Assessing the success of post-fire reseeding in semiarid rangelands using Terra MODIS

Fang Chen[1*], Keith T. Weber[1], John L Schnase[2]

[1]GIS Training and Research Center, Idaho State University, 921 S. 8th Ave, Stop 8104, Pocatello Idaho 83209-8104

[2]Office of Computational and Information Science and Technology, NASA Goddard Space Flight Center, Greenbelt, MD 20771

*Corresponding author. *E-mail address*: chenfang@isu.edu.

Abstract

Successful post-fire reseeding efforts may aid rangeland ecosystem recovery by rapidly establishing a desired plant community and thereby reducing the likelihood of infestation by invasive plants. While the success of post-fire remediation is critical, few efforts have been made to leverage existing geospatial technologies to develop methodologies to assess reseeding success following a fire. In this study, Terra Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data were used to improve the capacity to assess post-fire reseeding rehabilitation efforts, with particular emphasis on the semiarid rangelands of Idaho. Analysis of MODIS data demonstrated a positive effect of reseeding on rangeland ecosystem recovery as well as differences in vegetation between reseeded areas and burned areas where no reseeding had occurred ($P < 0.05$). We conclude that MODIS provides useful data to assess the success of post-fire reseeding.

Keywords: rangelands; reseeding; fPAR; remote sensing; Idaho

INTRODUCTION

Wildfire is a common hazard in the semiarid rangelands of southeast Idaho. Following wildfire, ground vegetation is typically eliminated, leaving the landscape devoid of vegetative cover. These communities frequently undergo a series of adverse ecological changes, such as soil erosion, invasion by introduced annual grasses (e.g., cheatgrass[*Bromus tectorum*] and Medusahead [*Taeniatherum caput-medusae*]), and long-term native species decline (Pierson et al. 2002; Hilty et al. 2004). Rehabilitation is often necessary after fire, particularly in areas with high topographic relief. Monitoring how ecological systems respond to rehabilitation efforts is a critical step for determining long-term sustainability of the communities affected and for planning future land management practices.

Over the years, increasing resources have been devoted to fire rehabilitation efforts through various federal agencies such as the U.S. Department of Agriculture (USDA), Forest Service (USDA-USFS), the U.S. Department of Interior, Bureau of Land Management (USDI-BLM), and the National Park Service (NPS), and many efforts have been made to monitor post fire recovery of ecosystem in southeast Idaho (Beyers 2004; Weber 2010). In particular, the USFS, BLM, and NPS have proposed a series of recovery projects focused on better understanding the effects of fire along the wildland-urban interface (WUI), where certain human activities (e.g. prescribed fire and grazing) can negatively impact and potentially accelerate interrelated ecological changes. The objectives of these projects were to identify ways to prevent soil erosion, water loss, and the permanent impairment of ecosystems along the WUI (Gibbons 1995; Ercanoglu et al. 2006).

Many wildfire studies indicate that successful post-fire reseeding aids in the rapid establishment of a desired plant community and assists in the recovery of the ecosystem (Hubbard 1975; Beyers 2004). Fires consume the protective vegetation and organic litter cover from hillsides, which destabilizes the soil surface on steep slopes. Reseeded plants can rapidly stabilize soils and promote water infiltration. Furthermore, successful reseeding treatments can better control erosion and prevent loss of topsoil (Anderson et al. 1975; Beyers 2004). In New Mexico, post-fire reseeding decreased soil loss after the Cerro Grande Fire (Miller et al. 2003) and similarly, post-fire reseeding reduced hill slope erosion after the 1998 North 25 Fire in north central Washington (Robichaud et al. 2006). Reseeding may also increase the availability and quantity of range forage for both wildlife and livestock and help control the spread of invasive plants on public lands when using optimal initial plant establishments (Hubbard 1975; Sheley et al. 1997; Eiswerth et al. 2009).

Many factors affect the success of post-fire reseeding, including the initial choice of plant species (Martin and Wilsey 2006), mechanical and non-mechanical treatments used for planting (Ott et al. 2003), soil conditions (Gillen and Berg 1998), terrain (Miles et al. 1989), and precipitation (Robichaud et al. 2006). Various assessment approaches have been developed to measure reseeding success and the impact of reseeding on the ecosystem. The focus of these assessment approaches can be categorized into one of three ecosystem attribute appraisals: (1) biodiversity and vegetation type (SER 2004; Ruiz-Jaen and Aide 2005), (2) vegetation structure (Peterson et al. 1998), and (3) ecological processes (e.g., vegetation productivity) (Allen 1993;; Wilkins et al. 2003). While, the BLM's emergency fire rehabilitation (EFR) funds have been used to monitor reseeding efforts (U.S. General Accounting Office 2003) since the mid-1980s, few efforts have used geospatial technologies to accomplish this task (Miller et al. 2003). In contrast, most assessments have relied upon field-measurements comparing ecosystem attributes in restored sites with corresponding attributes at reference sites (SER 2004). While these conventional assessments are straightforward and accurate for small scale studies, they are also labor intensive and may be difficult to implement across the vast fire areas common to the Intermountain West. Due to the large expanse of Idaho rangelands coupled with the heterogeneity and variability of vegetation in semiarid ecosystems, field-based methods are limited in assessing post-fire reseeding success and ecosystem recovery over an entire region as compared to the synoptic view provided with remote sensing technology.

Satellite remote sensing has the ability to perform land assessments over large spatial areas with frequent periodicity. The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra and Aqua satellites. One of the derived products developed by the MODIS Land Discipline Team (MODLAND) for the MODIS sensor is the fraction of photosynthetically active radiation (fPAR) product that provides global 1 km spatial resolution fPAR imagery at 8-day intervals

(Knyazikhin et al., 1998; Myneni et al., 2002). fPAR is directly related to the top of canopy spectrum and measures the proportion of available radiation in specific photosynthetically active wavelengths (i.e., 0.4 - 0.7 µm) which are absorbed by the plant canopy (Chen 1996; Cramer et al. 1999; Hély et al. 2003; Chen et al. 2010). In many ecological studies, fPAR has been used to represent vegetation characteristic (e.g., vegetation cover, density, and biomass) within several biomes (Bonan 1995; Chen et al. 2008).

In this study, we used MODIS fPAR products to generate layers of primary productivity from 2004 to 2009. Geospatial technologies and earth observation data were used to improve the capacity to assess post-fire reseeding rehabilitation efforts, with particular emphasis on the semiarid rangelands of Idaho. Our study addressed two specific science questions: (1) how can post-fire reseeding success be determined using geospatial technologies in the semiarid rangelands of Idaho? And (2) how do reseeding projects affect post-fire ecosystem recovery of semiarid rangelands?

MATERIALS AND METHODS

Study area

The study area of the proposed research focused on the Big Desert area in southeast Idaho (Fig. 1). The area lies approximately 71 km northwest of Pocatello Idaho, and with the center of the study area is located at 113º 4’ 18.68” W and 43º 14’ 27.88” N. Large portions of the Big Desert are managed as grazing allotments by the BLM. The area is a semiarid sagebrush-steppe ecosystem with a high proportion of bare ground ($\bar{x}$ bare ground ~ 17%), and with a vegetation component consisting of primarily native and non-native grasses, forbs, and many shrub species including sagebrush (*Artemisia tridentata* Nutt. *ssp. wyomingensis* Beetle & Young) and rubber rabbitbrush (*Chrysothamnus nauseosus*) (West 1999; West and Young 2000). The elevation of the study area ranges from 1349-2297 m above sea level, and annual precipitation is 230 mm with 40% of the precipitation falling from April through June.

In 2006, the Big Desert study area was the site of a large lightning-caused wildfire. The Crystal Fire, one of the largest fires in southeast Idaho since 1936, burned approximately 40% of the Big Desert study area. The Crystal Fire burned approximately 89,117 ha of grasslands and sagebrush between August

15 and August 31, 2006, and more than 16,100 ha burned in a single day. While this large scale disturbance had the potential to adversely affect the rangeland ecosystem of southeast Idaho for a decade or more, it also presents scientists with a unique opportunity to monitor and assess post-fire reseeding efforts and ecosystem recovery within this study area.

Rehabilitation plan and field survey

To assist in the recovery of the rangelands ecosystem, the Idaho state office of the BLM developed a three-year reseeding plan for the "Crystal Fire Burned Area Rehabilitation", with estimated costs exceeding $2M (Hankins 2008). The reseeding plan included ground seeding, aerial seeding, and plug planting. Ground seeding was conducted along with cheatgrass herbicide treatments, native grass seeding, and sagebrush drill seeding. Herbicide treatments were conducted within homestead, butte native, and sagebrush plug reseeding areas which began in the spring of 2007 using a contract helicopter or fixed-wing aircraft that flying at low altitude (Fig. 1). Herbicide was applied at a low rate (95.82 ml per ha) so existing perennial native bunchgrasses would not be killed. After reducing the abundance of existing exotic invasive annuals, native grass seeding and sagebrush drill seeding were conducted and completed in the fall 2007. Between fall 2007 and spring 2008, sagebrush plug planting was conducted to re-establish Wyoming big sagebrush. In addition, to help establish sagebrush from seed over a portion of the burned area, sagebrush aerial seeding was conducted using a whirlybird spreader attached to a utility terrain vehicle (UTV) in the winter of 2008 (e.g., December 2008) (Table 1) (Peterson et al. 2009).

In June 2008, these areas were visited by BLM personnel to examine the effectiveness of reseeding. Sample plots were established in each seeding area and in adjacent unseeded areas. Vegetative cover and density were measured using Daubenmire cover measurement methods in both reseeded and control sites (Daubenmire 1959; Hanley 1978).

MODIS image processing

A series of Collection 5 MODIS fPAR (MOD15A2) scenes were selected for 2004 to 2009, and projected into Idaho Transverse Mercator projection (IDTM), NAD 83, using ESRI's ArcGIS 9.3 for datum transformation and projection (ESRI 2011). Using quality control (QC) layers, MODIS fPAR data were screened to reject data of insufficient quality. Only pixels with the best possible quality (i.e., values on all bit fields were equal to zero) under the QC definition table were retained (Table 2). The QC filter includes pixels with good quality and removes pixels which were impaired by cloud cover or other calibration errors created by the sensor.

Using a single fPAR scene to characterize vegetation would likely result in an underestimation of annual productivity, because a single fPAR image may not capture the maximum fPAR value for each pixel over an entire growing season. For instance, within the Big Desert cool season grasses like cheatgrass (*Bromus tectorum*) germinate and "green-up" early in the growing season (e.g., April and May) and then quickly senesce (June and July). During the senescent period of *Bromus tectorum*, native grasses such as Indian rice grass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*) are actively growing and achieving peak biomass. Therefore, monthly composite fPAR layers (April through September) were developed to better characterize the vegetation across the dynamic study site where distinct vegetation communities (grasses, forbs, and shrubs) experience divergent periods of peak biomass and/or greenness.

To enable quantitative assessment of fPAR differences between reseeding areas (Re) and burned areas where no reseeding had occurred (NRe), a total of 460 randomly distributed test points were generated using Hawth's analysis tools for ArcGIS within both Re areas (n=230) and NRe areas (n=230) (Spatial Ecology LLC. 2011). After removing all points falling within the "bad data quality" areas of the imagery (n= 193 and 178 remained in the Re and NRe areas, respectively), fPAR pixel values were extracted using the ArcGIS "Sample" tool. To further evaluate post-fire ecosystem restore, monthly mean fPAR values were calculated for Re and NRe areas, respectively. In addition, a t-test was used to quantitatively assess whether fPAR values in Re areas were statistically different from fPAR values in NRe areas.

RESULTS AND DISSCUSSION

Monthly composite fPAR values across the entire Re areas (including homestead, mule butte native, sagebrush drill, sagebrush plug, and sagebrush aerial seeding areas) and NRe areas were relatively similar between 2004 and 2007, but Re areas are substantially higher than NRe in 2008 (0.027, P=0.009 [May]; 0.023, P=0.000 [June]; 0.020, P=0.004 [July]; 0.011, P=0.000 [August]; 0.004, P=0.016 [September]) and 2009 (0.012, P=0.370 [May]; 0.019, P=0.003 [June]; 0.025, P=0.000 [July]; 0.006, P=0.002 [August]; 0.003, P=0.098 [September]) (Table 3 and Fig. 2). In comparison to NRe areas, fPAR values in Re areas increased 9%, 8%, 10%, 7%, and 3% from May to September in 2008 and 4%, 7%, 11%, 4%, and 2% from May to September in 2009. fPAR values were higher in Re areas, indicating either increased ground cover was established or higher rates of photosynthetic activity was observed by those plants in the Re area. While the specific reason explaining higher fPAR is not certain, it is clear that reseeding had a positive effect on the primary productivity of these areas as evidenced by the continued elevated values through September in both 2008 and 2009.

Between August 2006 and October 2007, before the post-fire reseeding project began, ground vegetation conditions were very similar in both Re and NRe areas. Interestingly, the smallest difference in fPAR between the entire Re and NRe areas was observed between April to September, 2007 (Fig. 2). Results from t-test analyses revealed monthly composite fPAR values were statistically different ($P < 0.05$) between Re and NRe areas in 2008 and between the majority of the 2009 growing season (June through August) (Table 4).

During the 2008 field survey conducted by the BLM, no Wyoming big sagebrush seedlings were found within the sagebrush drill seeding areas and subsequently, the sagebrush drill treatments were considered unsuccessful. Using MODIS imagery, no significant difference in fPAR was detected between sagebrush drill seeding areas and NRe areas during the same time period (June 2008) ($P > 0.05$) thereby corroborating BLM field results. However, between May through July 2009, MODIS monthly composite fPAR data indicated significant differences between these same areas. As no field monitoring was conducted in these areas in 2009, it is difficult to determine what caused this difference.

In contrast to sagebrush drill seeding areas, 2008 field survey data indicate that sagebrush plug reseeding areas had a relatively high survival rate ($\bar{x}$ = 31%). fPAR values comparing sagebrush plug reseeding areas and NRe areas also demonstrated statistically significant differences ($P < 0.05$) from June through August, 2008 and throughout 2009. In comparison to NRe areas, fPAR values in sagebrush plug Re areas increased 2%, 12%, 14%, 7%, and 2% from May to September in 2008 and 4%, 13%, 31%, 16%, and 4% in 2009 (Fig.3). Higher fPAR values in the sagebrush plug Re areas demonstrate the reseeding project likely helped increase sagebrush cover and density. We conclude the information represented by field-based monitoring followed the same trend as suggested using MODIS imagery.

In the semiarid rangelands of Idaho, many herbaceous plants, and especially introduced annual grasses tend to be green only during active growth periods. In contrast, most shrubs maintain greenness when grasses senesce, resulting in a substantial reduction in observed fPAR (e.g., the fPAR value of a pure grass areas is close to 0) late in the summer. Field survey data demonstrate that both native perennial grasses and annual grasses like cheatgrass, regenerated in both Re and NRe areas with comparable estimates of total plant density in each (e.g., 180 density-plants per m^2 in mule butte native and homestead reseeding area; 187 density-plants per m^2 in unseeded area). The natural regeneration of Wyoming big sagebrush requires a longer time period and therefore fewer plants were expected in NRe areas compared to the Re area. The increase in monthly composite fPAR values between June and August in 2008 and 2009 (Fig. 3) was attributed to fewer Wyoming big sagebrush plants in the NRe areas.

BLM field survey data demonstrated that reseeding treatments had an effect on the generation of perennial native grasses and annual invasive grasses like cheatgrass. For example, in 2008, the density of perennial grasses in the mule butte native grass reseeding area was about twice that found in the unseeded area. In addition, while cheatgrass was more prevalent in the Re areas compared to the NRe areas, the density of perennial grasses in the homestead Re area was about the same as that found in the NRe area. The Homestead treatment also resulted in fewer cheatgrass plants within the Re area than were found in the NRe area.

MODIS fPAR data cannot detect the difference between perennial native grasses and annual invasive grasses like cheatgrass. Thus, it was not possible to assess reseeding success of native grasses. However, Morisette et al. (2006) conclude that MODIS NDVI and EVI could be used to map invasive tamarisk (*Tamarix spp.*) habitat suitability in the United States and this method may be also useful for mapping native and invasive grasses based on MODIS data. Future work will seek to incorporate MODIS NDVI, EVI, and fPAR data for a more comprehensive assessment of reseeding success in the semiarid rangelands of Idaho.

MANAGEMENT IMPLICATIONS

In this study, we determined the success of post-fire reseeding and the impact of human activity (specifically reseeding applied using three different management practices), within a sagebrush-steppe ecosystem in southeastern Idaho. MODIS fPAR data were used to assess the success of post-fire reseeding over a large scale. The results demonstrated differences in vegetation between reseeding areas and fire areas where no reseeding occurred ($P < 0.05$). Furthermore, the specific reseeding projects evaluated in this study appear to have had a positive effect on the primary productivity of these rangelands. The implementation of these and similar remote sensing techniques by land managers 1) may improve regional-scale assessments of ecosystem recovery, 2) are more cost-effectiveness than traditional ground-based assessments, and 3) broaden our understanding of how specific reseeding projects affect post-fire recovery. Furthermore, we conclude that field-measurement methods continue to play a significant role in the assessment of reseeding effects and while MODIS data alone cannot act as a substitute for field surveys, it can certainly complement field efforts and enhance future assessments.

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Table captions

Table 1. Summary of reseeding treatment areas following the 2006 Crystal Fire

Table 2. MODIS fPAR general quality control definitions for collection 5 data

Table 3. Difference in monthly composite fPAR values between reseeding areas and no reseeding areas (NRe)

Table 4. Results of t-test analyses comparing fPAR values within reseeding areas (Re) and no reseeding areas (NRe)

Table 1. Summary of reseeding treatment areas following the 2006 Crystal Fire

	Treatment Type				
	Homestead	Mule butte native grass	Sagebrush drill	Sagebrush plug	Sagebrush aerial
Total area (*ha*)	527	3,726	405	405	4,050

Note: “Anatone” bluebunch wheatgrass, “Nordan” Crested wheatgrass, “Nezpar” Indian ricegrass, “Sodar” streambank wheatgrass, and “Eski” sanfoin were reseeded at Homestead areas.

Table 2. MODIS fPAR general quality control definitions for collection 5 data

Bit No.	Parameter Name	Bit Comb.	Description of Bitfield(s)
0	MODLAND_QC_bits	0	Good quality (main algorithm with or without saturation)
		1	Other Quality (back-up algorithm or fill values)
1	Sensor	0	Terra
		1	Aqua
2	DeadDetector	0	Detectors apparently fine for up to 50% of channels 1,2
		1	Dead detectors caused >50% adjacent detector retrieval
3-4	CloudState (inherited from Aggregate_QC bits {0,1} cloud state)	00	0 Significant clouds NOT present (clear)
		01	1 Significant clouds WERE present
		10	2 Mixed cloud present on pixel
		11	3 Cloud state not defined, assumed clear
5-7	SCF_QC (five level confidence score)	000	0, Main (RT) method used, best result possible (no saturation)
		001	1, Main (RT) method used with saturation. Good,very usable
		010	2, Main (RT) method failed due to bad geometry, empirical algorithm used
		011	3, Main (RT) method failed due to problems other than geometry, empirical algorithm used
		100	4, Pixel not produced at all, value coudn't be retrieved (possible reasons: bad L1B data, unusable MODAGAGG data)

Note: RT represents radiative transfer. SCF_QC represents the self-consistent field quality control.

Table 3. Difference in monthly composite fPAR values between reseeding areas and no reseeding areas (NRe)

Date	Reseeding areas *vs.* NRe		
	fPAR change	Rate of change (%)	P-value
2008-05	0.027	9	0.009
2008-06	0.023	8	0.000
2008-07	0.020	10	0.004
2008-08	0.011	7	0.000
2008-09	0.004	3	0.016
2009-05	0.012	4	0.370
2009-06	0.019	7	0.003
2009-07	0.025	11	0.000
2009-08	0.006	4	0.002
2009-09	0.003	2	0.098

Table 4. Results of t-test analyses comparing fPAR values within reseeding areas (Re) and no reseeding areas (NRe)

Date	Sagebrush drill *vs.* NRe*		Sagebrush plug *vs.* NRe		Overall *vs.* NRe **	
	F-value	P-value	F-value	P-value	F-value	P-value
2008-04	0.045	0.241	1.199	0.022	0.408	0.043
2008-05	4.703	0.768	9.543	0.457	2.991	0.009
2008-06	0.712	0.168	24.375	0.000	14.362	0.000
2008-07	0.682	0.148	2.191	0.000	0.055	0.004
2008-08	14.024	0.103	9.210	0.000	12.637	0.000
2008-09	6.087	0.130	7.555	0.137	10.813	0.016
2009-04	0.579	0.594	0.085	0.002	0.312	0.556
2009-05	14.815	0.000	4.136	0.045	0.113	0.370
2009-06	0.695	0.013	0.042	0.000	1.716	0.003
2009-07	8.764	0.002	3.620	0.000	16.362	0.000
2009-08	0.378	0.651	3.734	0.000	9.654	0.002
2009-09	2.174	0.035	1.463	0.006	0.492	0.098

* Sagebrush drill areas represent areas only conducted by sagebrush drill treatments.

** Overall reseeding areas represent all reseeding areas including homestead, mule butte native, sagebrush drill, sagebrush plug, and sagebrush aerial reseeding treatments.

Figure captions

Figure 1. Location of the Big Desert and reseeding categories in southeastern, Idaho.

Figure 2. Monthly composite fPAR values in entire reseeding areas and no reseeding areas.

Figure 3. Monthly composite fPAR values in sagebrush plug reseeding areas and no reseeding areas.

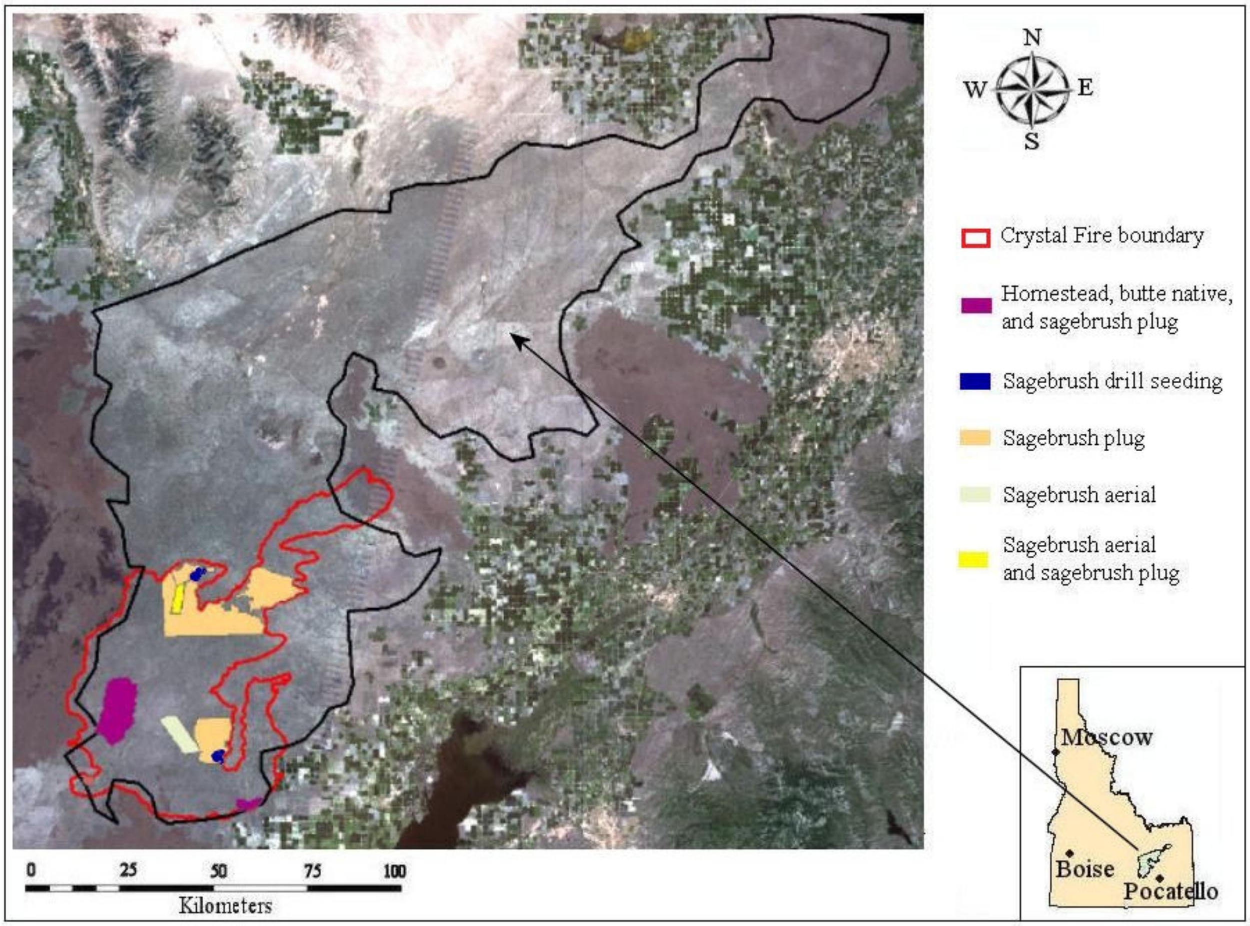

Figure 1. Location of the Big Desert and reseeding categories in southeastern, Idaho.

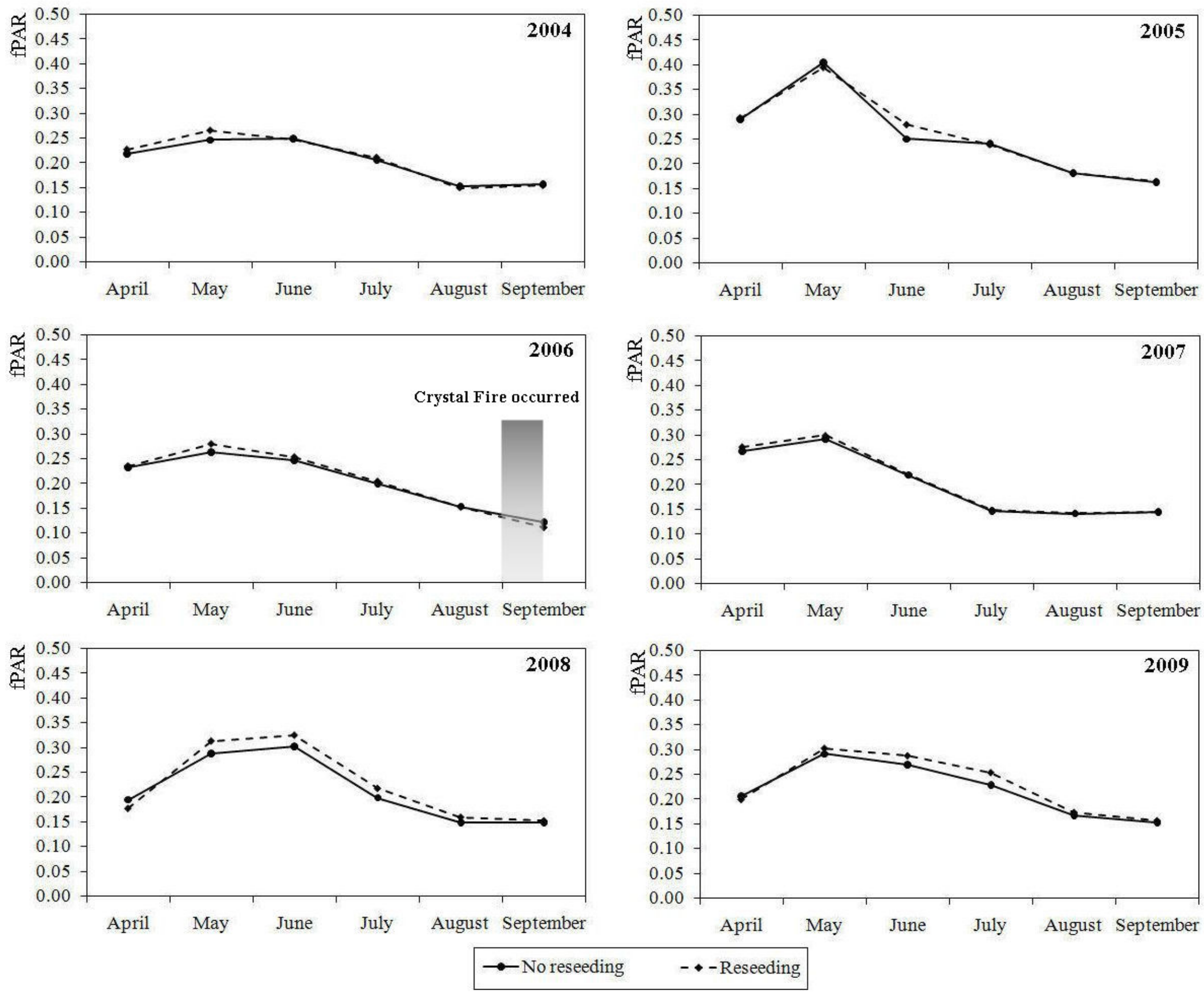

Figure 2. Monthly composite fPAR values in entire reseeding areas and no reseeding areas. Note: entire reseeding area includes homestead, mule butte native, sagebrush drill, sagebrush plug, and sagebrush aerial seeding treatments areas.

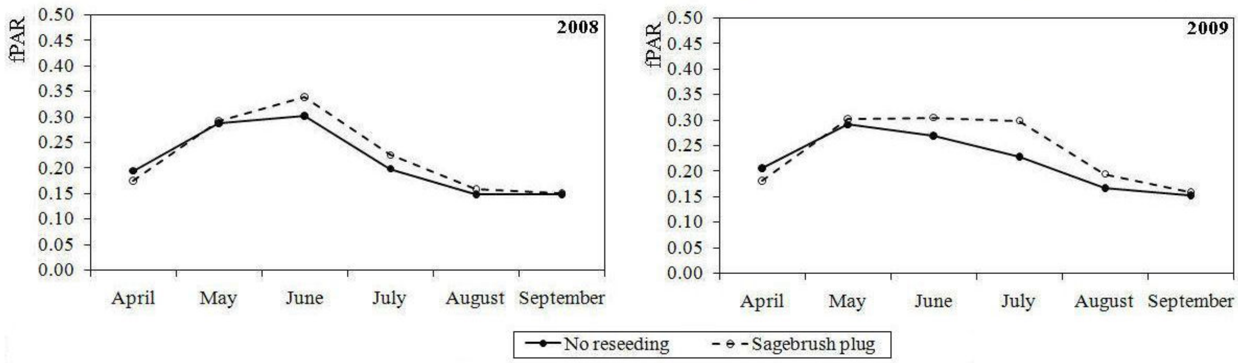

Figure 3. Monthly composite fPAR values in sagebrush plug reseeding areas and no reseeding areas.