

Remote sensing of WUI fuel treatment effectiveness following the 2007 wildfires in central Idaho

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Abstract

The 2007 East Zone and Cascade wildfires in central Idaho burned through fuel treatments in the wildland-urban interface (WUI) surrounding two local communities: Secesh Meadows and Warm Lake. The WUI fuel treatments funded by the National Fire Plan were designed to increase fire fighter safety, protect people and property, and mitigate severe fire effects on natural resources. It has been shown previously via two independent on-the-ground assessments that these WUI treatments were generally effective by these criteria. In this study, we demonstrate that fuel treatment effectiveness also can be assessed remotely, using data from Burned Area Reflectance Classification (BARC) maps that are customarily produced by the USFS Remote Sensing Applications Center (RSAC) in response to major wildfires. A simple GIS analysis was used to calculate and compare the proportion of hectares burned at high severity between treatment units and untreated lands in the two study landscapes. In both landscapes, a higher proportion of untreated lands burned at high severity than treated lands. Furthermore, this result was consistent whether using an immediate post-fire BARC map indicative of *fire severity* or a one-year post-fire BARC map indicative of *burn severity*. The method can be used to assess treatment effectiveness on other large wildfires.

Additional keywords: burn severity, fire severity, National Fire Plan, wildland-urban interface

Introduction

The 2007 wildfires burned more forest in Idaho than in any year since 1910. On the Payette and Boise National Forests (NF) in central Idaho, new annual records were set with an estimated 190,577 ha and 98,467 ha burned, respectively. Several large wildfires caused by multiple lightning strikes in July grew and converged to form the East Zone and Cascade complexes, that eventually merged and burned >240,000 ha by the end of September at a cost to suppress of >\$70M (Independent Large Wildfire Cost Panel 2008). The huge size and extreme fire behavior of these wildfires, rugged terrain, and paucity of available firefighting resources caused fire crews to use an Appropriate Management Response strategy (AMR) of wildland-urban interface (WUI) and point protection (McCarthy *et al.* 2008; Graham *et al.* 2009).

The cost to suppress wildfires nationally has doubled in the past decade and many expect this trend to continue due to increased residential development in the WUI, hazardous fuel build-

up, and probably climate change (National Wildfire Coordinating Group 2009). One strategy to try to mitigate these escalating costs is to remove or reduce hazardous fuels in advance of wildfire occurrence. Fuel treatments are implemented with the simple goal to reduce the surface, ladder, and canopy fuels available to burn in the event of a wildfire (USDA Forest Service 2005). Treatments are designed to moderate fire behavior to reduce fire intensity and fire severity (Graham *et al.* 1999, 2004).

Fuel treatments are widely believed to decrease wildfire risk to communities and increase ecosystem resiliency to wildfire effects (USDA USDOJ WGA 2002, 2006). Since 2000, the National Fire Plan (NFP) has annually provided millions of dollars to treat millions of acres, with the twin goals of reducing hazardous fuel loads and restoring healthy ecosystems. The NFP mandates that half of treated lands be strategically placed in the WUI.

Given that the NFP has invested so much into fuel treatments, a fair and obvious question to ask is: Have NFP-funded fuel treatments been effective? Treatment effectiveness can be assessed by three criteria: (1) evidence of a beneficial change in fire behavior (from a crown fire to a surface fire), (2) evidence of improved protection of people and property, and (3) evidence of diminished negative impacts on vegetation and soil resources. The emphasis of this study is on the third criterion.

The East Zone and Cascade wildfires burned through WUI treatment units designed to help protect homes in the local communities of Secesh Meadows and Warm Lake in Idaho. Graham *et al.* (2009) found that the WUI fuel treatments at Warm Lake were highly effective at slowing the momentum of the advancing crown fire, allowing firefighters to safely and effectively protect several dozen homes at Warm Lake. Hudak *et al.* (2011) reached a similar conclusion at Secesh Meadows and Warm Lake, using a simple statistical comparison of paired field sites to show that the fuel treatments did effectively mitigate adverse fire effects on vegetation and soils. Furthermore, Hudak *et al.* (2011) showed that a satellite-image derived indicator of fire-induced change between pre- and post-fire environments, the differenced Normalized Burn Ratio (dNBR), calculated by differencing NBR indices calculated from pre- and post-fire Landsat Thematic Mapper (TM) images respectively (Key and Benson 2005), significantly differed between treated and untreated sites at both Secesh Meadows and Warm Lake. Therefore, it appears feasible to assess fuel treatment effectiveness remotely (Wimberly *et al.* 2009), and not just on the ground.

The USFS Remote Sensing Applications Center (RSAC) produces Burned Area Reflectance Classification (BARC) maps from continuous dNBR values. The maps are delivered to incident management teams on important wildfires and are used as preliminary inferences of four burn severity classes (high, moderate, low, and unburned) as defined by Key and Benson (2005). These maps are used by Burned Area Emergency Rehabilitation (BAER) teams that rapidly respond to major wildfire events, where they plan and implement emergency rehabilitation treatments (e.g., hydromulch, straw mulch, aerial seeding) to mitigate post-fire erosion (Robichaud *et al.* 2009). Harbert *et al.* (2007) demonstrated that the number and proportion of hectares burned at high or moderate severity as indicated by four-class BARC maps provide a useful measure of fuel treatment effectiveness.

In this paper we report the utility of two post-fire BARC maps for assessing fuel treatment effectiveness. The first BARC map was produced operationally by RSAC immediately post-fire and indicates immediate fire effects that are considered measures of *fire severity* (Lentile *et al.* 2007). Examples of immediate fire effects include fuel consumption, ash deposition, and soil

charring. The second BARC map was produced for this research study one-year post-fire and indicates extended fire effects that are considered measures of *burn severity* (Lentile *et al.* 2007). Examples of extended fire effects include delayed tree mortality and vegetation regrowth. Hudak *et al.* (2011) reviewed previous quantitative studies of fuel treatment effectiveness, nearly all of which were based entirely on ground assessments. Our objective in this study is to determine if it is feasible--either immediately or one-year post-fire--to use BARC maps and GIS tools to remotely assess fuel treatment effectiveness more quickly, cheaply, and broadly than is practical using only expensive ground assessments.

Methods

Study landscapes

The community of Secesh Meadows (45.245°; -115.822°) is located ~50 km north-northeast of McCall in central Idaho. The community occupies the Secesh River valley with steep, forested terrain on both sides (Fig. 1). The subalpine forest type is dominated by lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*). Several homeowners implemented Firewise fuel treatments around their homes circa 2005. Thirteen pile and burn fuel treatments totaling 220 ha were funded by the NFP and implemented in 2006 on surrounding Payette NF lands. The fuel piles had been burned in only eight of the units when the Loon Fire (part of the East Zone Complex) burned through them in 2007 (Hudak *et al.* 2011).

The Warm Lake community (44.645°; -115.688°) is built around Warm Lake located ~45 km east-northeast of Cascade in central Idaho. The Warm Lake Basin is relatively flat but is surrounded by steep, heavily timbered slopes (Fig. 2). The mixed conifer forest type is dominated by lodgepole pine, Douglas-fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*). A popular resort destination, Warm Lake is surrounded by approximately 70 structures including two lodges, three public campgrounds, a youth camp, a church camp, and a USFS project camp. Most of the residents are part-time lessees of Forest Service administered land; therefore, treatments were implemented within 15 m of each residence (Graham *et al.* 2009). The ten treatments include 1215 ha in three units northeast of Warm Lake that were treated with prescribed burns in 1996, 1997 or 1998, and 412 ha in seven units funded by the NFP. The NFP-funded treatments include: one 2004 mastication unit; five 2000-2005 pile and burn units, two of which were further treated with prescribed surface fire; and one 2006 prescribed burn unit on Kline Mountain immediately west of Warm Lake.

Remote sensing and GIS data analysis

To produce BARC maps for Type I and BAER teams working at the East Zone and Cascade Complexes, RSAC followed normal operational procedures to geometrically and radiometrically correct Landsat imagery (http://landcover.usgs.gov/pdf/image_preprocessing.pdf) and then calculated NBR as the difference between Landsat TM bands 4 and 7 divided by their sum (Key and Benson 2005). The dNBR subsequently was calculated as pre-fire NBR minus post-fire NBR. Because the East Zone and Cascade complexes were such high priority fires, RSAC produced three BARC maps using dNBR values derived from an 11 October 2004 Landsat 5 Thematic Mapper pre-fire image and either Landsat 5 TM or Landsat 7 Enhanced Thematic Mapper Plus (ETM+) post-fire images that were acquired 25 August (ETM+), 2 September (TM) and 26 September 2007 (ETM+) in the case of the East Zone Complex and on 25 August (ETM+), 10 September (ETM+), and 26 September 2007 (ETM+) in the case of the Cascade

Complex. For this analysis, the 26 September ETM+ image was selected because the firelines did not fully progress through Secesh Meadows and Warm Lake until 17 September 2007.

The 31 May 2003 failure of the scan line corrector mechanism on board Landsat 7 causes data voids in the image parallel to the scan direction (perpendicular to the satellite path) that widen toward the edges of the scene. A majority filter is employed to fill the categorical data gaps in the classified BARC map and produce a more visually satisfying result but can produce local inaccuracies. To overcome this difficulty in preparing a one-year post-fire BARC map for this study, two successive ETM+ images that were collected on 10 July 2008 and 26 July 2008 were merged. The data gaps in the two scenes fortunately offset just enough to produce a composite one year post-fire image with continuous coverage across the entirety of both study landscapes. A 13 July 2006 TM image from Landsat 5 provided the pre-fire NBR values needed to calculate dNBR.

The Quickbird satellite was tasked to collect high resolution (0.6 m panchromatic and 2.4 m 4-band multispectral) imagery over the two study landscapes. The scene in a standard order has a spatial extent of 64 km², so we used the boundaries of the two Quickbird scenes to define the boundaries of the two study landscapes. A simple rectangle fully encompassed the treatment units surrounding the Secesh Meadows landscape (Fig. 1), but in the case of the Warm Lake landscape, some reshaping of a simple rectangle was required to encompass all of the fuel treatment units and adjacent areas of relevance (Fig. 2). The multispectral-panchromatic fused image product was ordered to provide 0.6-m resolution in color for maximum visual benefit. While Quickbird imagery is obviously superior to Landsat for visual interpretation, we did not use the Quickbird imagery analytically for three reasons: 1) Quickbird lacks the spectral equivalent of 30-m Landsat band 7 needed to calculate NBR, 2) pre-fire Quickbird imagery was not available for calculating an alternative indicator of fire-induced change (i.e., differenced Normalized Difference Vegetation Index, or dNDVI), and 3) Landsat images are freely available and are the customary choice by RSAC to produce BARC maps, making Landsat more relevant for evaluating BARC maps as a tool to assess fuel treatment effectiveness.

The simple GIS procedure applied for this analysis was to calculate the areal percentage of hectares that burned in each severity class within each treatment unit, and on untreated lands, within the two 64 km² study landscapes. These percentages were then compared with the assumption that, had the units not been treated, they would exhibit the same percent area burned in each severity class as observed on untreated lands. At Secesh Meadows, 277 ha of private lands containing some unknown number and extent of Firewise treatments were considered separately, while in the Warm Lake landscape a 201-ha area including the lake plus a 50-m riparian buffer zone was excluded from consideration. Also excluded from consideration were 130-ha and 69-ha buffer zones within 50 m of the Secesh and South Fork Salmon Rivers that cross the Secesh Meadows and Warm Lake landscapes, respectively (Figs. 1 and 2). This left 5,774 ha and 4,506 ha that were considered untreated in the Secesh Meadows and Warm Lake landscapes, respectively.

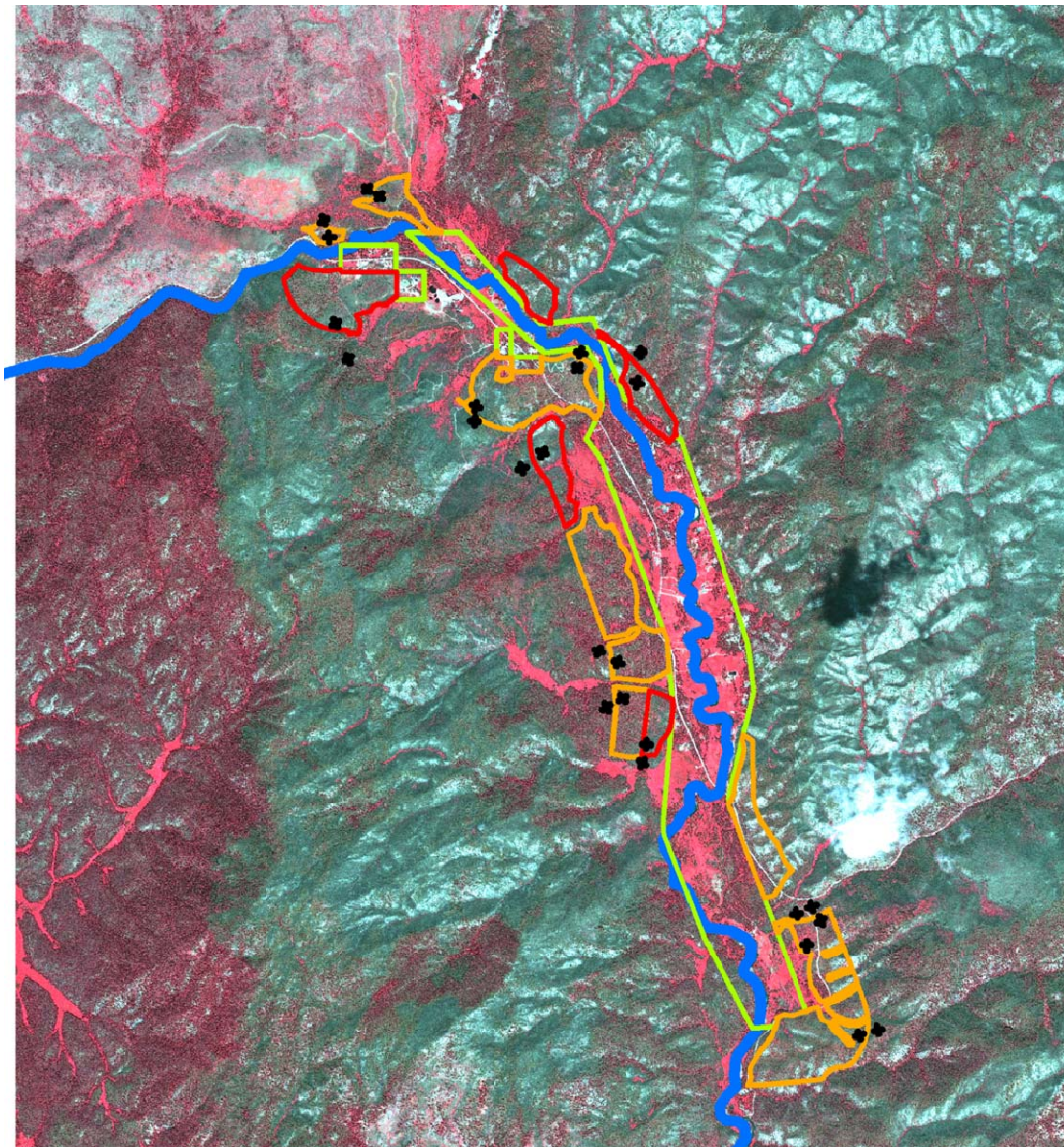


Fig. 1. Quickbird satellite image (collected 16 July 2009) of the 64 km² Secesh Meadows area burned by the 2007 Loon Fire in central Idaho. Pile and burn treatment units (2006) where the fuel piles were burned as prescribed prior to the wildfire are indicated in orange. Pile and burn treatment units (2006) where the fuel piles burned in the wildfire are indicated in red. Firewise treatments (2005) on private lands are located within the polygons indicated in green. The Secesh River is indicated by the blue line. The black dots indicate the location of paired field sites installed by Hudak *et al.* (2011) to assess treatment and fire effects. This is a color infrared composite display that highlights unburned forested areas in dark red, unburned grassy meadows in bright pink, and burned areas in bluish-green. The pale pink area in the upper left is from the 2000 Burgdorf Fire and served as an effective firebreak to the northward advance of the 2007 Loon Fire. A white cloud is visible in the lower right, and its black shadow to the north.

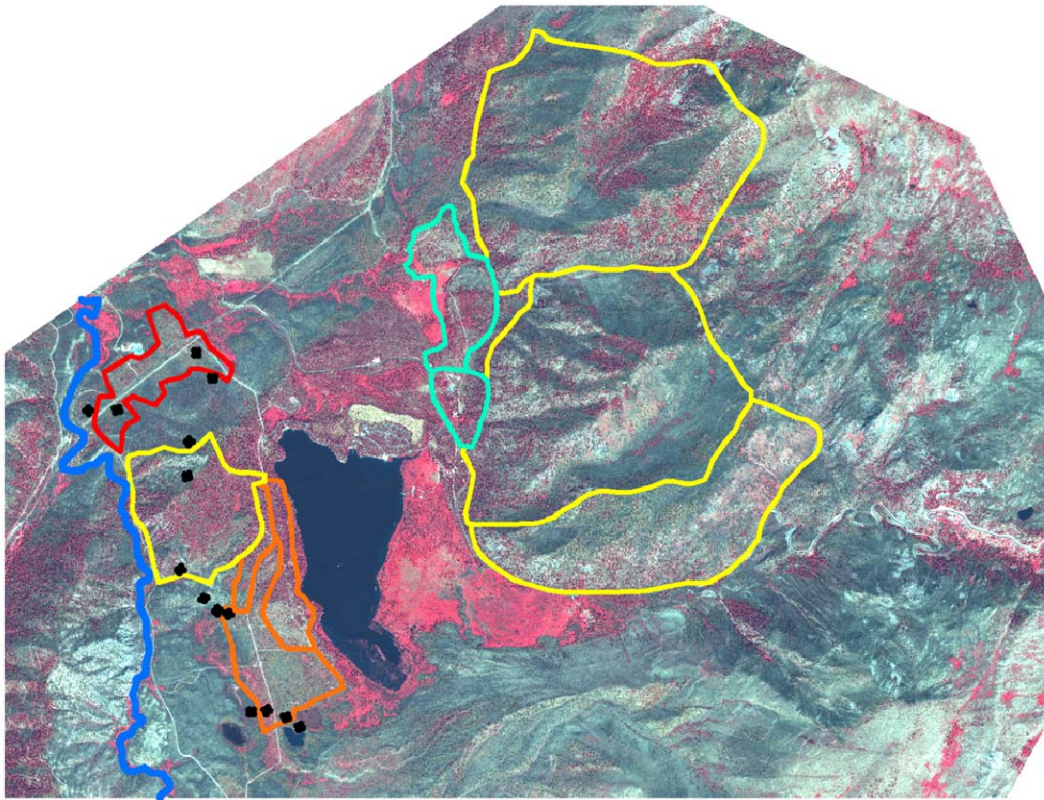


Fig. 2. Quickbird satellite image (collected 18 August 2008) of the 64 km² Warm Lake area burned by the 2007 Monument and North Fork Fires in central Idaho. A mastication treatment unit (2004) straddling the Warm Lake Highway is indicated in red. Pile and burn treatment units (2000-2005) are indicated in orange. Pile and burn treatment units that were subsequently burned by prescribed surface fire (2004-2005) are indicated in cyan. Underburn treatment units west (2006) and east (1996-1998) of Warm Lake are indicated in yellow. The South Fork Salmon River is indicated by the blue line. The black dots indicate the location of paired field sites installed by Hudak *et al.* (2011) to assess treatment and fire effects. This is a color infrared composite display where unburned forested areas are dark red, unburned grassy meadows are bright pink, and burned areas are bluish-green. The 2007 Monument Fire burned through the southern portion of the scene from SW to NE, while the 2007 North Fork simultaneously burned through the northern portion of the scene from W to E, so it was the treatment units west of Warm Lake that proved critical for slowing the momentum of these advancing crown fires.

Results and discussion

The areal extent of the Secesh Meadows and Warm Lake study landscapes was delimited at 6400 ha (64 km²) to include not just the treatment units but also adjacent untreated lands that burned at

the same time and under the same weather conditions, to provide context and allow quantitative comparison of BARC severity classes between treated and untreated lands. The proportion classified as high severity decreased in both landscapes after one year. This result was not surprising, as some areas can be mapped as high severity in immediate post-fire BARC maps due to the lack of any residual green vegetation immediately post-fire (Hudak *et al.* 2007), but subsequently vigorous vegetation regeneration suggest only minor effects on soils and available seed sources. The one-year post-fire dNBR is thus considered a more accurate indicator of ecological impact than the immediate post-fire dNBR (Key and Benson 2005).

At Secesh Meadows, Firewise treatments on private lands appeared most effective for reducing high severity fire, according to either BARC map. Both BARC maps also indicated that a lower areal percentage within pile and burn treatment units burned at high severity in the wildfire, provided the piles were burned as prescribed ('Rx Piles', see Fig. 3), compared to untreated lands. In the pile and burn treatment units where the piles burned in the wildfire ('WF Piles', see Fig. 3), the areal percentage burned at high severity was similar to that observed on untreated lands according to the immediate post-fire BARC map. However, the one-year post-fire BARC map showed a marked decrease in the high severity class within the WF Pile units, suggesting that fire effects were not as severe as indicated by the immediate post-fire BARC map. Vegetation recovery in these units was similar to the other, Rx Pile units, which corroborates what was observed by Hudak *et al.* (2011) at paired field sites (Figs. 1, 3). They found that field sites located in the five treatment units where the fuel piles burned in the wildfire exhibited more severe fire effects than their paired sites situated on adjacent untreated land; conversely, sites located in the eight treatment units where the fuel piles had been burned as prescribed exhibited less severe fire effects than their paired sites situated on adjacent untreated land.

At Warm Lake, pile and burn treatments were most effective at mitigating high severity fire, especially if followed by prescribed surface fire treatments. The mastication treatment was less effective, although it is important to consider that this treatment unit bore the brunt of the North Fork crown fire coming from the west. The prescribed underburn treatments were least effective at reducing high severity fire relative to untreated sites (Fig. 4). As reported by Graham *et al.* (2009), the weather and fuel moisture conditions during prescribe burn implementation were highly variable with some areas experiencing low fire intensities and less fuel consumption. In places where prescribed fires were applied, the wildfire effects were more heterogeneous (some crown fire and crown scorch did occur) compared to the more homogeneous wildfire effects in mechanical treatments which were not affected by weather conditions during implementation (Graham *et al.* 1999, 2004). However, there is evidence that the prescribed burn treatments did have a beneficial influence on subsequent wildfire behavior and effects (Graham *et al.* 2009). In addition, Hudak *et al.* (in press) found significantly less severe wildfire effects at treated sites than at their paired sites situated on adjacent untreated land (Figs. 2, 4).

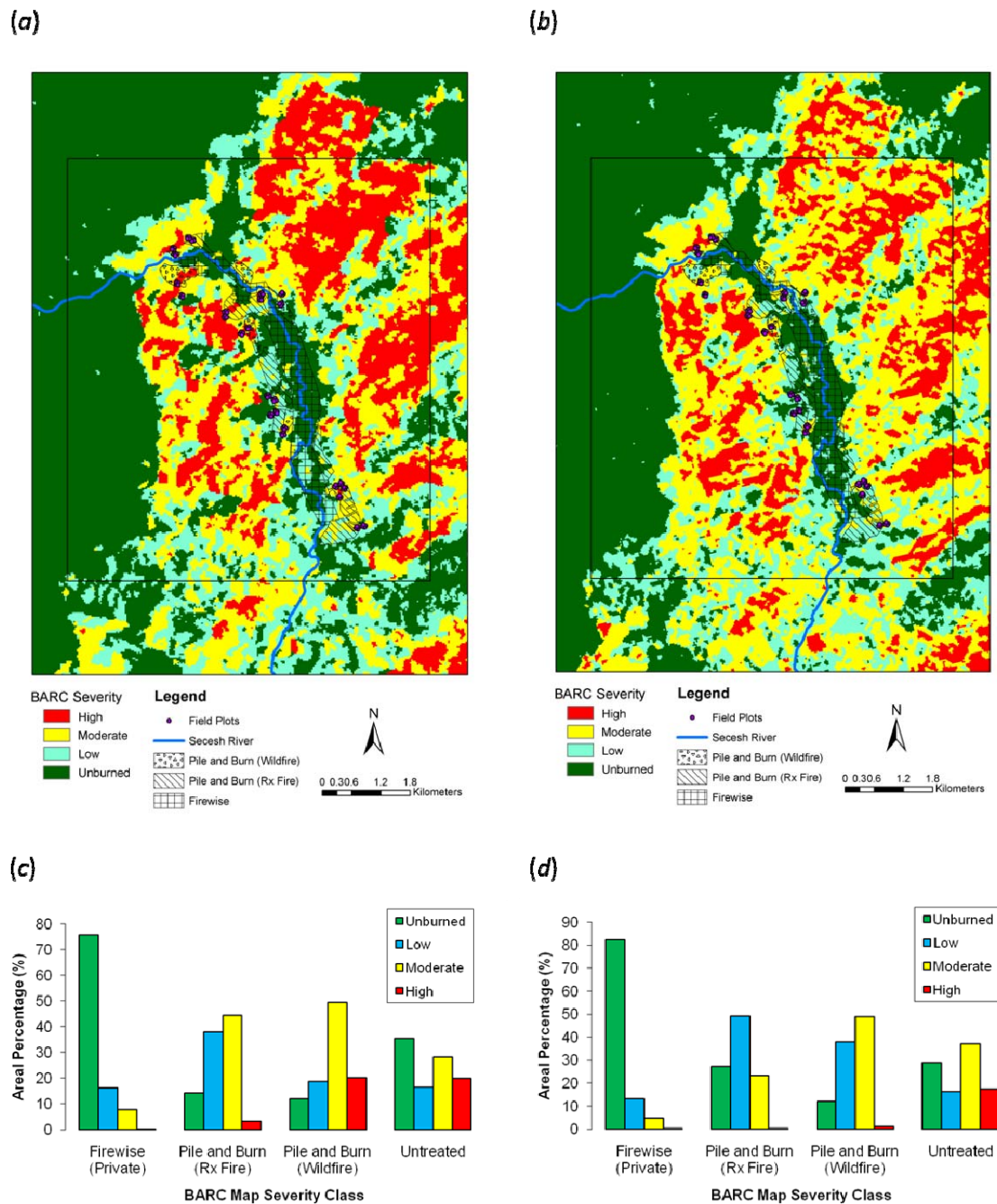


Fig. 3a-d. BARC maps produced from Landsat satellite imagery collected at Secesh Meadows (a) immediately post-fire and (b) one-year post-fire. The areal percentages of each burn severity class within the different types of treatments were calculated from these BARC maps and are shown in (c) and (d), respectively. The large black rectangle indicates the extent of the Quickbird satellite image displayed in Fig. 1.

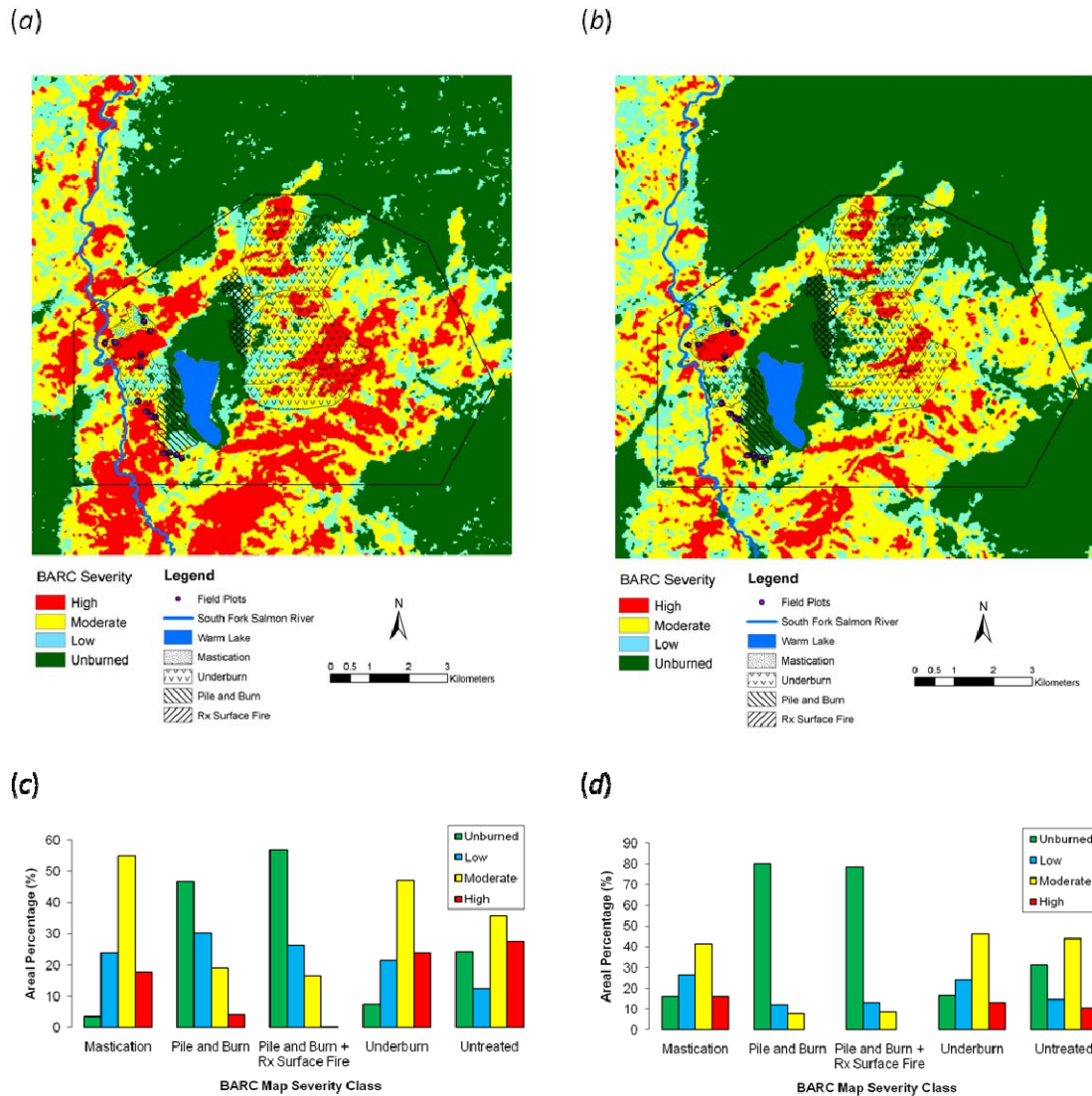


Fig. 4a-d. BARC maps produced from Landsat satellite imagery collected at Warm Lake (a) immediately post-fire and (b) one-year post-fire. The areal percentages of each burn severity class within the different types of treatments were calculated from these BARC maps and are shown in (c) and (d), respectively. The large black polygon indicates the extent of the Quickbird satellite image displayed in Fig. 2.

Concluding remarks

The BARC maps customarily produced by RSAC in response to major wildfires have utility for remote assessment of the effectiveness of fuel treatments for mitigating severe fire (Harbert *et al.* 2007), as do the dNBR values from which classified BARC maps are derived (Wimberly *et al.* 2009). The dNBR is sensitive to post-fire vegetation condition whether collected immediately post-fire or one-year post-fire (Key and Benson 2005; Hudak *et al.* 2007; Lentile *et al.* 2007). The results of this remote assessment of fuel treatment effectiveness corroborate on-the-ground

assessments by Graham *et al.* (2009) and Hudak *et al.* (2011) in these local communities. They also support the consensus widely held by managers that fuel treatments generally are effective for mitigating severe fire effects.

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