MONITORING POST-FIRE FOREST RECOVERY USING MULTI-TEMPORAL DIGITAL SURFACE MODELS GENERATED FROM DIFFERENT PLATFORMS

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ABSTRACT

Wildfires can greatly affect forest dynamics. Given the alteration of fire regimes foreseen globally due to climate and land use changes, greater attention should be devoted to prevention and restoration activities. Concerning in particular post-fire restoration actions, it is fundamental, together with a better understanding of ecological processes resulting from the disturbance, to define techniques and protocols for long-term monitoring of burned areas. This paper presents the results of a study conducted within an area affected by a stand-replacing crown fire (Verrayes, Aosta (AO), Italy) in 2005, which is part of a long-term monitoring research on post-fire restoration dynamics. We performed a change detection analysis through a time sequence (2008-2015) of DSMs (Digital Surface Models) obtained from LiDAR (ALS - Airborne Laser Scanner) and digital images (UAV - Unmanned Aerial Vehicle flight) to test the ability of the systems (platform + sensor) to identify the ongoing processes. New technologies providing high-resolution information and new devices (i.e. UAV) able to acquire geographic data "on demand" demonstrated great potential for monitoring post disturbance recovery dynamics of vegetation.

KEYWORDS

Forest fire, LiDAR, Monitoring, UAV, Post-fire management, DSM.

INTRODUCTION

Wildfires are one of the major natural disturbances affecting the dynamics of forest ecosystems. Since a modification in fire regimes is foreseen worldwide because of climate and land use changes (1), it is essential to investigate potential effects on post-fire regeneration dynamics and to define mitigation strategies. Climate change is in fact causing a significant increase in fire frequency, intensity and size of the burned areas, further influencing, directly and indirectly, post-disturbance vegetation recovery.

Properly calibrating management strategies and eventually defining mitigation actions require an in-depth knowledge of regeneration patterns and processes over space and time. Monitoring post-fire forest recovery with high-resolution data over large areas is thus becoming a key feature in disturbance ecology studies.

In this context, remote sensing provides useful tools and analyses, which have been often applied to assess for instance the impact of a fire, especially to characterise fire severity over large and heterogeneous burned areas (2,3). In the last decades, the availability of new sensors and platforms greatly improved our ability to derive sound information on terrestrial ecosystems.

DOI: 10.12760/01-2016-1-01

LiDAR (Light Detection And Ranging) technology has recently been widely used, since it allows data to be obtained on the structure and geometry of objects. The use of LiDAR in the forestry sector is becoming more and more widespread (4) and the first experimental applications begin to be developed also in the field of forest fires (5).

Among the new platforms, Unmanned Aerial Vehicles (UAVs) could prove particularly suitable for on-demand data acquisition over disturbed forest ecosystems with low costs (6,7).

Within a long-term research aiming at analysing the impact of different post-disturbance management practices on the recovery of *Pinus sylvestris* stands affected by high severity crown fires (8), we tested the possibility to monitor post-fire vegetation dynamics through a time sequence of DSMs (Digital Surface Models) obtained from LiDAR (ALS - Airborne Laser Scanner) and photogrammetric approach using digital images (UAV flight). In this paper, preliminary analyses within a subset of the monitoring site are reported.

METHODS

Study area

The study site is located in the Aosta Valley Region (NW Italy), within the municipality of Verrayes, in an area called Bourra (45°46'21" N, 7°33'16" E) that was severely affected by a stand replacing fire in March 2005. The wildfire, which was one of the biggest and most severe fire events ever experienced in the region, burned 257 ha, destroying 160 ha of an almost pure *Pinus sylvestris* L. stand with sporadic *Larix decidua* Miller, *Picea abies* (L.) Karst, *Quercus pubescens* Will., *Populus tremula* L., and *Betula pendula* Roth (8). This pine stand was a dense, even-aged secondary forest of about 60-70 years developed on a south-facing slope (1650-1800 m a.s.l.) after rangeland abandonment. The average slope is 25°. The bedrock is ophiolite and schist and the soils are entisols (Soil Taxonomy USDA). The mean annual temperature is 5.6 °C and the mean annual precipitation is approximately 750 mm with less than 250 mm in summer months (JJA). The driest month is February (less than 50 mm), where the main peak of the fire season in the Region is usually recorded.

A post-fire monitoring methodology was developed through the integration of two different approaches:

a) field data surveys on intensive monitoring plots (see (8) for details);
b) remote sensing data surveys on the entire burned area.

Following the disturbance event, the burned area was subjected to a salvage logging program (realized from 2007 to 2012), consisting in the removal of burned trees and the release of branches regularly piled on site. Within this area, three long-term monitoring plots were instead established in 2009 in non-salvaged areas A, B and C (Figure 1). Each plot was characterized by a different post-fire treatment:

A. Logging (cutting height = 1 m), branch removal and release on the ground of all deadwood (the stems were left on the ground according to a fishbone arrangement (45° with respect to the line of maximum slope) (1 ha);
B. Logging (cutting height close to the ground), felling with random directions (to simulate natural snag fall dynamics), no branch removal, all deadwood left on site (1 ha);
C. No intervention (control) (3 ha); snags were permanently identified using numbered plastic labels to monitor fall and decomposition dynamics.

Remote sensing acquisition

The study area was covered by two subsequent ALS data acquisitions:

- a low resolution (0.5 pts/m^2) survey (platform: fixed-wing aircraft), made by the Aosta Valley Region during 2008 (distributed as a 2 m Digital Surface Model - DSM$_{2008}$);

- a high resolution (10 pts/m^2) survey (platform: helicopter) with the full waveform information, made by the University of Padova – TESAF during 2011, coupled with a high resolution photogrammetric acquisition leading to a 10 cm orthophoto.

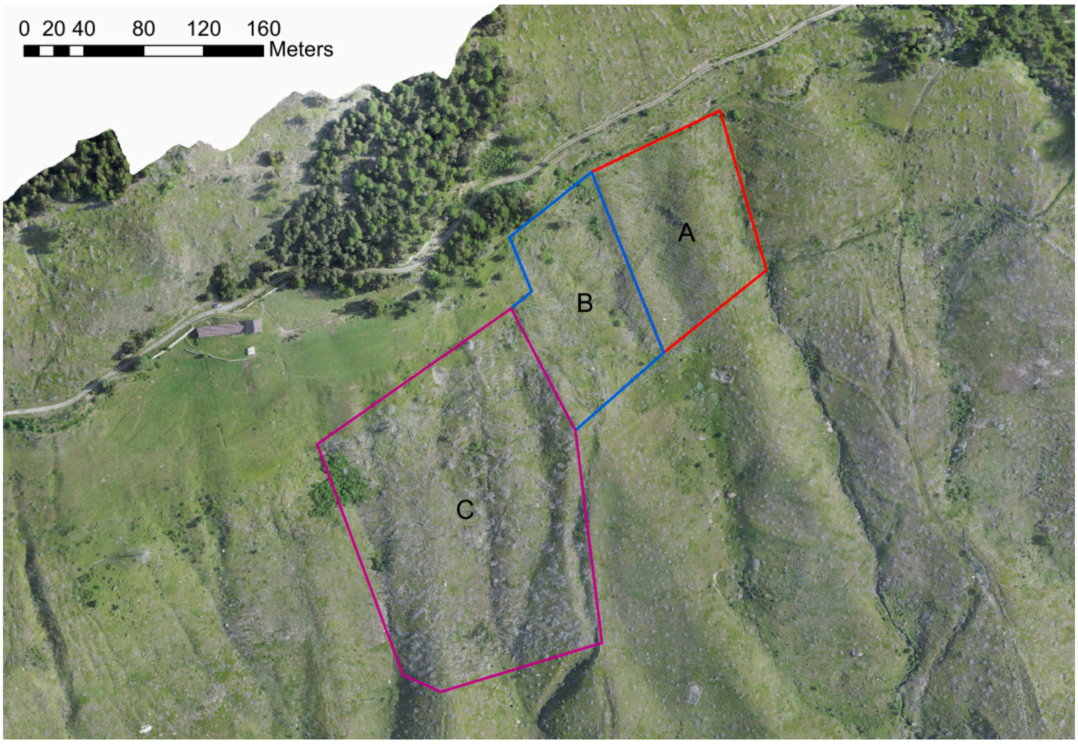

Figure 1: Detail of the burned area after salvage logging with the three long-term monitoring plots characterized by different post-fire treatments as described in the text (orthophoto 2015 from UAV acquisition).

In June 2015 the Politecnico di Torino - DIATI planned and realized a photogrammetric acquisition through UAV. Considering the size of the area to be covered and its complex topography, a fixed-wing UAV was chosen (9). In particular, a commercial eBee Sensefly was used, given its flight autonomy (up to 40 minutes) with completely automatic take-off and landing, which allows it to cover about 40-50 ha, under normal operative conditions (Table 1).

Table 1: Characteristics of the UAV system used in 2015 (eBee fixed wings UAV).

Technical Specifications		**Operative Specifications**	
Mass with camera	0.69 kg	Maximum flight time	50 minutes
Dimension	55 × 45 × 25 cm^3	Flight velocity	40 – 90 km/h
Wingspan	96 cm	Radio-link range	3 km
Propulsion	Electric, DC 160 W brushless motors	Maximum surface detectable	12 km^2 with 974 m of altitude
Battery	11.1 V, 2150 mAh	Ground sampling distance (GSD) at 100 m with the RGB camera	0.03 m

This UAV makes it possible to house different kinds of camera sensors; in this case the photogrammetric acquisitions were carried out through a RGB Canon IXUS 110 (12.1 megapixels resolution, 1.33 μm pixel distance).

The flight planning was made using the eMotion software, considering a constant ground resolution and a photogrammetric overlap between images of 80% in the lateral and longitudinal directions to cover an area of about 45 ha.

The eBee has its own navigation sensors that it uses to perform the flight through the waypoints generated in the planning. Using these sensors, during the flight it also registers a position of acquisition of each photo that can be used to geotag the images.

To better georeference the model generated from the images, 27 targets (GCP – Ground Control Points) were put on the ground and measured with a topographic approach.

The acquired images were processed with a SFM (Structure From Motion) approach using PhotoScan (10) and a 3D model of the area was created and georeferenced with the use of the measured GCPs obtaining 7 cm of planar accuracy.

The main products directly extracted from the photogrammetric modelling were the DSM (DSM_{2015}) and the orthophoto (Figures 2 and 3).

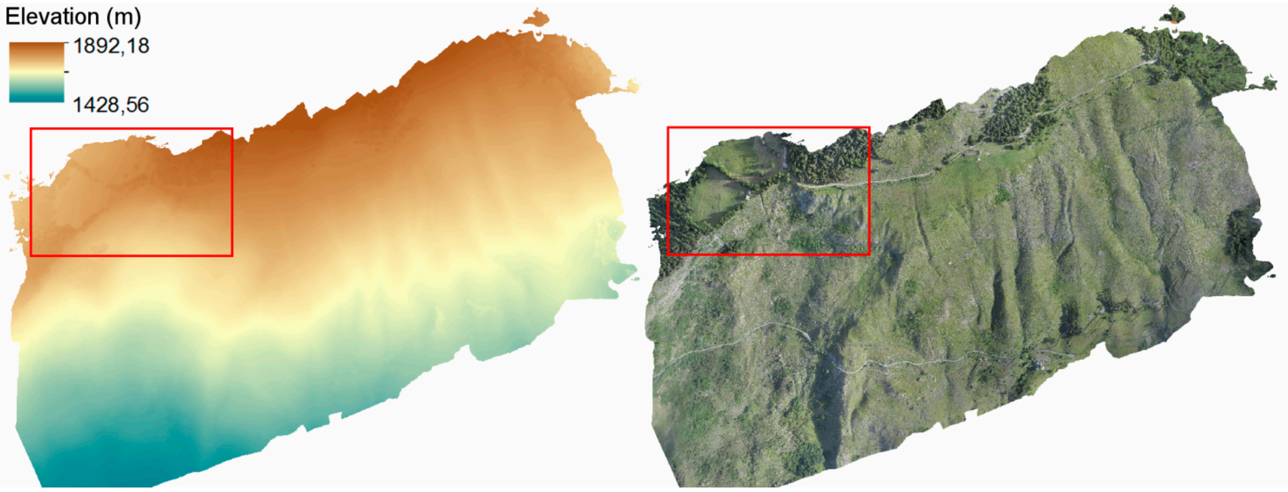

Figure 2: DSM_{2015} (left) and orthophoto (right) of the study area generated through the photogrammetric approach (UAV flight 2015). 3D zooms of the area included in the red rectangles are represented in Figure 3.

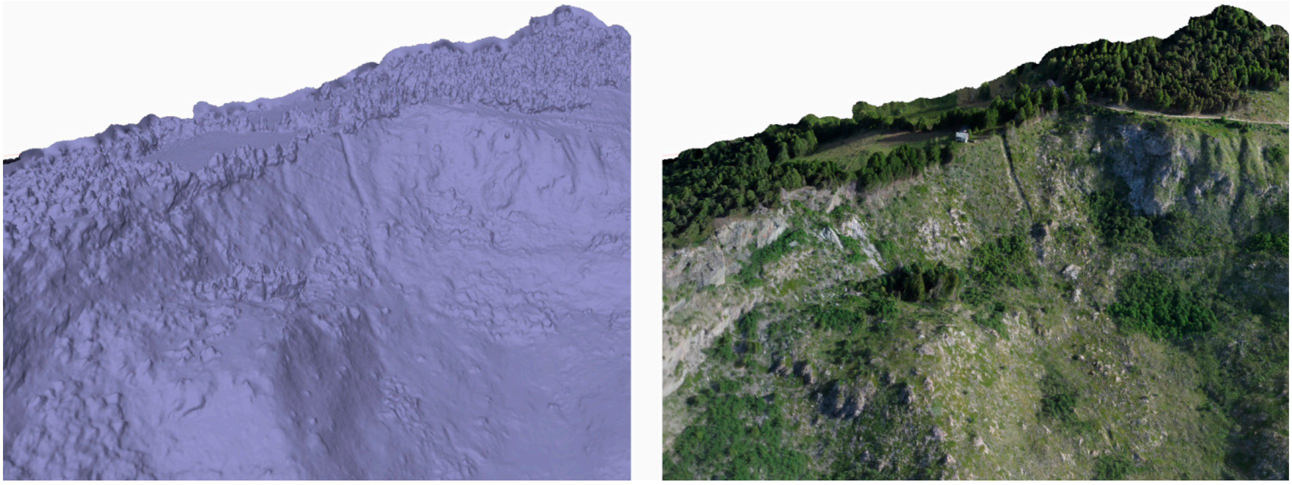

Figure 3: 3D view of a sector of the study area (included in the red rectangles in Figure 2): on the left the 3D model, on the right the textured one.

Data analysis

We performed a change detection analysis subtracting from DSM_{2015} the DSM_{2008} with the *Raster Calculator* available in the *Spatial Analyst Tool* of ArcMap. Positive and negative deltas in height are expected as a result of post-disturbance processes, such as vegetation recovery and snag fall, respectively.

Within the disturbed area, three main processes were observed in the field:

1. agamic regeneration of European aspen (*Populus tremula*);
2. deadwood dynamics (lying and standing dead trees);
3. logging activities (with or without log extraction).

A profile (135 m long) representative of each process type was extracted from DSM_{2015} and DSM_{2008} (Figure 4).

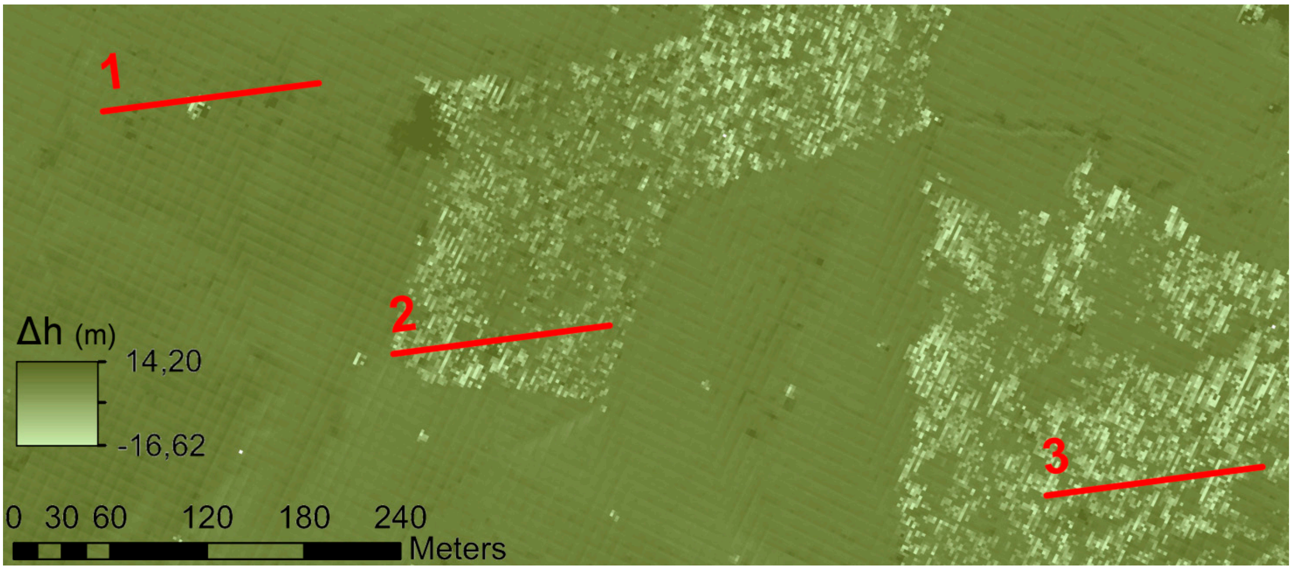

Figure 4: Location of the three test profiles superimposed on the raster obtained from the change detection analysis between DSM_{2008} and DSM_{2015}. See text for details on the profiles.

Profile 1 highlights aspen regeneration process, profile 2 was located in a snag-fall area, and profile 3 in a site harvested between 2011 and 2015 (as detected from the comparison between 2011 and 2015 orthophotos).

RESULTS AND DISCUSSION

The use of multi-temporal DSMs derived from different platforms allowed to highlight the main dynamics occurring in the burned area: the process of forest regeneration dominated by the agamic expansion of aspen patches and deadwood demography (mostly snag fall).

The georeferencing error was quantified as about 10 cm between the two DSMs; differences lower than this value were not taken into account.

The increase in height (dark green colour in Figure 4) is mostly caused by post-disturbance regeneration of vegetation, particularly by the vegetative re-sprouting of *Populus tremula* that tends to constitute dense patches of root suckers (11). The observed decrease in height (bright green colour in Figure 4) identifies mainly areas affected by the harvesting or fall of snags, as confirmed through both photointerpretation and direct field observations.

From the profile analysis (Figure 5) it was possible to evidence a good fit between DSM2008 and DSM2015 in those regions where overground elements were absent (e.g., in the absence of live vegetation or deadwood).

New peaks in DSM_{2015} (Figure 5, red line) were related to newly established or expanding vegetation patches (Figure 5a, referring to Profile 1). Negative values (expressed by peak absence or reduction in DSM_{2015} compared to DSM_{2008}) were mostly due to snag fall (Figure 5b, referring to Profile 2) and logging activities (Figure 5c, referring to Profile 3).

Figure 5: DSMs sections of the three test profiles: a) Profile 1 with P. tremula regeneration patches; b) Profile 2 with snag fall processes; c) Profile 3 in a recently harvested site.

CONCLUSIONS

Multi-temporal high resolution DSMs can provide useful information to assess post-disturbance dynamics. Considering the phenomena under investigation, data obtained from different platforms and sensors proved to be efficient in building a post-fire time sequence. Both systems allowed the efficient detection of snag fall dynamics and regeneration of trees, providing the possibility to ease and speed up the characterization of small-scale post-fire processes over large areas and with high accuracy.

These preliminary results highlight the usefulness of low cost, highly flexible UAV systems within areas affected by natural or anthropogenic disturbances, given the possibility to fly on-demand (e.g. immediately after the event) and quickly repeat measures when requested for environmental monitoring.

Further applications and analyses over the whole burned area are currently being conducted as a following step of the research. The described profile analysis is being applied on a larger dataset, while Near Infrared (NIR) images obtained from the UAV flight are being tested to improve tree and shrub species detection.

ACKNOWLEDGEMENTS

The work was performed in collaboration and in line with the AF3 (Advanced Forest Fire Fighting) programme of the Politecnico di Torino aiming at increasing the efficiency of fire-fighting operations, saving human lives and reducing damages to the environment. This research was in part financially supported by the University of Padova (PRAT 2009 – CPDA097420), and by the European Commission (Alpine Space 2-3-2-FR NEWFOR). The authors would like to thank Paolo Maschio and Filiberto Chiabrando of the Politecnico di Torino, and Paola Bolzon of the University of Padova for their useful collaboration during survey operations.

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