Interim Performance Report:

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

Project ID: 10-1-04-7

September 30, 2013

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 focused 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, 2012 to September 31st 2013.

II. Changes to the project

We have completed the third year of this project and were approved for a no-cost extension of one year, extending the project end date to 7/31/2014. The extension was granted to fulfill the principal project objective to develop time series remote sensing methods for estimating fine fuels in hot desert areas that are increasingly susceptible to wildfires due to fire regime change and invasion by non-native annual plant invasion. Principal objectives of this project remain unchanged. However, during the course of this research we have identified key modifications needed to better characterize growing season conditions and fuel parameters using remotely sensed data in the Sonoran Desert study area and other hot desert environments.

III. Project progress

This project has completed its third year of investigation. The following deliverables have been completed to date (**details on pages 6-7**):

- Kick-off meeting with BLM cooperator
- Fire modeling workshop
- Individual meetings with land managers and project collaborators in the study area
- Field data collection (2011, 2012)
- MODIS and Landsat satellite image processing 2000-2011
- Spatial models of invasive plant species
- R scripts and models for calculating comparative yield biomass
- Preliminary model of fine fuel biomass with 2011 field data
- ENVI spectral library invasive species, native shrubs and substrates
- Three publication submissions, and a fourth in preparation
- Seven conference presentations
- Five posters at conferences

Further progress has been made for principal project objectives to finalize algorithms to compute biomass on plots and subplots and develop new techniques to estimate fine fuel biomass with time series MODIS data. In addition, we are in the final stage of testing single-date high spatial resolution, 8-band Worldview-2 (WV2) satellite imagery to estimate target invasive plant distributions, cover and biomass. A publication manuscript using the WV2 imagery is currently in preparation. These and other aspects of project activities completed or in progress during the reporting period are described below.

a. Biomass calculations

For the 2012 field season, biomass sampling conducted on subplots was enhanced to more efficiently collect and process data (*see* 2012 interim report for sampling methods). We used a modified comparative yield sampling method where areas of maximum biomass by non-native target species[1], 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, placed in a paper bag and transported 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 all subplots.

A total of 506 plots and 2,530 sub-plots were measured in 2012. Biomass samples and comparative yield ranks were collected for a total of 280 subplots. Processed sample data were then used to estimate herbaceous biomass for all ranked samples on subplots. For each subplot, and target invasive plant, the reference max was weighed after oven drying. The reference maximum for each subplot was collected within a circlet ($0.25\ m^2$) and summarized as g/m^2. A subplot estimate of biomass for a given target was calculated as the average estimated biomass across all point intercepts. Each subplot had a total of 100 point intercepts measured at 1m intervals and the biomass rank was estimated in quartiles where 0=none present, 1=0-25%, 2=25-50%, 3=50-75%, and 4=75-100%. Ranks were averaged over all 100 points, but to ensure that ranks were "centered" in each range, each rank was reduced by 0.5. To produce a subplot-wide summary of ranks in terms of a percentage of the reference max as follows:

$$Subplot\ Pct\ of\ Reference\ Max = \frac{\sum_{i=1}^{100}(rank_i - 0.5)}{4 * 100}$$

where *i* designates the specific point intercept, of which there are 100 per subplot. The division by 400 in the denominator normalizes the modified sum of all ranks (numerator) to be between 0 and 1. The subplot biomass estimate is the product of the reference max biomass by this percentage:

$$Subplot\ biomass = Subplot\ Pct\ of\ Reference\ Max * Reference\ Max\ biomass$$

A model to estimate biomass as a function of cover measured on all 2,530 subplots was developed for each of three herbaceous target non-native plants and native plants grouped by life form (i.e., forb, perennial grass, annual grass), using the subplots where biomass and cover were measured (n=280). Two non-native targets species, *B. madritensis* var. *rubens* and *P. ciliare* were very rare in the study area and were not be modeled. Models were clamped to the 0 intercept. Six models were highly significant and R^2 values ranged from 0.54 to 0.64 (**Figure 1**).

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[1] Target non-native species include *Bromus madritensis* var. *rubens*, *Schismus arabicus*, *Schismus barbatus*, *Brassica tournefortii* , *Eruca vesicaria* var. *sativa,* and *Pennisetum ciliare*.

We considered models and estimates to be acceptable given the extremely low biomass production on subplots, with a mean total herbaceous biomass of 43.9 kg/ha. Approximately 2,300 kg/ha of herbaceous biomass is a typical amount of fine fuel accumulation needed for larger fires in the Sonoran Desert (BLM cooperator Wade Reaves, personal communication).

b. Time series data

Remote detection of areas experiencing increased fuels biomass production and rapid expansion of invasive annual grasses and forbs continues to be the central focus of this project. During the course of this research, our challenge has been to complete this objective in light of a sampling effort during 2011 and 2012 that were concurrent with two extremely dry growing seasons. These conditions have persisted after a high moisture period of two or three years (i.e. 2008 – 2010), which had drawn considerable attention to changing fire regimes in this region.

Our project extension is being used to improve processing for time series Moderate Resolution Imaging Spectroradiometer) MODIS normalized difference vegetation index (NDVI) product and to develop modeling approach that is robust to Sonoran Desert environmental conditions. This entails further exploration of satellite vegetation indices and time series metrics as well as models which can incorporate spatially explicit differences in seasonal conditions, plant growth and fuel production. While a number of techniques have been developed to characterize and model land surface phenology with the use high temporal resolution satellite imagery (deBeurs and Henebry 2010), most are not well suited to hot desert environments. Desert systems often lack a consistent growth period that can be problematic when using curve-fitting and threshold-based approaches are used to define plant phenology and productivity patterns. Therefore, we have begun to develop an approach that is more robust to the nonlinear and non-stationary plant growth cycle patterns for the Sonoran Desert. An empirical mode decomposition (EMD) method (Huang et al. 1998) is currently being used to reduce the noise often exhibited by time series of vegetation indices (e.g., NDVI) in arid systems. The approach relies on two key elements, the first being an iterative, random sampling routine to identify annual and bi-annual growing season events and secondly the use of EMD to extract plant phenology-related parameters (**Figure 2**). The EMD process has potential to account for parameters influenced by meteorological and ecological processes operating at different spatial and temporal scales that are characteristic of the study area.

Fine fuel production and increased fire risk is a spatially and temporally heterogeneous process in hot desert systems that require up-to-date information to better target fuels mitigation. Therefore, one advantage of the EMD approach is that the most recent time series NDVI data can be incorporated to readily update phenology patterns and metrics. We consider this a potential improvement over methods such as phenology data derived from TIMESAT gap filled smoothed NDVI (Gao et al. 2008, Tan et al. 2011) which requires an additional year of NDVI data following the season of interest. Approaches requiring pre- and post-season NDVI extending a year into the future can limit management applications, such as targeting hazardous fuels reduction activities in locations with high fire risk when and where they occur on the landscape.

c. High spatial resolution satellite image applications

Higher spatial and spectral resolution imagery from the WV2 satellites was acquired across for portions of the study area during the 2012 field season. This imagery was collected at no-cost to the JFSP or DoD SERDP projects 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. The WV2 satellite platform provides an image data source that is readily available to federal agencies under current agency/vendor agreements. WV2 imagery was collected until February 14th over approximately half of the study area in two 1˚ x 1˚ consolidated areas. Image collection was focused in areas sampled in the field during 2012. 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 3**). WV2 is 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 (*but see* Marshal et al. 2012).

Given the spatial and spectral characteristics of WV2, our objectives were to first develop and test the potential for mapping target invasive plant distributions using single-date image classification techniques and secondly determine its feasibility for fine-scale mapping of herbaceous canopy cover and biomass in the study area. A manuscript in preparation entitled "*WorldView-2 high spatial resolution improves desert invasive plant detection*" to be submitted to Photogrammetric Engineering and Remote Sensing is currently in draft form. Results suggest that Mixture Tuned Match Filtering (MTMF) can achieve an overall classification accuracy of *B. tournifortii* of 87.6% (**Figure 4**), but canopy cover and biomass showed was poorly correlated with WV2 NDVI. Further work will be dedicated to developing herbaceous canopy cover and biomass models using additional spectral indices and WV2 bands.

d. Workshops and meetings

During the spring of 2013, land managers, science staff and technical staff from the US Fish and Wildlife Service, DoD, National Park Service and tribes were visited individually to present project outputs and receive feedback on preliminary products. These meetings were also used to gauge interest and identify how to provide final stage products applicable to manager's needs. Further results and data products developed to date from combined JFSP/SERDP DoD projects will be presented in a workshop with land managers and collaborators scheduled for November 14^{th} and 15^{th}, 2013. Outputs such as digital data layers of invasive plant distributions, models of fire risk, and decision support and analytical tools will be presented to DoD, USFWS, BLM, NPS and tribal collaborators.

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Figures

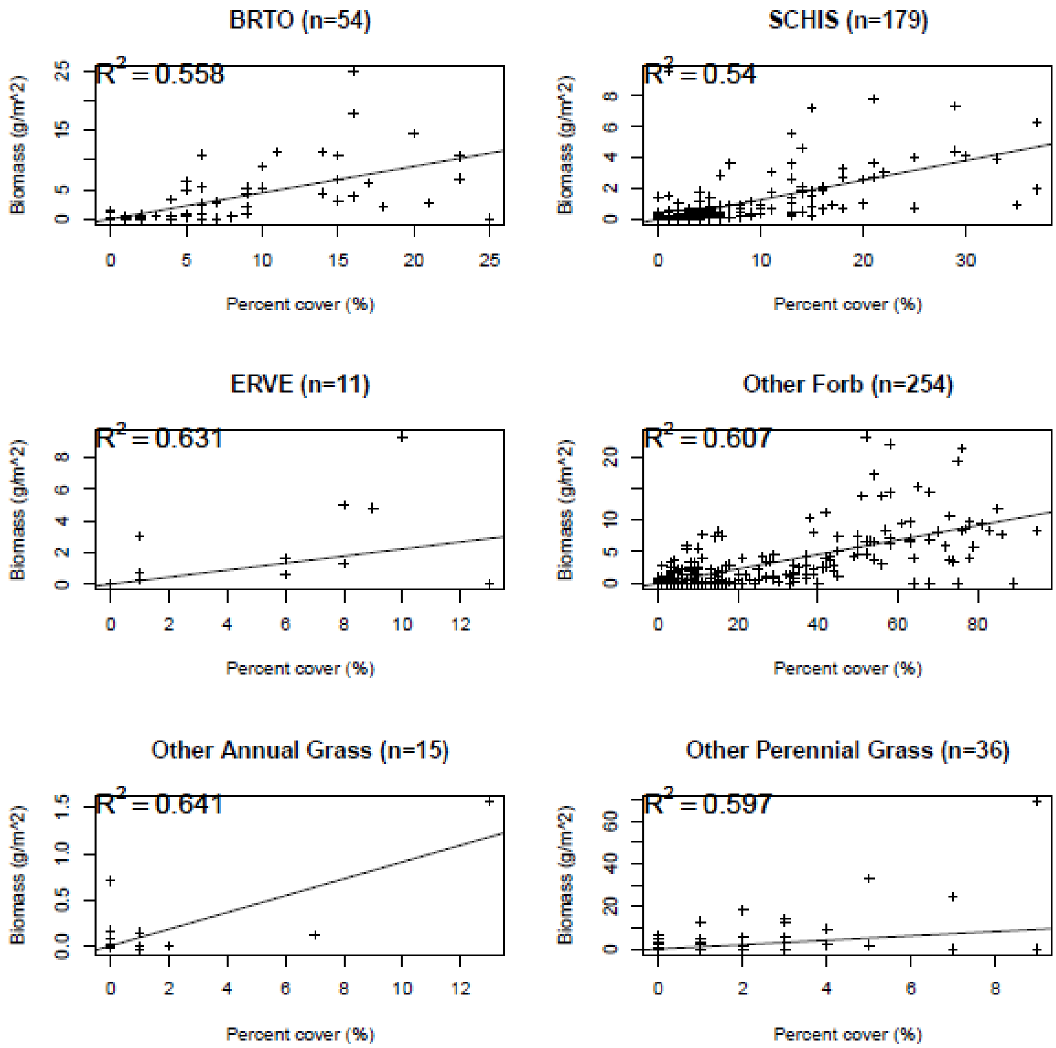

Figure 1. Biomass regression model results for non-native plants *Schismus arabicus* and *Schismus barbatus* (SCHIS), *Brassica tournefortii* (BRTO), and *Eruca vesicaria* var. *sativa* (ERVE) in addition to native plant life forms.

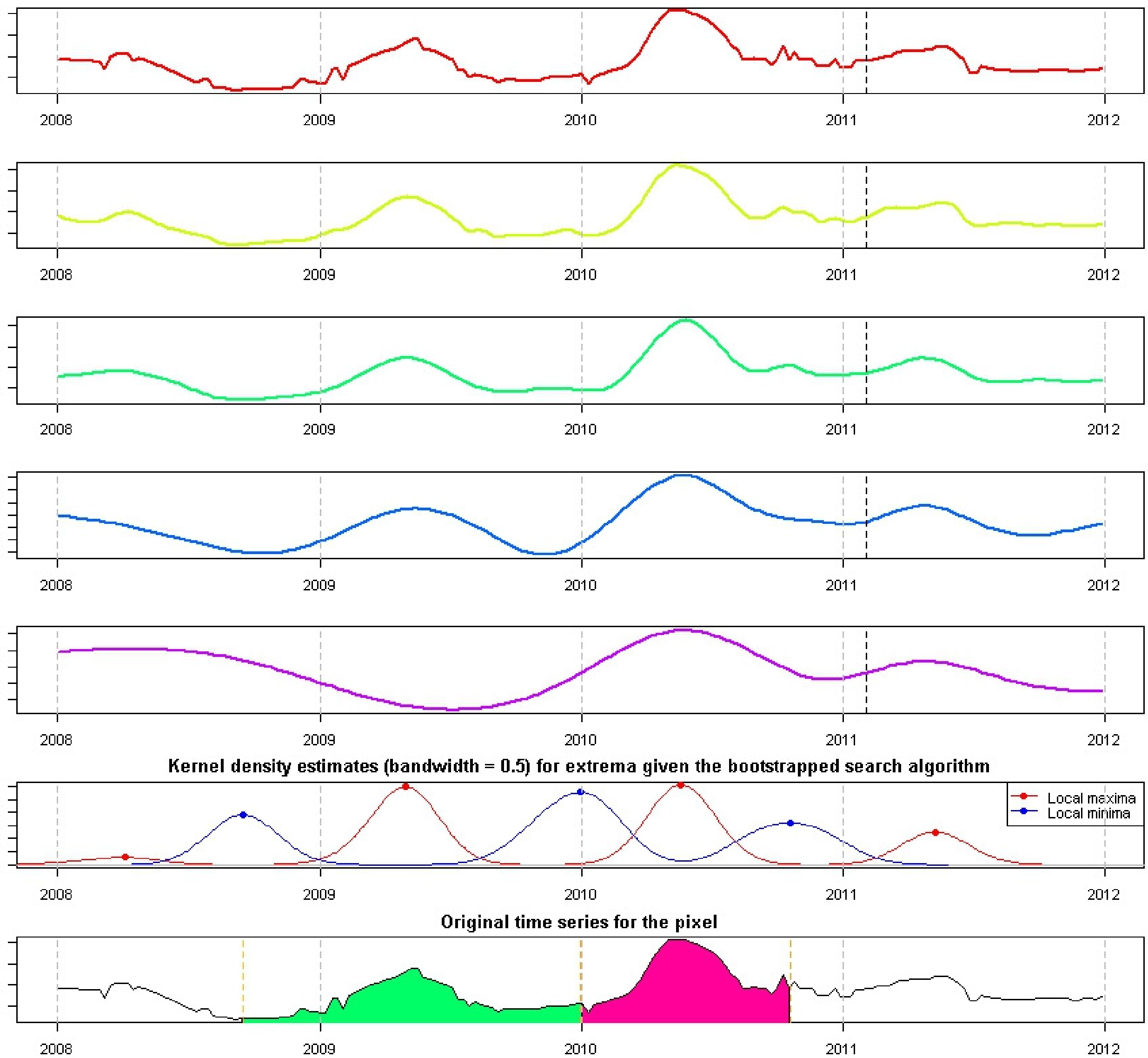

Figure 2. Empirical mode decomposition of a MODIS 8day NDVI time series for a single pixel. The top five figures show progressively smoother versions of the time series constructed be deleting higher-order (noisier) intrinsic mode functions from the original time series. The bottom two figures identify local minima and maxima and growing seasons identified by the randomized sampling routine. These methods reduce noise and allow computation of phenology metrics for predicting invasive plant distributions, canopy cover and fine fuel biomass.

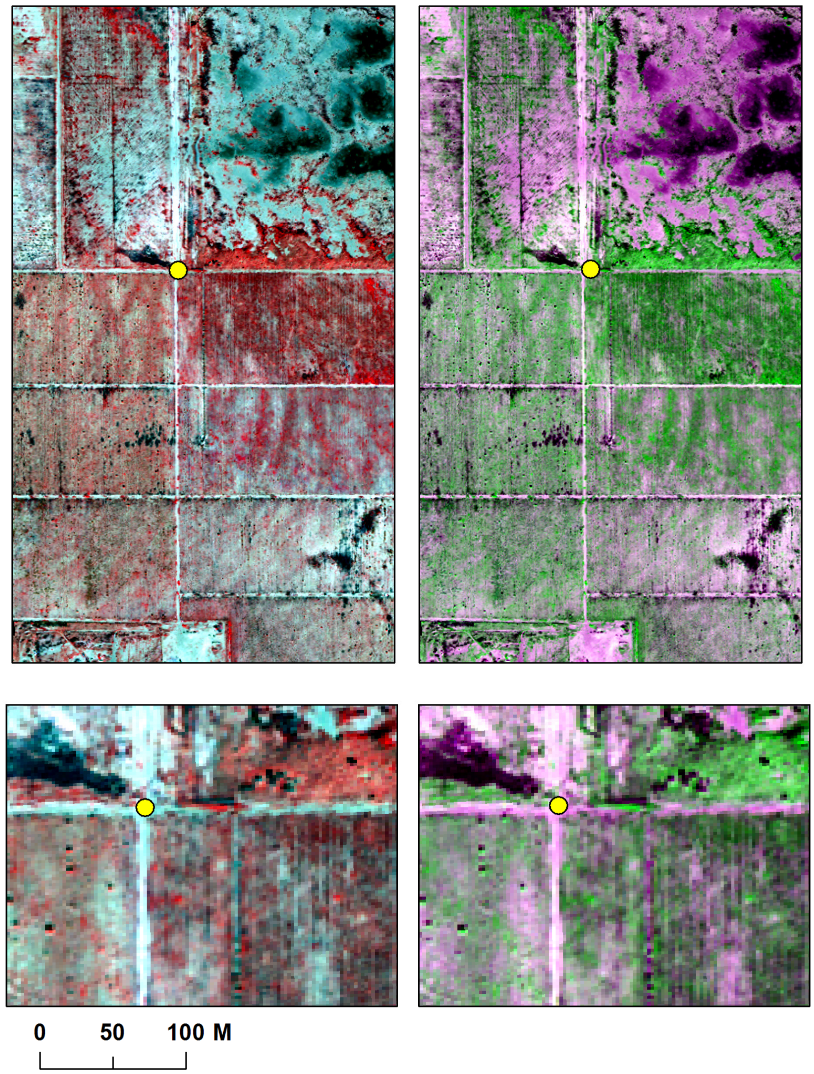

Figure 3. Worldview-2 imagery of abandoned farm fields dominated by arugula (*Eruca vesicaria satvia)* located near Sentinel, Arizona. Images are WV2 band combinations 5, 7 and 3 (left) and 4, 8 and 5 (right).

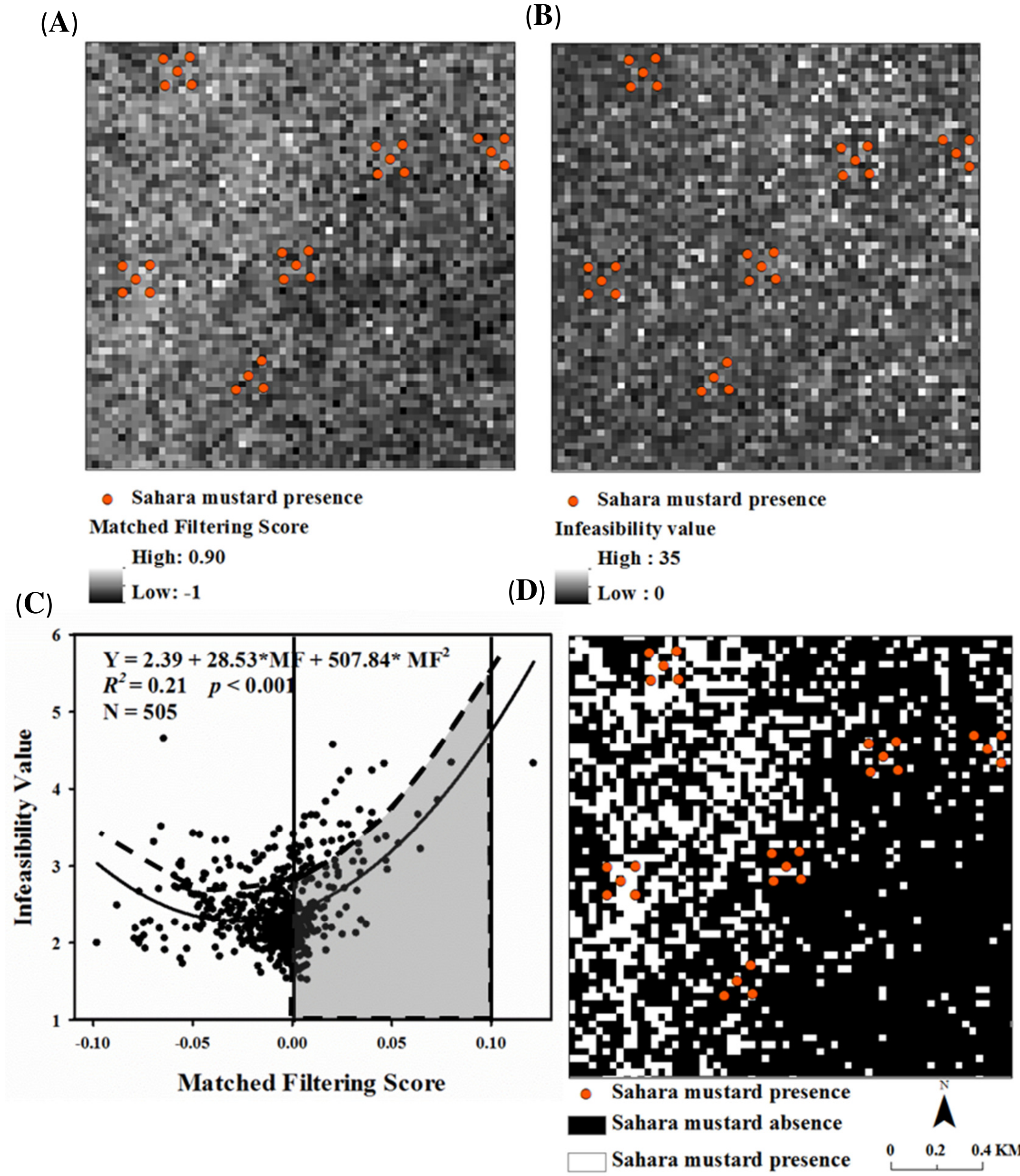

Figure 4. An example of the regression approach used to combine the matched filtering (MF) scores (**A**) and infeasibility values (**B**) from the MTMF classification with the resampled WV2 imagery. After the regression models (**C**) were fit to each of the image, all pixels that fell below the regression curve and one positive standard deviation above the regression curve that had matched filtering scores of 0-1 were classified as *B. tournifotii* presence (**B**). All other pixels were classified as *B. tournifotii* absence (**D**). The overall accuracy in this example was 67.1%.