NOTE: This report, maps, and data files have been through the USGS IPDS process and approved for distribution (see attached PDF memo from Bruce Wylie, July 25, 2012)

ADMINISTRATIVE: Principal Investigator—Bruce K. Wylie, USGS Earth Resources Observation and Science (EROS) Center, wylie@usgs.gov, 605.594.6078.

Project title—Mapping Cheatgrass Dieoff in the Northern Great Basin using Ecosystem Performance Modeling
Account number—
Date—July 9, 2012
Time period—September 1, 2011 – June 15 2012
Actual total cost—

PUBLIC SUMMARY: Cheatgrass began invading the Great Basin about 100 years ago, changing large parts of the landscape from a rich, diverse ecosystem to one where a single invasive species dominates. Cheatgrass is highly flammable; consequently, cheatgrass-dominated areas experience more fires that burn more land than in native ecosystems, resulting in economic and resource losses. Therefore, the reduced production, or absence, of cheatgrass in previously invaded areas during years of adequate precipitation could be seen as a windfall. However, this cheatgrass dieoff phenomenon creates other problems for land managers such as accelerated soil erosion, loss of early spring food supply for livestock and wildlife, and unknown recovery pathways. We used satellite data and scientific techniques to map annual estimated cheatgrass percent cover and areas of cheatgrass dieoff in the western and central parts of the northern Great Basin from 2000 to 2010. For this same area, we developed a map of cheatgrass percent cover variability and another map that displays cheatgrass dieoff probability.

These maps can assist land managers in understanding when and where cheatgrass did and did not exist over an extremely large landscape, and can possibly explain characteristics of dieoff areas that can help researchers pinpoint the cause or causes of cheatgrass dieoff. The cheatgrass dieoff maps show that dieoff areas are spatially and temporally variable; in other words, a dieoff may impact an area for a few years and then cheatgrass may return, only to dieoff again later. This pattern of variability also persists in different areas. During the study period, we estimated that, on average, about 2.6 million acres experienced cheatgrass dieoff annually. Restoring dieoff areas to a native ecosystem could be land management's goal, but until cheatgrass dieoff causes and natural recovery pathways are better understood, engaging in costly restoration activities may be unwise.

TECHNICAL SUMMARY: The goal of the original proposal was to develop a time series of cheatgrass dieoff maps using remote sensing technologies to reliably identify the current extent of the cheatgrass dieoff phenomenon in the northern Great Basin. To accomplish this goal, we accessed expedited Moderate Resolution Imaging Spectroradiometer (eMODIS) Normalized Difference Vegetation Index (NDVI) images at 250-meter spatial resolution derived from a remote sensing archive. We integrated the eMODIS data into a regression-tree application with topographic, edaphic, land cover, and weather data to develop multiple predictive models (not all datasets were used in all models). First, we created a cheatgrass start of sustained-growth model because identifying the start of cheatgrass' active growth period is critical in our method to determining annual cheatgrass percent cover. Cheatgrass phenology varies spatially and temporally based on location and weather conditions, and our study area is geographically diverse with significant weather, elevational, and latitudinal gradients. Second, we developed a cheatgrass percent cover model where Peterson's 2001 cheatgrass cover map and 2006 annual grass index map served as the dependent variable. We also used Peterson's maps to stratify our

training points. This model was used to map cheatgrass percent cover from 2000 to 2010. The cheatgrass percent cover model relied heavily on seasonal integrals of NDVI for its development, and seasonally integrated NDVI has been shown to represent vegetation dynamics (Wylie et al. 2008). Therefore, annual percent cover maps served as proxy for annual actual cheatgrass performance (ACP). ACP was used as the dependent variable in our third model, the expected cheatgrass performance model (ECP), which models cheatgrass performance. The ECP model incorporated seasonal weather data, allowing us to separate cheatgrass performance issues related to seasonal weather from those caused by dieoff. We statistically compared the annual ACP maps with the annual ECP maps to identify annual cheatgrass dieoff, also known as underperforming ecosystem anomalies. This method, ecosystem performance monitoring, has proven effective in enhancing the interpretation of vegetation monitoring in multiple ecosystems (Wylie et al. 2008, Gu et al. 2012, Wylie et al. 2012). Cheatgrass dieoff can be classified as a disturbance; therefore, it should be discernible from cheatgrass performance deviations caused by weather.

We developed a cheatgrass dieoff probability map to display areas vulnerable to dieoff. Dieoffs often persist for two or more years, so to increase the certainty that we did not label a non dieoff pixel as a dieoff, we defined a dieoff as pixels that experienced underperformance at least two consecutive years. The dataset was integrated with climate, topographic, edaphic, and land cover datasets and input into a decision-tree model to predict dieoff occurrence or absence. The model was applied to a mapping application that extrapolates the model output and predicts the probability of cheatgrass for the entire study area from 2000 to 2010.

The NW CSC funding made the following major research accomplishments possible: 1) the design and implementation of a technique to estimate cheatgrass start of sustained growth in the northern Great Basin using a predictive model; this technique was used to help define cheatgrass' dynamic growing-season period and was, we believe, partly responsible for improving our model results (submitted manuscript); 2) the creation of cheatgrass percent cover and cheatgrass performance models that can be extrapolated to nearby geographic areas; 3) the development of annual cheatgrass percent cover maps from 2000 to 2010; 4) the development of annual cheatgrass dieoff maps from 2000 to 2010; and 5) the development of a cheatgrass dieoff probability model and associated map that can be easily adapted to estimate dieoff probability under alternative climate scenarios.

Cheatgrass cover has been mapped in this region previously using a variety of sensors, but no publications describe the use of eMODIS at 250-meter spatial resolution for this purpose. This remote sensing product provides consistent historical (from the year 2000) to near-present day 7-day NDVI composite outputs, displaying a denser series of phenological change that more accurately captures cheatgrass green-up and senescence than other sensors. We used this remote sensing product to develop a unique time series of cheatgrass percent cover maps and cheatgrass dieoff maps at a landscape scale over a large geographic area, creating new scientific information about an invasive species that has degraded the Great Basin landscape for nearly a century. The resulting datasets can help inform and shape adaptive management, policy, and research. A journal article on cheatgrass percent cover using non-NW CSC funds is in development.

PURPOSE AND OBJECTIVES: The proposal's original objectives were to 1) facilitate an effective monitoring project that provided science-based information on dieoff magnitude and trends; and 2) provide robust data to inform predictive models and analytical tools for current and future management. To meet these objectives we produced a cheatgrass dieoff model to map annual cheatgrass dieoff from 2000 to 2010.

As we progressed in the research and development process of the cheatgrass models, we identified a dataset need that we believed would improve our modeling effort. This need was the cheatgrass start of sustained-growth dataset. Throughout the study's many years and over a large and diverse landscape like the northern Great Basin, the start of cheatgrass growth will vary widely, and our ability to model cheatgrass percent cover is predicated on our ability to identify when cheatgrass growth begins at a local level. Therefore, we developed the start of sustained-growth dataset to provide a more accurate way to incorporate the spatial and temporal dynamics of this phenomenon into our modeling process. We also increased the number of training data points for the dieoff model from the planned 22,000 (2,000 per year) to almost 39,000 (almost 3,500 per year). This increase in training points improved the model robustness to more topographic, edaphic, weather, and land cover conditions that were present.

Our findings and map products should be useful to land managers, scientists, and policymakers. As conditions in the Great Basin and beyond shift, these constituent groups need flexible modeling capabilities that can be adapted to new and potentially rapidly changing situations. Understanding current and potential future cheatgrass dynamics can inform the decision making process on managing and studying cheatgrass infested ecosystems.

ORGANIZATION AND APPROACH:

1) eMODIS NDVI datasets were smoothed, projected, and clipped to the study area.
2) Gridded ancillary datasets (topographic, weather, edaphic, and land cover) were selected that likely influence the annual dynamics of cheatgrass percent cover and cheatgrass dieoff. These ancillary datasets were prepared to ensure that their projection, resolution, and footprint matched the eMODIS NDVI datasets for modeling purposes.
3) The spatially and temporally dynamic start of sustained-growth datasets was developed to represent the start of cheatgrass' active growth over a range of conditions. Identifying cheatgrass' active growth period improved the selection of spring periods to integrate remote sensing images and enhanced development of a cheatgrass index[i] and improved the accuracy of the cheatgrass percent cover model.
4) The cheatgrass percent cover model was developed using the cheatgrass index, integrated NDVI spring images, integrated NDVI summer images, and relevant ancillary datasets. The model output was used with a mapping application to develop annual cheatgrass percent cover maps.
5) We used the cheatgrass percent cover maps as the dependent variable in the development of the cheatgrass performance model. Weather data, land cover datasets, and a site potential dataset were used as independent variables. The site potential dataset was used to represent long-term cheatgrass percent cover and captured the general spatial variation in cheatgrass percent cover. The model output map was differenced with ACP and regression tree model confidence limits to develop annual cheatgrass dieoff maps.

PROJECT RESULTS: The cheatgrass percent cover model improved (R^2 = 0.77 vs. R^2 = 0.85) over a preliminary study of cheatgrass percent cover we conducted in the Winnemucca, NV, area. We feel this improvement could be, in part, attributed to the use of the cheatgrass start of sustained-growth datasets to help define cheatgrass' annual active growth period. The cheatgrass percent cover model was integrated into a mapping application, MapCubist, to generate a time series (2000 – 2010) of cheatgrass percent cover maps. Interannual average percent cover, interannual coefficient of variation, and interannual standard deviation maps were produced for the study area.

We modeled the highest percent cheatgrass cover, on average, in the grass and shrub lands of the Snake River Plain. Other areas of high percent cover include east of Bend, OR, and northwest of Reno, NV. The

greatest standard deviations of cheatgrass percent cover also occurred in these same areas. However, when examining the coefficient of variation map, we noticed the greatest relative variation did not occur in the Snake River Plain, near Bend, or northwest of Reno. The highest relative measures of variation in cheatgrass percent cover were scattered across the map in small pockets of dark blue. They were mostly present in the bottom two-thirds of the map, which is also the section of the map where the areas of least variation and low mean cheatgrass percent cover are seen. The implication is that the areas of low cheatgrass percent cover experience wider variations than do areas of high percent cover. These low areas of variation are represented on the map by red colors.

The ECP model performed well (R^2 = 0.88) using 38,245 training points, indicating that the model's prediction of cheatgrass performance was strong based on our input variables. Maps of cheatgrass performance were created for eleven years using the ECP model output and MapCubist. Areas of predicted cheatgrass dieoff (underperformance) are shown on the maps in shades of magenta to red. Normal performance is displayed in brown tones (darker brown indicates low normal performance). Areas of cheatgrass overperformance are shaded from yellow to green. As a proportion of the study area dominated by grass or shrub at elevations lower than 2,000 meters, the annual predicted dieoff as a percent of total land area for the eleven years ranged from a low of 3.7 (2001) to a high of 5.7 (2004), with the eleven-year average equal to 4.8, or approximately 10,500 km^2 per year. The examination of the time series of cheatgrass dieoff maps reveals that the Snake River Plain experienced significant dieoff each year during our study. The dieoff pixels fluctuate in number and shift spatially year-to-year, but the eleven maps show persistent dieoffs in the Snake River Plain. This area also shows overperformance every year, and the overperforming pixels also fluctuate in number and shift spatially. Other areas where we estimate relatively consistent dieoff is 1) just east of Bend, OR, 2) in an area about 75 miles northwest of the Nevada, Idaho, Oregon tri-state point, 3) both north and south of Winnemucca, NV, and 4) west of Elko, NV.

The dieoff probability model accuracy equaled 92%. Warmer colors on the cheatgrass probability dieoff map indicate areas where the model estimates a higher probability of a dieoff occurrence. The concentration of dieoff probability areas are where the annual maps showed persistent dieoffs and in a small area northwest of Reno, NV. The model estimated no dieoff probability for 56% of the study area, and approximately 10% of the area has a greater than 80% chance of a dieoff.

ANALYSIS AND FINDINGS: We adapted Kokaly's (Kokaly 2011) idea of using a spring image and a summer image to detect cheatgrass infestation and created a cheatgrass index that served as an estimate of cheatgrass percent cover. The index was then used with integrated spring and summer images to form remote sensing vegetation index inputs into our cheatgrass percent cover model. Of 14 independent variables, these inputs, along with an elevation dataset and a latitude proxy dataset, were the five most often used in our cheatgrass percent cover model.

Annual maps of cheatgrass percent cover and interannual summaries provide land managers and researchers with vegetation histories relevant to wildlife and should allow stratification and prioritization of future studies and habitat restoration efforts. The annual maps and the probability map also can provide predictive information on dieoff trends and, with inputs from future climate data, inform climate change forecasts, especially as dieoff factors are better understood. Our analysis methods and products can be integrated into the Bureau of Land Management's Regional/Sub-regional Assessment framework as tools to be used in annual assessments of the cheatgrass dieoff phenomenon.

CONCLUSIONS AND RECOMMENDATIONS: On a pixel-by-pixel basis, the annual cheatgrass percent cover and cheatgrass dieoff maps show significant spatial and temporal variability. When viewed more regionally, there is much less variability, although significant change is evident from map to map. Cheatgrass percent cover is highly sensitive to precipitation events and this is reflected in its temporal variation. Cheatgrass dieoff is a moving target; it can persist in an area for several years or it can affect an area one year and not the next.

The cheatgrass dieoff probability model produced a spatially variable map. Large contiguous sections of the study area were modeled with no probability of dieoff or with varying probabilities of dieoff. Hot spots were geographically dispersed throughout the study area, with the Snake River Plain presenting the largest contiguous area of predicted high probability of dieoff.

Understanding cheatgrass dynamics in the northern Great Basin, especially in relation to fire dynamics, can assist land managers as they battle the loss of sagebrush and the resulting population declines of Greater sage grouse and focus future intense field studies and habitat conservation efforts. Further research ideas include 1) the application of a shrub model before fire and a cheatgrass model after fire to study the response of vegetation performance to fire, and 2) developing future climate-based projections of areas vulnerable to future cheatgrass dieoffs and cheatgrass invasion. Funding will be needed to develop these research ideas and increase the scientific community's understanding of cheatgrass dynamics.

The daily imaging of MODIS and subsequent maximum NDVI weekly composites provided by eMODIS (along with our temporal smoothing) effectively removed clouds and captured important phenological signatures which were used primarily to map cheatgrass cover. Obtaining reliable cloud-free imagery from high resolution sources or from Landsat would likely be problematic, especially during the spring growth period of cheatgrass.

One difficulty we encountered in this process was the timing of the funding. The funding came very late in Fiscal Year 2011. We were able to forward fund existing EROS contract staff to effectively complete the work by extending the FY11 project through June 2012.

OUTREACH: Stephen P. Boyte*, Bruce K. Wylie, and Donald J. Major presented a webinar to a group of land managers on March 6, 2012, titled "Mapping inter-annual cheatgrass production and dieoff using remote sensing and ecological models." See a YouTube video of this presentation as part of a larger cheatgrass dieoff seminar at http://www.youtube.com/watch?v=ZxcCJcDGXXQ.

Stephen Boyte*, Bruce K. Wylie, and Donald J. Major presented a paper at the 2012 Society for Range Management meetings titled "Identifying cheatgrass dieoff in the Great Basin by integrating eMODIS NDVI data with ecological models."

We developed a website, http://lca.usgs.gov/lca/epa_cheatgrass/index.php, which details preliminary work we have conducted on cheatgrass dieoff in the Great Basin near Winnemucca, NV.

One article is under review. The article is titled "Using a simple rule-based, piecewise regression-tree model to estimate cheatgrass (*Bromus tectorum*) start of sustained growth in the northern Great Basin, USA."

A second article on cheatgrass dieoff in the northern Great Basin is in preparation.

A presentation on cheatgrass dieoff in the northern Great Basin is planned for the 2013 Society for Range Management meeting in Oklahoma City, OK.

REFERENCES

GU, Y., BOYTE, S.P., WYLIE, B.K. and TIESZEN, L.L., 2012, Identifying grasslands suitable for cellulosic feedstock crops in the Greater Platte River basin-dynamic modeling of ecosystem performance with 250-m eMODIS. *Global Change Biology Bioenergy,* **4**, pp. 96-106.

KOKALY, R.F., 2011, DESI—Detection of Early-Season Invasives (software-installation manual and user's guide version 1.0). *U.S. Geological Survey Open-File Report*, 2010-1302, (Reston, VA: U.S. Geological Survey).

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[1] Cheatgrass index $= \frac{(Integrated\ spring\ image - Integrated\ summer\ image)}{(Integrated\ spring\ image + Integrated\ summer\ image)}$

ReadMe file to accompany the report "Mapping Cheatgrass Dieoff in the Northern Great Basin using Ecosystem Performance Modeling"

Submitted to the USGS Northwest Climate Science Center
July 2012

Author: Stephen P. Boyte, SGT, Inc. contractor to U.S. Geological Survey Center for Earth Resources Science and Observation

Time period: 2000 – 2010

Three main folders are associated with this readme file. They are:

1) "Data Files", which contains two subfolders, "Dieoffs" and "PercentCover".

a) The "Dieoff" subfolder contains every year's modeled cheatgrass dieoff estimates and their associated files, including a layer file. The dieoff estimates' file format is ERDASImagine signed 16-bit. Values < -100 are underperforming relative to weather and site conditions and > 100 are overperforming relative to weather and site conditions.

b) The "PercentCover" subfolder contains every year's modeled cheatgrass percent cover estimates and their associated files, including a layer file. The cheatgrass percent cover format is ERDAS Imagine signed 8-bit. 12 maps total. Interannual cheatgrass summaries (mean, standard deviation, coefficient of variation (CV) were also produced.

2) "Maps", which contains two subfolders, "Dieoffs" and "PercentCover".

a) The "Dieoff" subfolder contains every year's cheatgrass dieoff maps as .png files. This subfolder also contains the Dieoff Probability map, also as a .png file.

b) The "PercentCover" subfolder contains every year's cheatgrass percent cover maps, a map of mean values, a standard deviation map, and a coefficient of variation map. 14 maps total.

3) "Report" which contains the report titled "Mapping Cheatgrass Dieoff in the Northern Great Basin using Ecosystem Performance Modeling".

All maps and files are in USA Contiguous Albers Equal Area Conic USGS version projection (Central meridian -96; Latitude of first standard parallel 29.5; Latitude of second standard parallel 45.5; Latitude of origin of projection 23.0; False easting 0; False northing 0).

All maps and ERDAS Imagine files are 250-meter spatial resolution using temporally smoothed expedited Moderate Resolution Spectroradiometer (eMODIS) Normalized Difference Vegetation Index (NDVI) images.

Table of Contents

Data Files

Dieoffs

2000_2010dieoff.xml	(metadata for dieoff files)
2000Dieoff.img	(2000 Dieoff file)
2001Dieoff.img	(2001 Dieoff file)
2002Dieoff.img	(2002 Dieoff file)
2003Dieoff.img	(2003 Dieoff file)
2004Dieoff.img	(2004 Dieoff file)
2005Dieoff.img	(2005 Dieoff file)
2006Dieoff.img	(2006 Dieoff file)
2007Dieoff.img	(2007 Dieoff file)
2008Dieoff.img	(2008 Dieoff file)
2009Dieoff.img	(2009 Dieoff file)
2010Dieoff.img	(2010 Dieoff file)
DieoffProb.xml	(metadata for dieoff probability file)
DieoffProbmap.img	(Dieoff probability map)

Percent Cover

2000_2010cheatcover.xml	(metadata for the percent cover files)
2000cheatcover.img	(2000 Percent cover file)
2001cheatcover.img	(2001 Percent cover file)
2002cheatcover.img	(2002 Percent cover file)
2003cheatcover.img	(2003 Percent cover file)
2004cheatcover.img	(2004 Percent cover file)
2005cheatcover.img	(2005 Percent cover file)
2006cheatcover.img	(2006 Percent cover file)
2007cheatcover.img	(2007 Percent cover file)
2008cheatcover.img	(2008 Percent cover file)
2009cheatcover.img	(2009 Percent cover file)
2010cheatcover.img	(2010 Percent cover file)
CheatCV.img	(Percent cover coefficient of variation)
Cheatmean.img	(Percent cover eleven-year mean)
CheatStDev.img	(Percent cover standard deviation)

(Each .img file has associated files that must be present in the folder. The .lyr files retain the data files original color scheme.)

Maps

Dieoff

2000Dieoff.png	(2000 Dieoff map)
2001Dieoff.png	(2001 Dieoff map)
2002Dieoff.png	(2002 Dieoff map)
2003Dieoff.png	(2003 Dieoff map)
2004Dieoff.png	(2004 Dieoff map)
2005Dieoff.png	(2005 Dieoff map)
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2007Dieoff.png	(2007 Dieoff map)
2008Dieoff.png	(2008 Dieoff map)
2009Dieoff.png	(2009 Dieoff map)
2010Dieoff.png	(2010 Dieoff map)
DieoffProbability_model.png	(Dieoff probability map)

Percent Cover

2000cheatcover.png	(2000 Percent cover map)
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2007cheatcover.png	(2007 Percent cover map)
2008cheatcover.png	(2008 Percent cover map)
2009cheatcover.png	(2009 Percent cover map)
2010cheatcover.png	(2010 Percent cover map)
Cheatcoverlegend.png	(legend for the percent cheat cover maps)
CVcheatcover.png	(Percent cover coefficient of variation map)
CVlegend.png	(legend for the percent cover coefficient of variation map)
Meancheatcover.png	(Percent cover mean map)
Meanlegend.png	(legend for the percent cover mean map)
StDevcheatcover.png	(Percent cover standard deviation map)
StDevlegend.png	(legend for the percent cover standard deviation map)

Report

The funding report for the project titled “Mapping cheatgrass dieoff in the northern Great Basin using Ecosystem Performance Modeling.” Prepared for the USGS Northwest Climate Science Center.