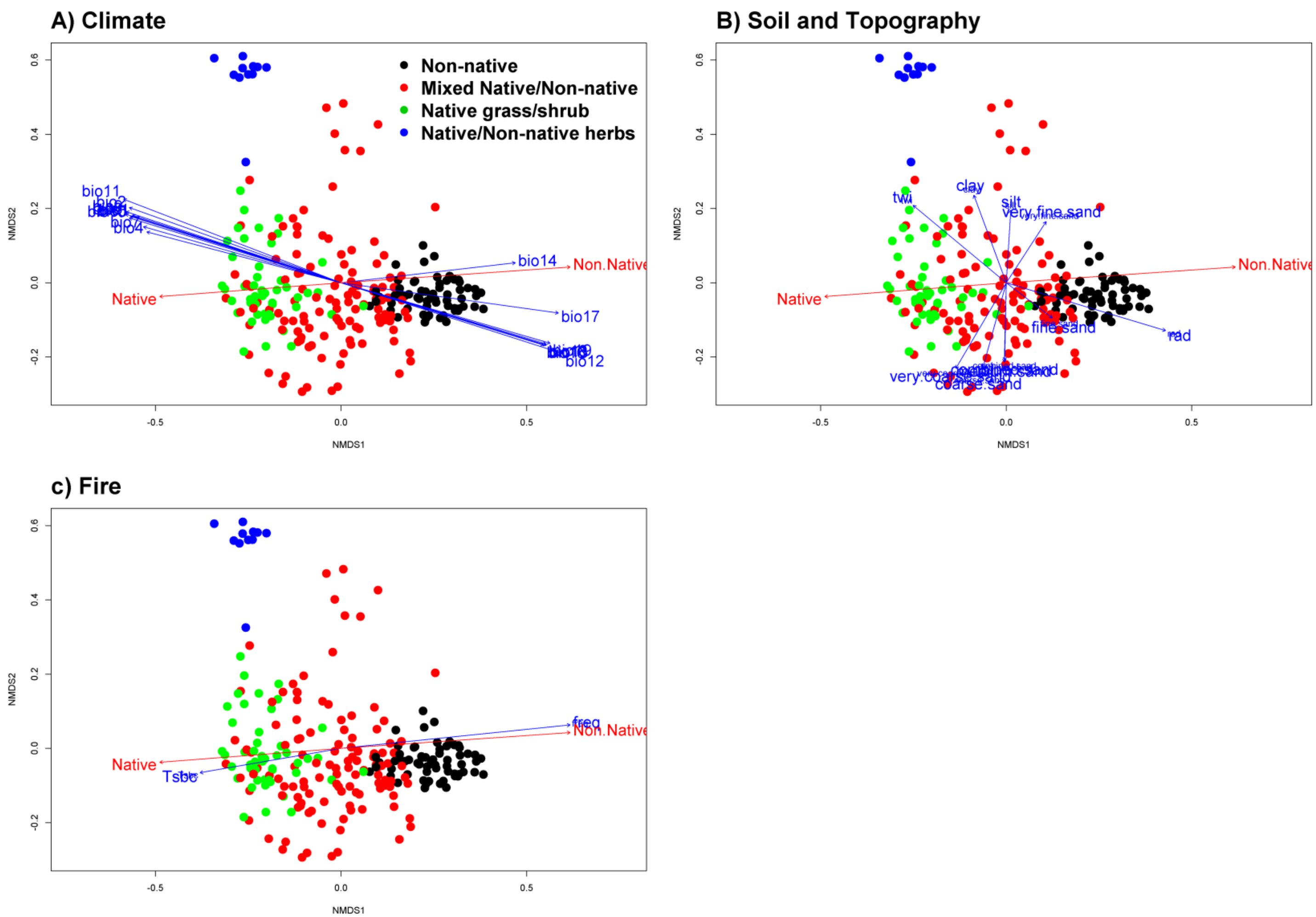


Figure 3. Mantel correlogram indicating the spatial correlation between plot species, fire history variables frequency (FREQ) and time since last burn (TSB), and soil texture variables (percentage by particle size classes for sand, silt and clay) within distance classes. Decreasingly positive and increasingly negative Mantel r values indicate that vegetation on plots are distributed along a soil texture and disturbance gradient (Legendre and Fortin 1989). Solid lines are 95% upper and lower confidence limits.

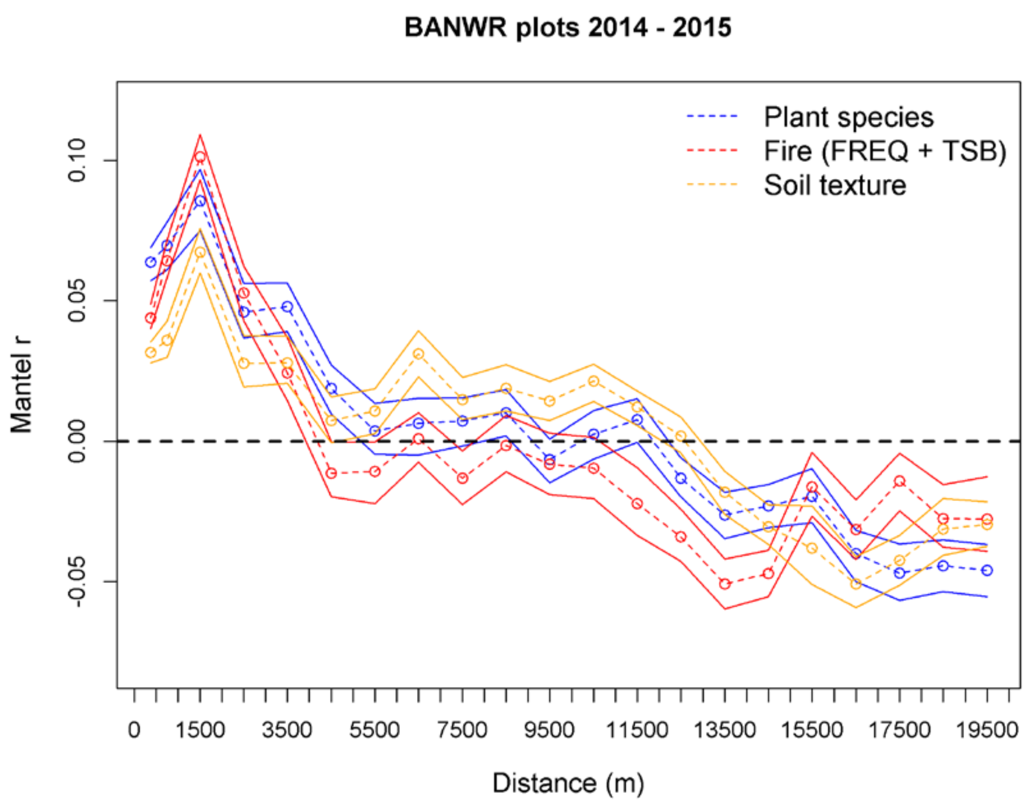


Figure 4. Preliminary SEM structure using NMDS axes 1 and 2 scores as dependent variables. Explanatory variables are topographic wetness index derived from a digital elevation model (DEM), percent clay (clay), time since last burn, fire frequency from the USFWS fire atlas, Worldclim precipitation from the warmest quarter of the year and combined sand which is the total percentage of sand. Each of the two model levels achieved an r^2 of 0.55 (NMDS1) and 0.61 (NMDS2) using forb and graminoid cover as endogenous variables strongly correlated with each ordination axis.

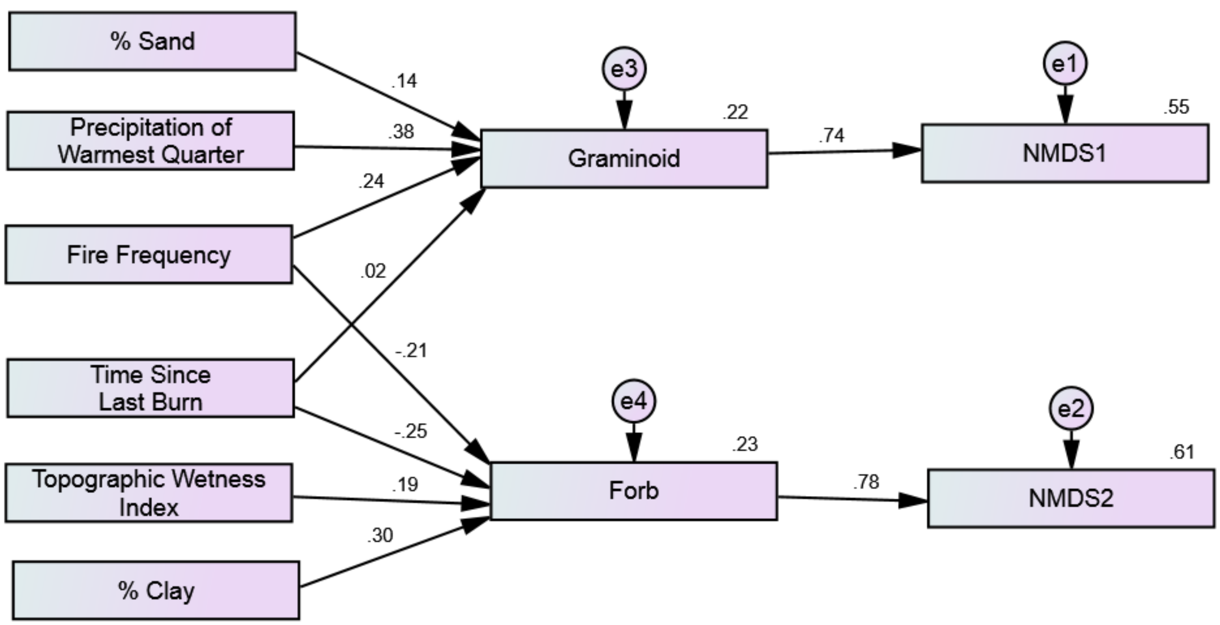


Figure 5. Masked bobwhite habitat suitability estimates from two separate expert derived HSI using the same plot data. Correlation between suitability outputs were extremely low (Pearson *r* = 0.06).

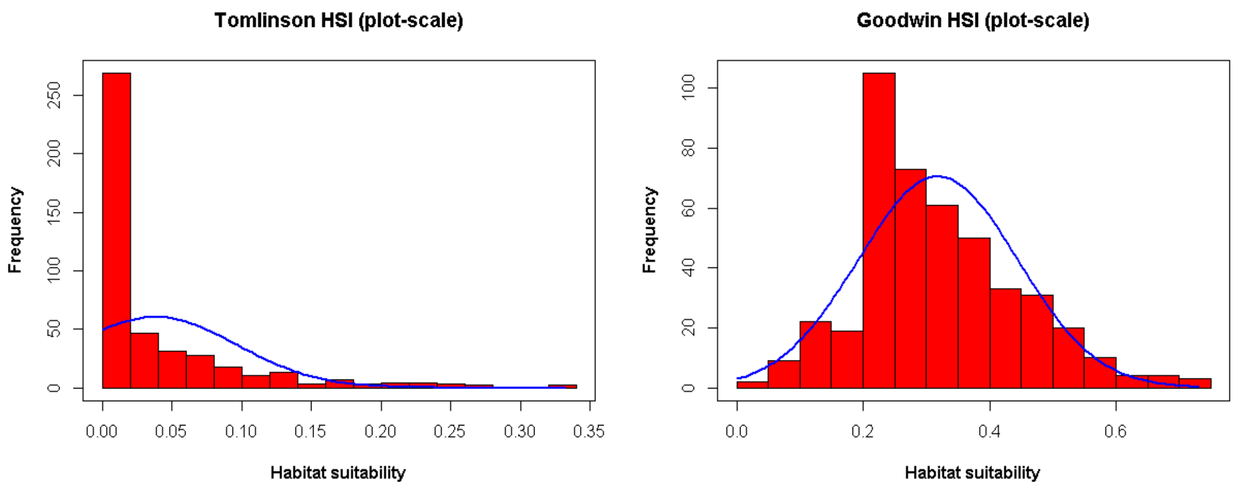


Figure 6. Landscape-scale using **A**) Worldview-3 2015 "peak-green" image used for to developing digital data layers of **B**) vegetation classes, **C**) herbaceous fine-fuels, and **D**) tree cover. Other digital layers developed were percent bare ground, woody vegetation cover (trees and shrubs) and herbaceous plant cover.

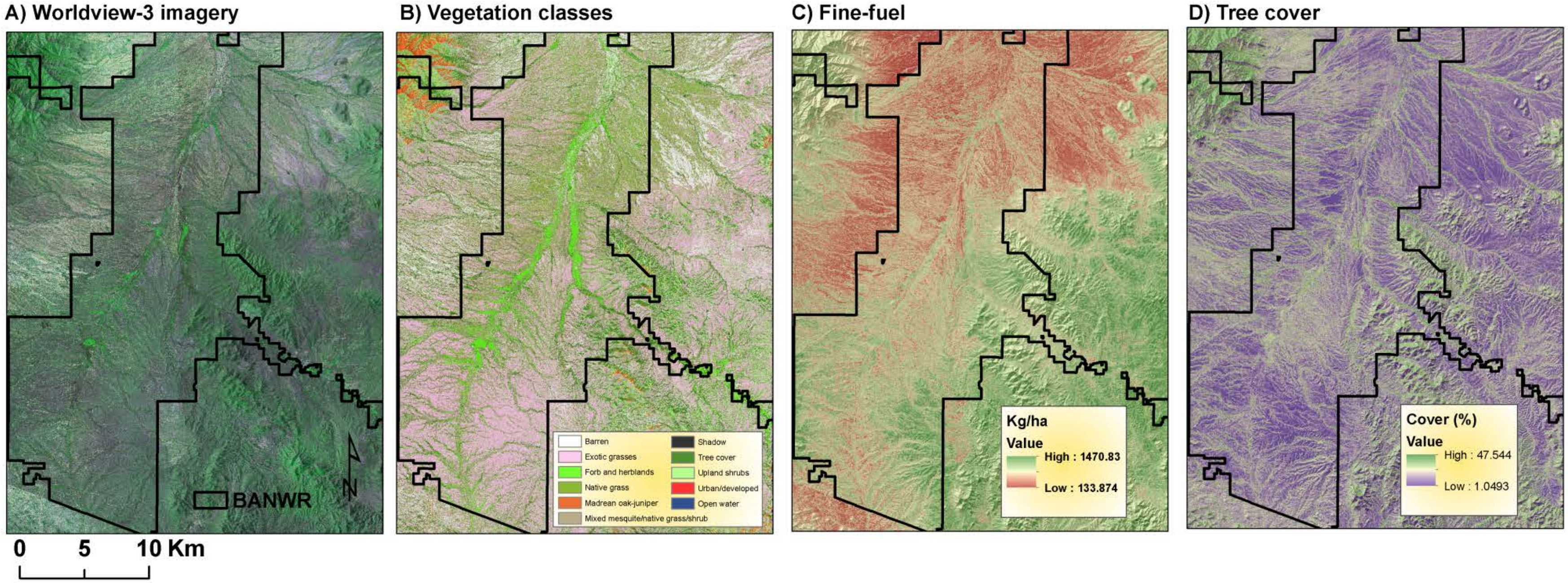


Figure 7. Vegetation class data from 2015 summarized for each BANWR management unit and grouped according to similar landscape conditions**.** Plots are an **A**) classical multidimensional scaling (cmds ordination) indicating group classes by color and vectors identifying which vegetation classes are driving differences among **B**) BANWR management units. For example, management units labeled with a 4 or a 5 in figures A and B are dominated by exotic grass cover (xgr) and management units labeled as a 1 are dominated by native grass cover (ngr), mixed mesquite, grass and other woody plants (mgrw), and bare ground (ba). Management units labeled with a 1 were further subdivided based on the hierarchical cluster analysis dendrogram. Correspondingly, many of the management units labeled with 1b and 1c were also recognized by Masked Bobwhite Endangered Species Recovery Team experts and refuge staff as containing the most favorable habitat conditions for m

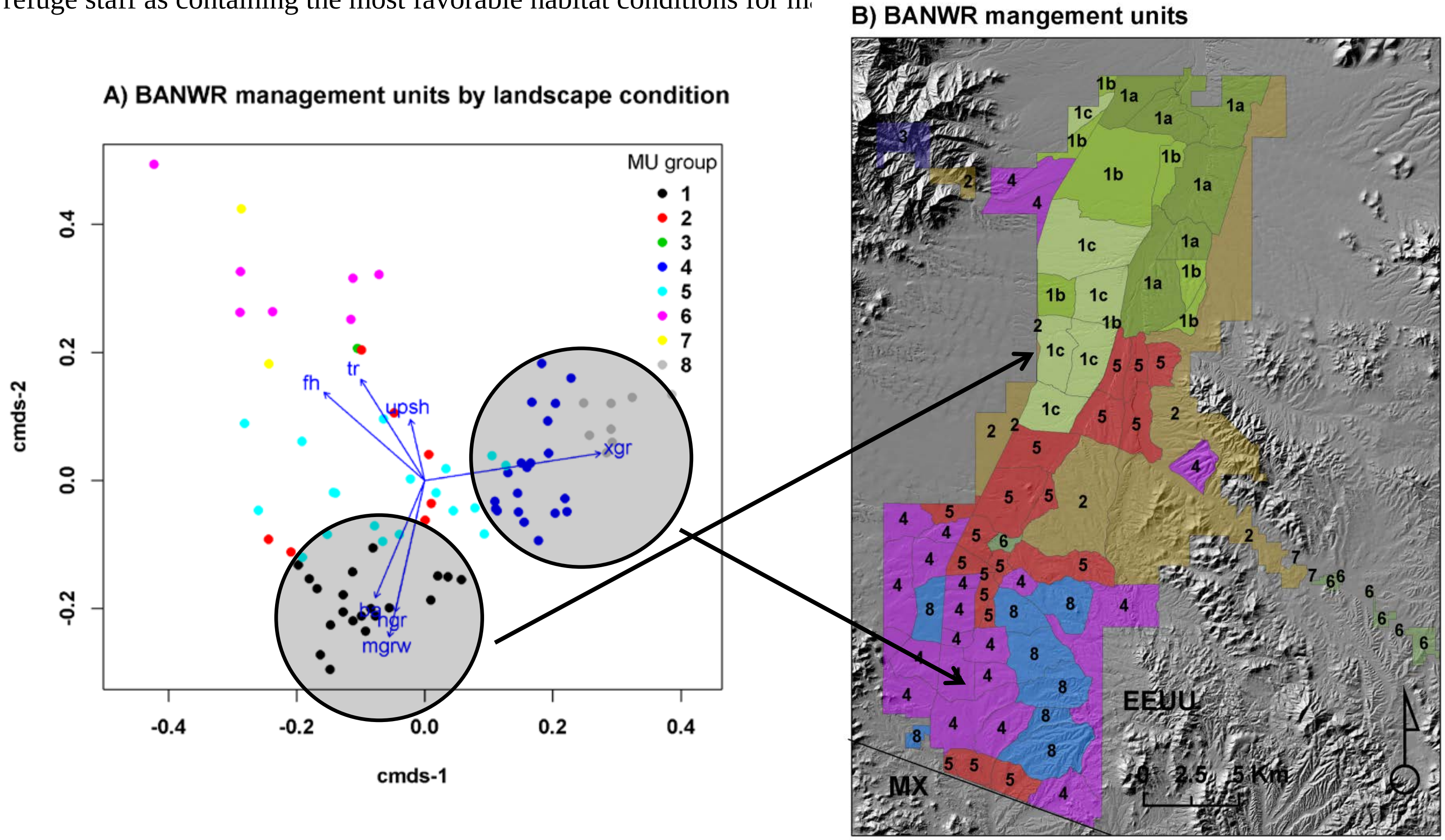
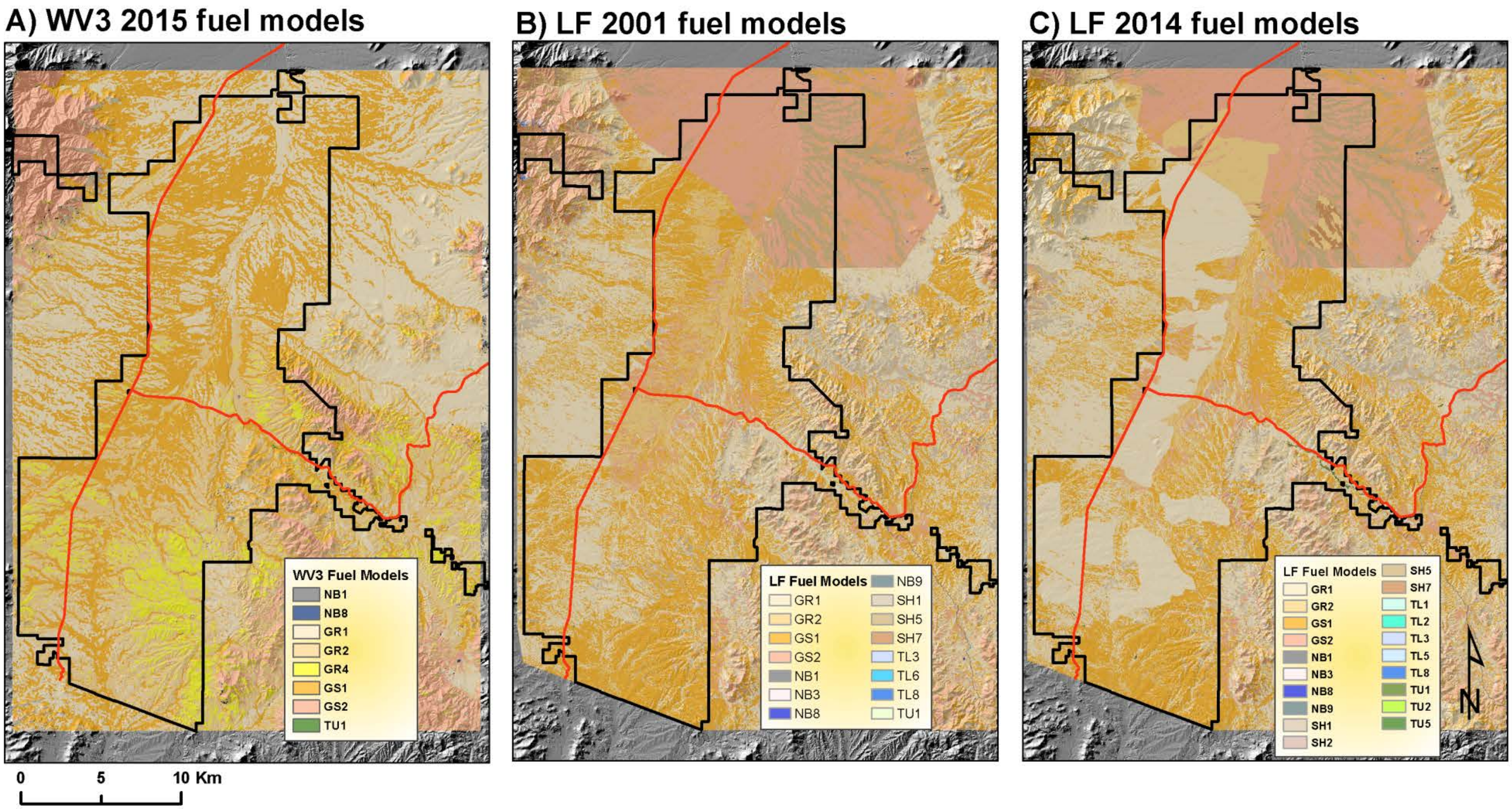


Figure 8. Fuel models developed for BANWR from **A**) 2015 fine-fuels and vegetation class data layers developed from Worldview-3 and Landsat 8 OLI satellite imagery and plot data, and **B**) 2001 fuel models and **C**) 2014 fuel models downloaded from the LANDFIRE website (http://landfire.gov/).



Appendices

Appendix A. General work flow for developing HSI models for the masked bobwhite quail from plots and geospatial data (LaRoche and Conway 2012). Empirical model functions were used to interpret expert information for quantifying habitat suitability on individual field plots.

Expert knowledge

Habitat Variable	Rank	Weight[-1]
Climate	1	2.166667
Leguminous Shrubs	2	2.25
Thermal Refugia	3	2.5
Winter Food	4	2.75
Herbaceous Species Diversity	5	3
Woodland /Grassland Edges	6	3.5
Vegetation Structural Diversity	7	3.5
Brush and Shrub Cover	8	3.666667
Bare Ground	9	4
Grass Cover	10	4
Tree Cover	11	4
Avian Predators	12	4.25
Forb Cover	13	4.333333
Mammalian Predators	14	4.5
Arthropod Diversity and Abundance	15	5
Invasive Plant spp	16	6.5
Vegetation Height (herbaceous)	17	9
Water	18	10.75