Interim Performance Report:

A New Time Series Remote Sensing Approach to Mapping Fine Fuels in Sonoran Desert Ecosystems

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Steven E. Sesnie

U.S. Fish & Wildlife Service

500 Gold Avenue SW, Rm 4127

Albuquerque, NM 87102

(505) 248-6631

Steven_Sesnie@fws.gov

I. Project objectives

The principal objectives of this project are to 1) develop an efficient means to measure Sonoran Desert fine fuels on the ground and 2) construct and validate time series and remote sensing-based models capable of repeatedly mapping seasonal and annual fine fuel production. In addition, methods are focus on determining the relative contribution of native and non-native herbaceous grasses and forbs to fine fuel biomass in the Sonoran Desert study area. Objectives have been developed in conjunction with the matched Department of Defense – Strategic Environmental Research and Development Program (DoD-SERDP) project entitled "Integrating spatial models of non-native plant invasion, fire risk, and wildlife habitat to support conservation of military and adjacent lands in the Sonoran Desert".

This interim report describes project activities and accomplishments during the performance period since project initiation on August 1st, 2011 to September 31st 2012.

II. Changes to the project

From the previous year's interim report, we implemented changes to the proposed field study that were necessary to obtain valid estimates of native and non-native herbaceous plant composition, abundance and biomass for fine fuel and vegetation modeling. Plot sampling was modified to improve biomass data collection and scalability with available remotely sensed data. A stratified plot and nested subplot design was used for both 2011 and 2012 field campaigns to allow for vegetation modeling using both Landsat Thematic Mapper (TM) and Moderate Resolution Imaging Spectroradiometer (MODIS) image pixels of 30m (0.0009 km^2) and 250m (0.0625 km^2) respectively. In addition to affording cross sensor applications, principal field sampling methods have been consistent across the two field seasons.

Herbaceous plant production is driven by the amount and distribution winter and spring precipitation in the western Sonoran Desert study area. Both 2011 and 2012 were characterized as below average rainfall years. Rainfall was also heterogeneously distributed within the study area creating dispersed patches of herbaceous plant production. This resulted in a larger number of low biomass areas sampled in 2011. For the 2012 field season, further modifications were aimed at improving the number of samples in relatively productive areas (i.e. locations receiving rainfall), increasing biomass sampling efficiency, and improving the likelihood of detecting target invasive species on plots. Each of these adjustments to 2012 field sampling methods is outlined below.

III. Project progress

Progress has been made for several key aspects of the project such as implementing a second field season in the spring of 2012, generating preliminary models of invasive plant distributions and biomass from 2011 field data, presenting interim results at a variety of venues and developing manuscripts for publication. These and other aspects of project activities realized over the reporting period are discussed below.

a. Year 2012 field study

Primary field sampling methods described in the 2011 interim report have been carried forward for the 2012 sampling effort. However, some refinements to sampling were made based on results from the previous year's field season. Given the low number of target invasive plant species detections for African buffelgrass (*Pennisetum ciliare*) and red brome (*Bromus rubens*) on 2011plots (≤15%), we focused sampling efforts in areas where Sahara mustard (*Brassica tournefortii*), Mediterranean grass (*Schismus* spp.), and arugula (*Eruca vesicaria sativa*) were more likely to occur. Arugula was encountered on relatively few plots and subplots (6%) in 2011, but is considered a non-native plant that is increasing its distribution within the study area and can occur at very high densities, similar to Sahara mustard, in some localized areas.

To improve target species detection on plots, we used refined species distribution models (SDM) utilizing available data on target species occurrences, principal components axes of six Landsat Thematic Mapper bands, winter precipitation data, four topographic layers and maximum over mean normalized difference vegetation index (NDVI) from 12 years of MODIS satellite imagery. An SDM for each target species was used to determine areas of greater habitat suitability (70th percentile) for initial estimate of sampling strata eliminating areas close to roads (≤ 250m) and on steep slopes (≥ 30 degrees). Plots confined to these areas were further stratified and allocated to locations with greater than average MODIS NDVI acquired just prior to sampling. 2012 plots were also clustered in closer proximity to one another to reduce travel time and increase the overall number of plots.

Lastly, biomass sampling conducted on subplots was enhanced to more efficiently collect and process data. Of the five subplots located at each plot, biomass was collected at zero, one, or two subplots, depending on the length of time spent collecting biomass. This enabled one or more field technicians to focus on biomass collection for a smaller area while a more mobile crew collected cover and related allometric data across the entire plot. We used a modified comparative yield sampling method where areas of maximum biomass by non-native target species, native grass or forb were identified at point intercepts on subplots. All other intercepts and 0.25m^2 sampling circles were compared and ranked as a percentage of biomass maxima identified within the subplot. Maximum vegetation areas for each target species, native grass or forb were clipped and placed in a paper bag for transporting them to Northern Arizona University (NAU) for oven drying and weighing. Field collected biomass was used to estimate ranked intercept areas and calculate the amount of fine fuels across plots and subplots.

b. Field study results

Field sampling for 2012 was conducted from February to April, similar to the 2011 sampling period (**Figure 1**). Modifications to sampling resulted in a greater number of plots measured in 2012 (506 plots, 2530 subplots) versus the 2011 (238 plots, 1190 subplots) field season. A greater number of plots, refined SDMs, and enhanced methods for sample site selection resulted in a greater number of target invasive plants detected on plots in some cases (**Table 1**). For example, enhanced SDMs resulted in a greater percentage of target species detected on subplots such as Mediterranean grass (**Figure 2**). A lower proportion of subplots with Sahara mustard detected is likely because of low rainfall in both 2011 and 2012, greatly diminishing the presence of this species on suitable sites (personal observation).

In 2011, biomass was collected at 1171 subplots and 238 plots. The mean biomass extrapolated to the subplots was 51.3 kg/ha with a maximum of 1,328 kg/ha. In 2012, biomass was collected at 213 plots and 302 subplots. The mean biomass extrapolated to subplots was 43.9 kg/ha with a maximum of 1,404 kg/ha (**Figure 3**). The sampling distribution of biomass was strikingly similar, though a greater proportion of biomass samples were obtained for the middle range of biomass values in 2012. This could be attributed to two successive years of drought with the first year (2011) following productive spring in 2010 vs. two successive years of drought preceding the 2012 field season (**Figure 4**).

c. **Time series models**

Remote sensing-based time series models of invasive plant distributions based on 2011 field data have been relatively successful for widespread target invasive plants. A novel approach using spatially weighted ensemble methods and MODIS time series data yielded accuracies of 89% for Sahara mustard and 86% for Mediterranean with a Kappa score of 0.59 and 0.33 respectively (Olsson et al. in review). Landsat time series data yielded >90% accuracy for these two species and Kappa scores ranging from 0.33 to 0.60. Spatial ensembles optimize models based on the spatial scale at which plant phonologies are most similar in place of utilizing all plots in a regionally constructed model. These methods are aimed at mapping areas of high probability for detecting prevalent invasive plants to compare with fine fuels biomass (**Figure 6**).

Fine fuels and biomass models for 2011 have been less successful, principally due to below average rainfall and extremely low herbaceous plant production. For preliminary biomass models using MODIS imagery, we calculated mean, min, and max NDVI for every pixel for spring and summer growing seasons for all years between 2000 and 2011 (aka phenometrics). Additionally, we recorded the date associated with each of those metrics. For 238 field plots, we extracted the phenometrics for 2010 and 2011 and derived a model to predict our observations of plot biomass as a function of phenometrics. Using random forest regression trees, we found no relationship between biomass collected in spring 2011 and MODIS-derived phenology from 2010 and 2011. The variance explained was -2.1%. Restricting the model to only spring 2011 phenometrics lowered variance explained to -5.1%, but the two are essentially equally poor and no better than random. For model runs using Landsat Thematic Mapper (TM) imagery, the study area is divided evenly between two TM scenes and associated subplots. We employed similar methods to identify biomass as a function of phenometrics for the two Landsat TM scenes. Acquisition dates differed between the two tiles and so the scenes were treated separately. We used random forests to model biomass as a function of Landsat TM-based spring and fall phenometrics using all subplot data from each scene. For p38r37, the model based on 2010 and 2011 phenometrics explained 0.92% of the variance. The p37r37 model based on 2010 and 2011 phenometrics explained 2.0% of the variance.

Biomass data development and error screening has recently been completed and new models will be developed using newly acquired satellite imagery. However, the results above indicate that extensive refinement of biomass models and approaches are needed for utilizing 2011 and 2012 field data. Further data exploration is required to evaluate the relationship between satellite based vegetation indices and areas of low and higher biomass production in the study area. Further methods to model biomass such as multiple linear and partial least squares regression will also be explored to reduce data dimensionality and construct predictive models. Spatially weighted ensemble models have not applied for biomass estimation and may also improve results. Nevertheless, extreme drought and low productivity years may preclude developing robust models suitable for retrospective or prospective analysis of fine fuel production. In the absence of samples from high biomass productivity sites, the Miranda Grey NAU study described below will provide useful information on the linkage between satellite derived vegetation indices such as NDVI and the occurrence of large fires. Other higher spatial and spectral satellite imagery described below will also be tested for improving biomass model performance.

d. Spectral library development

High resolution spectral data has been collected in the field with an ASD Inc. FieldSpec Max3 spectrometer for target invasive plant species, soil substrates and other common native plants. A spectral library and Microsoft Access relational database is being developed to accommodate these data and make them available for public access on our spectroscopy website (http://www.cefns.nau.edu/seses/llecb/Spectrometer/index.html). These data will also be used to test new remote sensing techniques for mapping fine fuels and invasive plant distributions with higher spatial and spectral resolution imagery acquired during the 2012 field sampling period.

e. New satellite image applications

Higher spatial and spectral resolution imagery from the SPOT and Worldview2 (WV2) satellites was acquired across much of the study area during the 2012 field season. This imagery was collected at no-cost to the JFSP or DoD SERDP project through the President's US Commercial Remote Sensing Space Policy accessed through the Commercial Image Data Requirement by PI Sesnie with the US Fish and Wildlife Service. Each of the two satellite platforms provides an image data source that is readily available to federal agencies under current agency/vendor agreements. Image dates from 2012 range from January 16th to April 16th. However WV2 imagery from collected only until February 14th over approximately half of the study area in two 1˚ x 1˚ consolidated areas. Image data collection was focused in areas sampled during plot measurements taken in 2012. SPOT 10m data covers green, red, near infrared and shortwave infrared wavelengths that are appropriate for vegetation applications. WV2 imagery is a new generation of high resolution commercial satellites producing 2m multispectral and 0.5m panchromatic imagery. WV2 multispectral channels cover the visible and near infrared spectral range (400 – 1050nm) with yellow (585 – 625nm), red edge (705 – 745nm) and near infrared 2 (860 – 1040nm) bands, making 8 bands total (**Figure 7**). WV2 is strategically designed and centered on more narrow spectral channels for vegetation analysis and is relatively untested for mapping target invasive species in the study area and elsewhere.

Given the spatial and spectral characteristics of both SPOT and WV2, our objectives are to 1) develop and test the potential for mapping target invasive plant distributions using single-date image classification techniques, 2) determine the feasibility of fine-scale mapping of small populations of target species, and 3) explore image fusion and other modeling techniques to potentially improve methods for characterizing fine fuel biomass in the study area.

f. Predictive models of Sonoran Desert fuels and fire occurrence

As part of her Masters thesis project, NAU student Miranda Gray has been developing spatial models of large fire probability based on an empirical database of fire occurrences from 1989-2010. The models predict the probability of fire occurrence greater than 50 acres, accounting for interannual variability in fuel loading, as well as static landscape variables of topography, elevation, road density and vegetation communities. At a 1km resolution using AVHRR data, the models show a strong positive correlation with yearly maximum NDVI. The next stage of model refinement will be modeling this probability at 30m resolution using Landsat TM NDVI. These spatial prediction models, coupled with other outcomes of this project, will provide managers with long-lead predictions of large fire occurrence based on projected maximum NDVI in any given year.

g. Publication outputs

Drawing on data during the 2011 field season, we have submitted a manuscript for the journal Ecography entitled "A spatially-weighted ensemble approach to modeling invasive species occurrence in the Sonoran Desert". This paper details new remote sensing time series and phenology methods for mapping invasive plant species that we developed to account for the challenges posed by asynchronous phenology of the Sonoran Desert caused by spatial variation in rainfall. We are preparing a manuscript for submission to Ecological Applications, entitled "Invasive species detection based on habitat suitability models and nested sampling at a regional scale". In the coming year of this project, we will begin drafting a manuscript detailing our latest analyses, including recommendations for whether invasive plant species abundance and biomass can be accurately predicted from plot data.

h. Workshops and meetings

Results from the combined JFSP/SERDP DoD projects were presented at the DoD Resource Conservation & Climate Change (RC) Spring Interim Progress Report (IPR) meeting in Tucson, Arizona on May 15th and 16th of 2012. Feedback from land managers working on military installations within the study area (Yuma Proving Ground and Barry M. Goldwater Air Force Range) highlighted the high importance of efficiently estimating invasive plant distributions and fine fuels with the use of remote sensing tools, in the absence of established field inventory methods. Data products such as annual plant productivity and herbaceous biomass were identified as important information for making natural resource decision. A workshop with land managers from agency partners (e.g., Bureau of Land Management, DoD, National Park Service, US Fish and Wildlife Service) to present project outputs and natural resource management and decision support tools is currently being planning for the Spring of 2013.

Additional outputs are as follows:

PAPERS

Bradley, B.A., Olsson, A.D., Wang, O., Dickson, B.G., Sesnie, S.E. (2012). Species detection vs. suitability: Are we biasing habitat suitability models with remotely sensed data? *Ecological Modelling* 244:57-64; doi: 10.1016/j.ecolmodel.2012.06.019.

Olsson, A.D., Morisette, J. (in press). Comparison of HyspIRI with two multispectral sensors for invasive species mapping. *Photogrammetric Engineering and Remote Sensing*

Olsson, A.D., Dickson, B.G., Sesnie, S.E., Bradley, B., Zachmann, L., Wang, O., Rundall, J. (submitted to *Ecography*). Phenology as a predictor of non-native plant invasion in the Sonoran Desert: a spatially weighted ensemble approach.

PRESENTATIONS

Olsson, A.D., Dickson, B., Zachmann, L., Sesnie, S., Wang, O. Remote Sensing Phenology for Invasions: A Challenge and an Opportunity. *4th Phenological Research and Observations of Southwest Ecosystems* (Tucson, AZ). October 2011.

Olsson, A.D., S.E. Sesnie, B.A. Bradley, L.J. Zachmann, B.G. Dickson, and O. Wang. 2012. Phenology as a predictor of non-native species invasion in the Sonoran Desert: a spatially weighted ensemble approach. American Society of Photogrammetric Engineering and Remote Sensing (ASPRS) Rio Grande Chapter Annual Spring Meeting, April 12, 2012. (La Cruces, NM)

Olsson, A.D., Sesnie, S.E., Dickson, B.G., Zachmann, L., Wang, O., Bradley, B., Rundall, J. Phenology as a predictor of non-native invasive species invasion in the Sonoran Desert: a spatially-weighted ensemble approach. *Invited seminar, National Taiwan University Department of Geography* (Taipei, Taiwan). April 2012.

Olsson, A.D. Spatiotemporal modeling of buffelgrass invasion, ecosystem transformation, and adaptive management in the Sonoran Desert. *Invited talk, International Symposium on Invasive Plants and Global Change* (Urumqi, China). June 2012.

Dickson, B., A. Olsson, O. Wang, S. Sesnie, L. Zachmann, B. Bradley, J. Rundall, and T. Sisk. 2012. Regional-scale models of non-native plant phenology and invasion to support conservation on military and adjacent lands in the Sonoran Desert. Society for Conservation Biology North America Section Meeting. (Oakland, California).

Wang, O., A. Olsson, L. Zachmann, B. Dickson, and S. Sesnie. 2012. Ensemble of habitat suitability and remote sensing models for sampling design: a new approach to detect invasive plant species in the Sonoran Desert. Society for Conservation Biology North America Section Meeting. (Oakland, California)

POSTERS

Dickson, B., Olsson, A.D,, Wang, O., Zachmann, L., Sesnie, S., Bradley, B., Rundall, J., Sisk, T. Landscape models of non-native plant phenology and invasion to support conservation of military and adjacent lands in the Sonoran Desert. *Annual Partners in Environmental Technology Technical Symposium & Workshop of the Strategic Environmental Research and Development Program (SERDP).* December 2011.

Olsson, A.D., Dickson, B., Wang, O., Zachmann, L., Sesnie, S., Bradley, B., Rundall, J., Sisk, T. Landscape models of non-native plant phenology and invasion to support conservation of military and adjacent lands in the Sonoran Desert. *8th Annual RISE Symposium (Research Insights into Semi-arid Ecosystems).* October 2011.

Wang, O., Olsson, A.D., Zachmann, L., Sesnie, S., and Dickson, B. African buffelgrass infestation in the Sonoran Desert of Arizona: a preliminary plant community assessment. *Annual meeting of the Ecological Society of America* (TX). August 2011.

Wang, O., Olsson, A.D., Zachmann, L., Sesnie, S., and Dickson, B. Maximizing invasive plant detectability in the field using integrated habitat suitability models, GIS, and remote sensing data. *Annual meeting of the Association of American Geographers* (WA). April 2011.

Gray, M., Dickson, B.G., Olsson, A.D. Landscape scale models and maps of fire connectivity in the Sonoran Desert. *North America Congress for Conservation Biology* (Oakland, CA). July 15-18, 2012.

Tables

Table 1. Number of target non-native invasive plant species detected on field plots and subplots during 2011 and 2012 field seasons.

	Number of detections			
Species	**Plot 2011**	**Plot 2012**	**Subplot 2011**	**Subplot 2012**
Mediterranean grass	133	473	505	2020
Sahara mustard	113	260	329	748
Red brome	15	11	54	13
Arugula	14	26	32	77
African buffelgrass	21	3	46	3

Figures

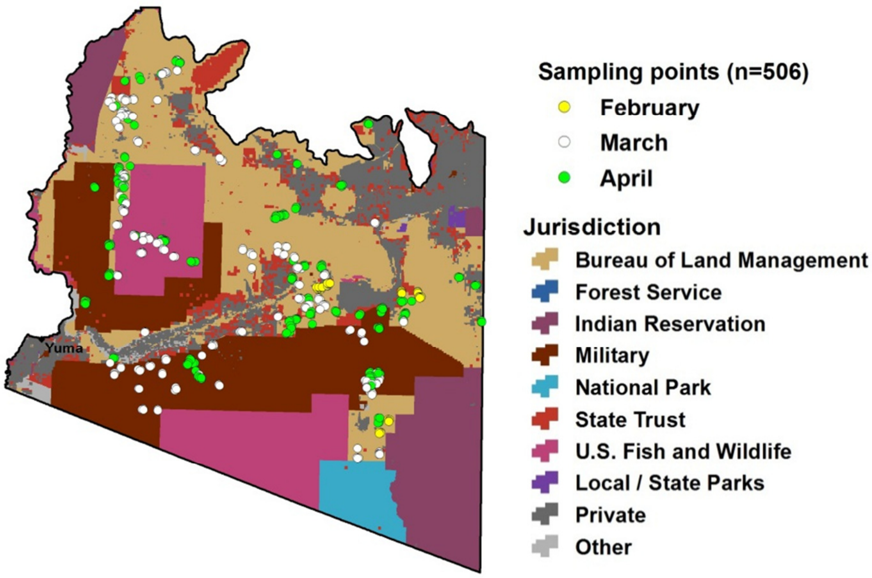

Figure 1. Distribution of plots sampled in 2012 and land management jurisdictions included in the study area.

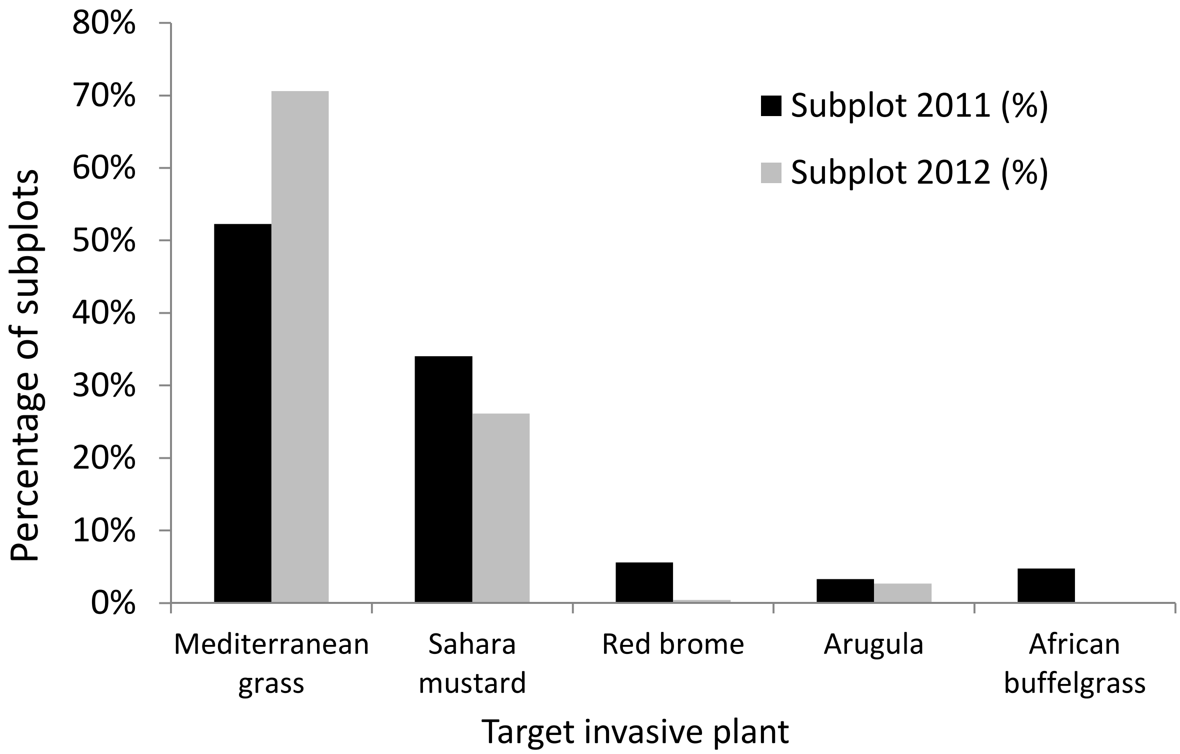

Figure 2. The percentage of subplots sampled where a target non-native plant species was detected during 2011 and 2012 field season.

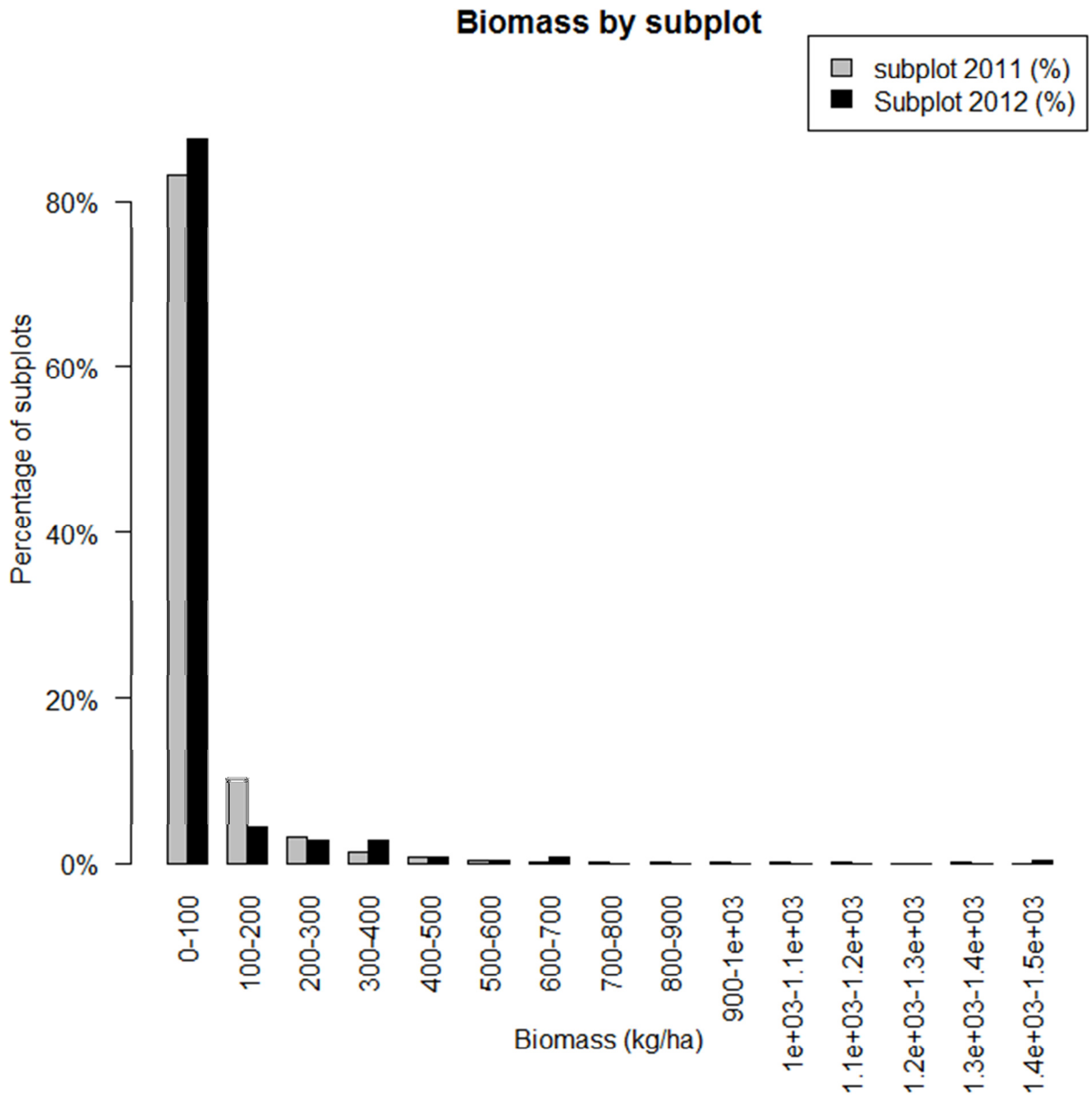

Figure 3. The percentage of subplots containing different amounts of biomass sampled in 2011 and 2012. The number of subplots from which biomass was collected in the two years varied significantly, with 1171 subplots sampled in 2011 and 591 sampled in 2012. This decrease was met with an increase in efficiency in terms of the total number of plots sampled and in the relative biomass collected where biomass sampling did occur.

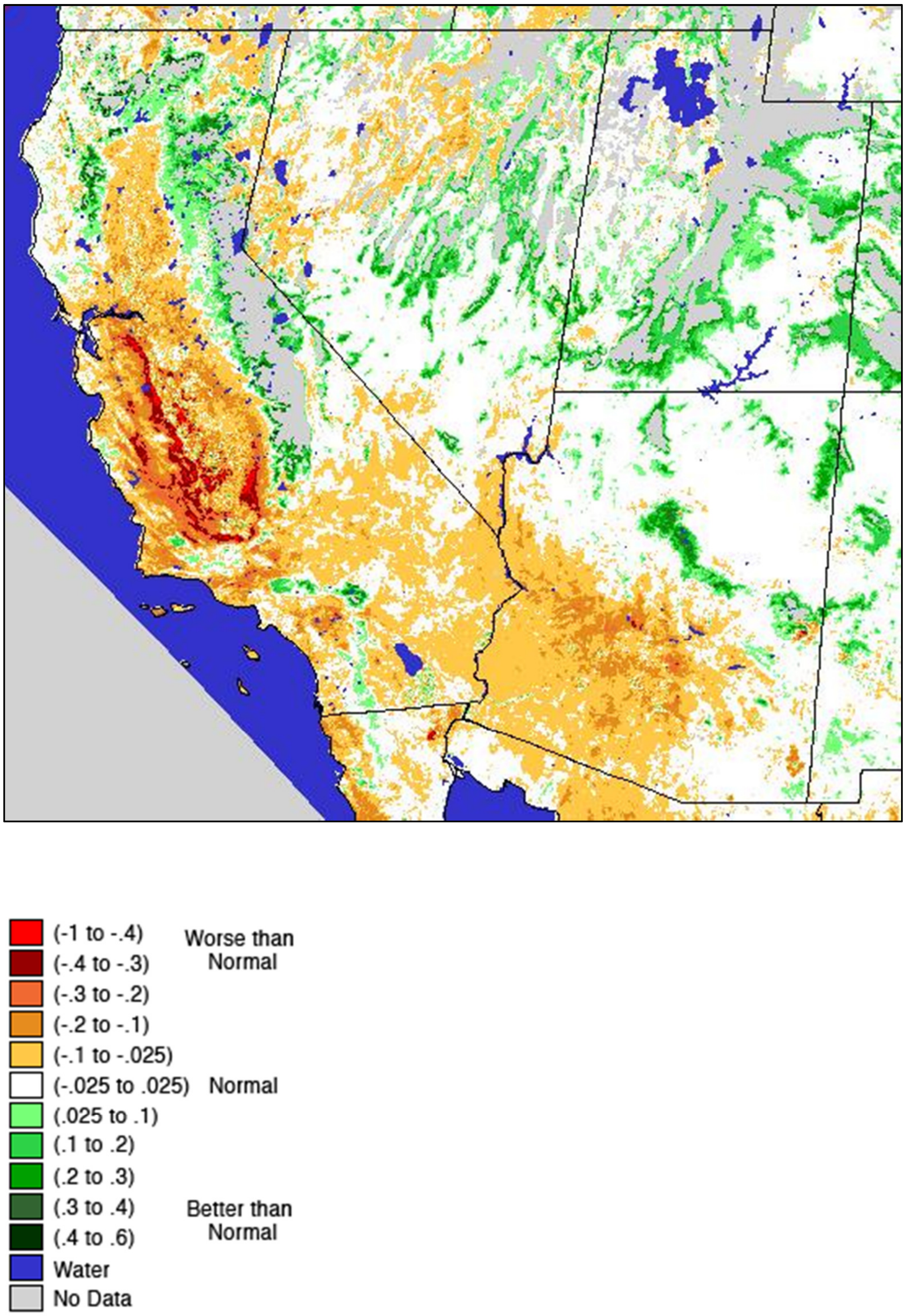

Figure 4. Difference in MODIS NDVI values from 2012 vs. 2011, using image dates from peak spring (March) production period. Warm colors (yellow, orange, red) indicate areas with NDVI that was lower in 2012 than for the same date range in 2011.

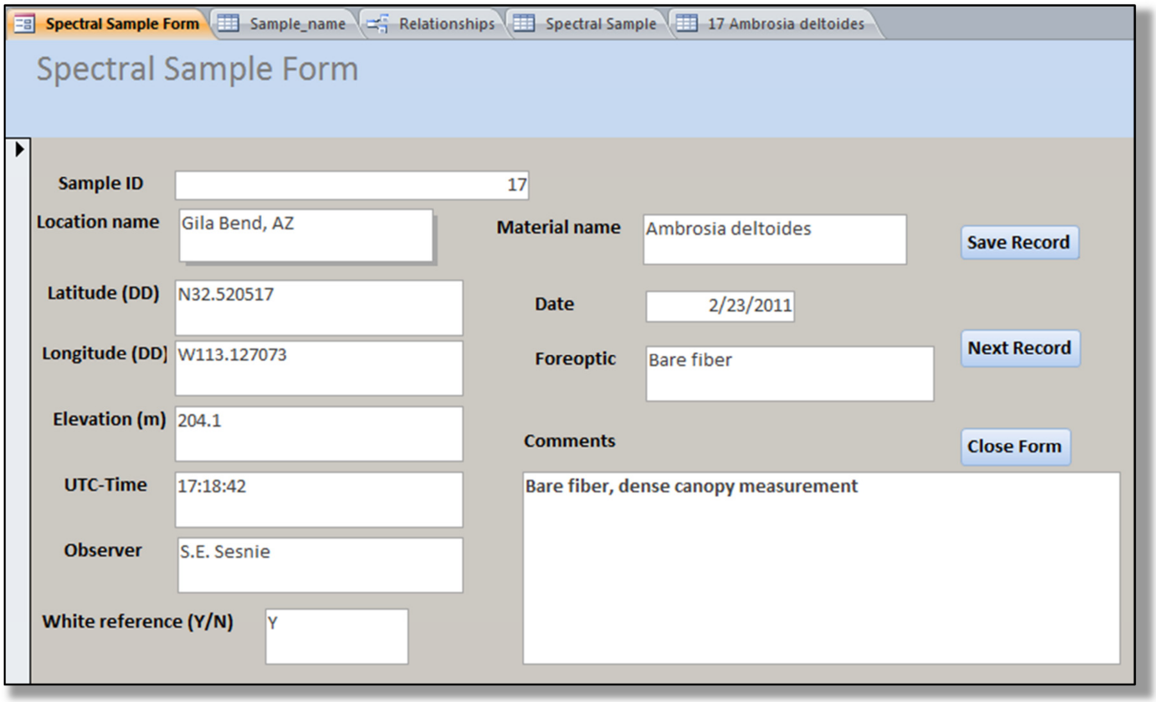

Figure 5. Microsoft Access relational database and standardized data entry form for recording field spectral samples of native and target non-native plants in the Sonoran Desert study area.

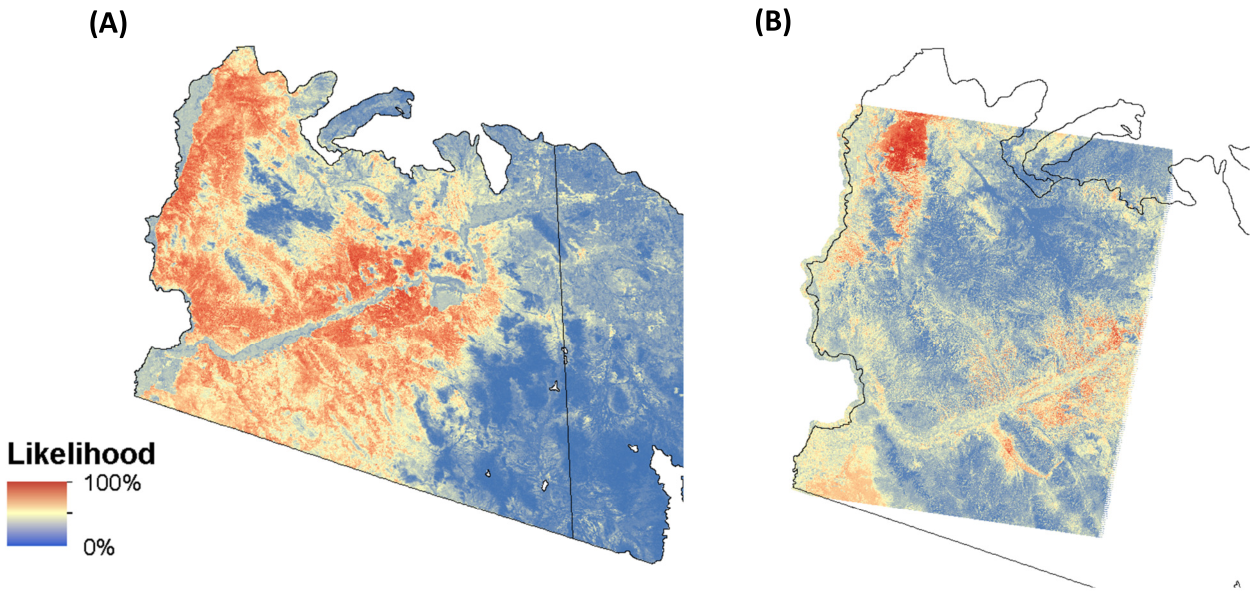

Figure 6. Spatially weighted ensemble model predictions of the likelihood of detecting Sahara mustard in a (**A**) MODIS pixel and (**B**) Landsat TM pixel.

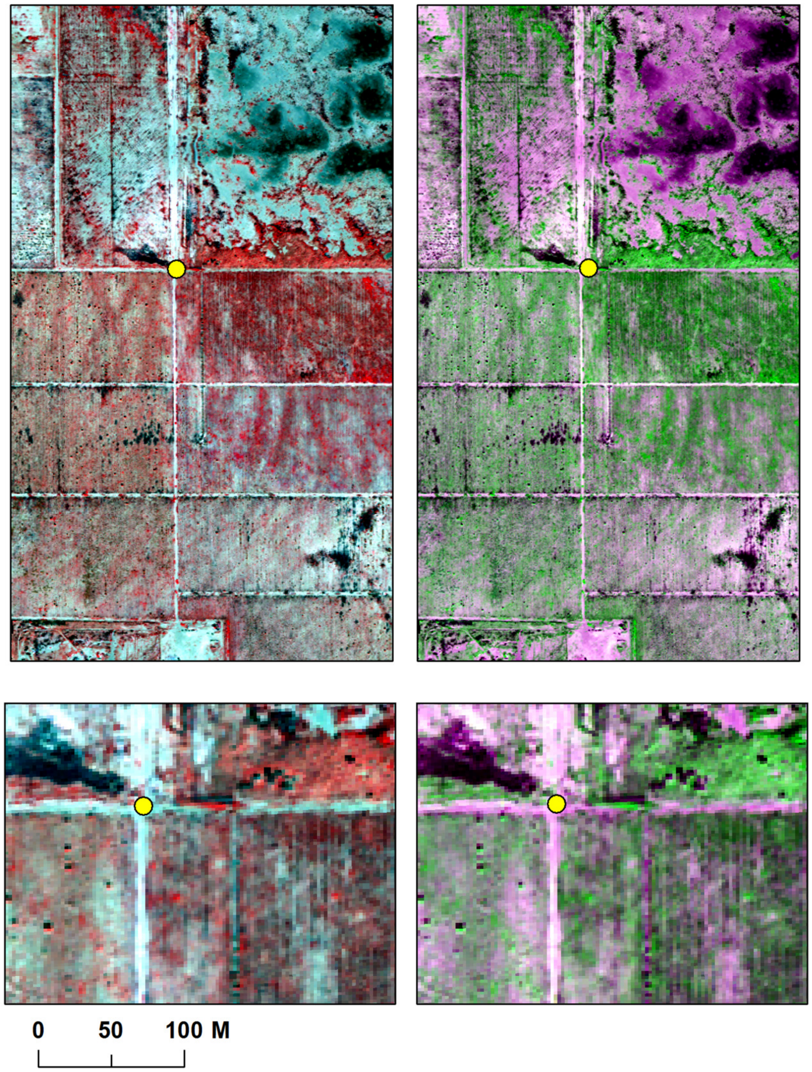

Figure 7. Worldview2 imagery of abandoned farm fields dominated by arugula (*Eruca vesicaria satvia)* located near Sentinel, Arizona. Images are WV2 band combinations 5, 7 and 3 (left) and 4, 8 and 5 (right). These data will be used to potentially improve predictive models of fine fuels using 2012 field data.