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DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

High Resolution Wildfire Fuel Mapping for Community Directed Forest Management Planning

Patrick Robinson*; Che Elkin; Scott Green

University of Northern British Columbia. Prince George, BC, Canada,
{robinsonp, che.elkin, scott.green}@unbc.ca

**Corresponding author*

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Abstract

Climate change and institutional forest management practices have lead to more frequent and severe wildfire events around the world, a trend that is projected to increase in coming years. Wildfire plays an important role in maintaining ecological systems, but wildfires also pose threats to health, safety, infrastructure, and ecosystem services. Reactionary response to these threats has predominantly informed management decisions in recent decades and greater focus on mitigation and adaptation is needed. Through a community-directed consultation process, the goal of this work has been to provide direct, operational information to aid in local management decision making for a First Nations community in British Columbia, Canada. Using a combination of field sampling and high-resolution Airborne Laser Scanning (ALS) data, we assessed vertical and horizontal fuel loading at fine resolution. Our analysis found a high degree of fuel loading heterogeneity in areas characterized as homogeneous using coarser fuel layers and provided a means of identifying high fire risk areas that may be targeted for ecosystem rehabilitation aimed at reducing current and future fire risk. We discuss how this spatially explicit data can be used to evaluate feedback between forest dynamics and fuel loading, information critical for managing forests for multiple objectives into the future. Following our analysis, we compiled our results into an interactive decision support web mapping platform designed with the goal of providing a user friendly, accessible land management planning tool for the community.

1. Introduction

Wildfire is an integral part of natural forest dynamics across a range of different forest types globally (Moritz et al., 2014). In many areas, fire serves an important role in maintaining forest ecosystem functioning by rejuvenating plant health, creating animal habitat and forage, and mitigating the risk of large scale destructive stand-replacing wildfire events (Driscoll et al., 2010). In addition, wildfires also account for significant contributions to the global carbon budget (Driscoll et al., 2010; Ager et al., 2010). Although wildfire plays an important role in maintaining ecological systems, management objectives relating to wildfire are most often directed at mitigating the near term and immediate threats it poses to society (Duff et al., 2017). The negative impacts of wildfires on human health and safety, values and infrastructure, and ecosystem services cannot be ignored. However there is room for more attention to be paid towards managing wildfires to promote the positive impacts they can have in forest ecosystem dynamics. Understanding how wildfire will interact with a given landscape and forest ecosystem requires information about the three most influential factors for fire behavior: weather, topography, and fuels. Of these three elements, the only one manageable on an attainable scale is fuels. Having the ability to meausre fuel load and structure at scale across forest ecosystems is critical to understanding how to better manage wildfires overall. In addition, the ability to include and prioritize local community knowlegde and input in forest management planning can greatly enhance the positive impact of managment actions.

2. Project Overview

This project is part of a multi-year collaboration between a First Nations community in southwestern British Columbia and University of Northern British Columbia researchers Patrick Robinson, Dr. Scott Green, and Dr. Che Elkin, with support from the Pacific Institute of Climate Solutions. This project is a community-directed initiative, with the aim of assessing how high resolution aerial laser scanning (ALS) data can best be used to evaluate and quantify forest fuels, and directly aid in fire risk mitigation, forest ecosystem restoration, and climate adaptation planning efforts at local and regional scales. The project is guided by the shared goal of promoting the re-establishment of traditional management principles and practices, which pre-date modern intitutional mangement and have been around since time immemorial. In collaboration with the community, the goal is to provide information relating to wildfire fuel load distributions with local context that is directly applicable and immediately useful to the community's unique forest management planning and ecosystem restoration objectives. Additionally, the results of the analysis are intended to contribute to and support general wildfire fuel mapping efforts around the province and amongst the broader scientific community.

Previous work and existing data have established that the community is facing significant risk of catastrophic stand replacing wildfire. To address this risk effectively, the spatial distribution and connectivity of hazard fuels types is required in greater detail than previously existed. High resolution data provided by ALS has the potential to describe fuel structure and distribution with the detail required to enable tangible and prioritized management throughout the study area. This work probes beyond fuel mapping alone, taking into consideration community objectives and First Nations Traditional Ecological Knowledge in the process of determining how wildfire and fuels distribution, both past and present, play a role in the restoration and responsible future management of forests for multiple values. In addition, there is interest in the identification of areas potentially suitable for the integration of prescribed burning practices in support of landscape-level wildfire resilience and risk mitigation, as well as the cultural revitalization of traditional burning practices.

3. Study Area

The study area is located in southwestern British Columbia, Canada, east of Lillooet in the Pavilion Ranges Ecosection (Figure 1). In the past, the area has experienced a relatively frequent fire return interval (6.6 to 11.6 years over the last 500 years), of regular low-intensity surface fire within fire resilient, open forest areas of Douglas Fir and Ponderosa Pine stands, and less frequent fire occurrence in higher elevation stands comprised of Montane Spruce and Lodgepole Pine (Gray et al., 2002). Over the past 100 years, largely as a result of aggressive fire suppression, the forests throughout the area have become less fire resilient with increased hazardous fuel load build-up, resulting in an altered fire regime of less frequent and more severe fires. In response to the increased fire risk, several areas throughout the territory have undergone fuel treatments, fire-smarting, and ecosystem restoration initiatives, including thinning and pruning, with a particular focus placed around community areas and recreation sites (Diver, 2016).

Figure 1- Map of Southwestern British Columbia, indicating the general location of the study area in red.

4. ALS Data

Airbourne laser scanning (ALS) data was collected for the entire study area at approximately 15 points per square meter. ALS can be used to model forest biophysical structure and inventory variables at a fine grain (plot level) over a large landscape extent (Hayashiet al., 2016; Hummel et al., 2011; Treitz et al., 2012; White et al., 2016). Forest structural characteristics are critical for develping forest fuel load maps, which classify fuel attributes relevant for the evaluation of fuel treatments, risk mitigation and other related planning activities (Chen et al., 2016; Hayashi et al., 2016; Peterson et al., 2015; Pimont et al., 2016). ALS data has the capacity to significantly enhance the current spatial understanding of forest fuels by providing detailed three-dimensional forest structural characteristics (fuel metrics) for entire landscapes (Ahmed et al., 2015; Coops et al., 2016; Filotas et al., 2014; Gao et al., 2014). Improving the spatial resolution of the fuel mapping enables more confidence in fire and forest management planning and promotes more informed decision-making for ecosystem restoration and general management objectives.

Forest fuels can be considered as a physical complex composed of surface fuels, understory fuels, ladder fuels and canopy fuels. Some of the key metrics used to describe these structural attributes include total tree/canopy biomass, canopy bulk density, canopy base height, canopy fuel loading, stems per hectare, ladder fuel load, understory fuel load, and basic surface classification (fuel/non-fuel) (Jakubowksi et al., 2013; Zhao et al., 2011; Reinhardt, 2006). We acknowledge the importance of understanding ground fuels as a fundamental component of fire risk mapping, however this study focuses on above-ground forest fuel structure. Considering that these above ground metrics all relate to structural components of the forest, ALS data is well suited to provide this type of data.

5. Empirical Data

Empirical forest and fuel data were collected in the form of field plots throughout the study area and used to calculate various forest fuel load metrics. To develop the models responsible for deriving the fuel metrics from the ALS point cloud, empirical field data is required to train and calibrate the models (Andersen et al., 2005; Zellweger et al., 2014). The empirical field data in this application was collected in the form of forest plots designed to capture relevant structural characteristics of the various forest types in the study area, pertinent to fuel load calculation (Andersen et al., 2005; Price & Gordon, 2016). The forest sample plot characteristics have been informed by reference to the literature and reliance on the best practices described by White et al., (2013). A random stratified sampling framework was used to ensure a representative sample set across the complete range of forest type diversity.

6. Modelling and Analysis

We used a machine learning framework to develop predictive models for several important forest fuel characteristics in common forest types of interior southwestern BC with the goal to determine how forest structure differs across the landscape and how those differences are reflected in ALS derived fuel metrics. The following objectives guided this work:

- Being able to accurately evaluate the distribution of metrics for describing fuel load throughout the study area (i.e., Canopy Bulk Density, Canopy Base Height, Ladder Fuel Density, Understory Fuel Density) across multiple forest strata in a way that enables the community to easily target focal areas for restoration and treatment;
- Assess the variation in fuel loading components within the standard Canadian Forest Fire Danger Rating System Fire Behaviour Prediction system fuel types categories, and to test if emergent clusters of fuel loading classes can be used to better classify fire risk across the landscape; and
- Analyze how historic management practices and recent forest ecosystem restoration activities have altered fuel loading.

Random Forest (RF) was used to model the fuel metrics by identifying statistical relationships between the ALS data and the empirical data.

7. Results

The landscape level fuel load distribution map products produced from the process described above have proven effective in their ability to accuratley describe fuel struture throughout the study area, and have produced relatively high R^2 values (Table 1). As expected with ALS derived data, the model confidence is lower in the fuel metrics that describe fuel attributes for lower elements of the vertical forest/vegetation profile (i.e., Ladder Fuel Density and Understory Density). This is largely due to the effect of the upper canopy components shading out the lower components during the ALS data collection, however preliminary field validation excercises have helped to validate the accuracy of these lower level metrics as seen in the ladder fuel density image displayed in Figure 2.

Fuel Metric/Response Variable	R^2 Value
Tree Height	0.90
Canopy Bulk Density	0.86
Canopy Fuel Load	0.84
Canopy Base Height	0.89
Ladder Fuel Density	0.33
Understory Density	0.38
Total Biomass	0.95

Table 1- R^2 values for the model results, produced for the k-fold cross validation.

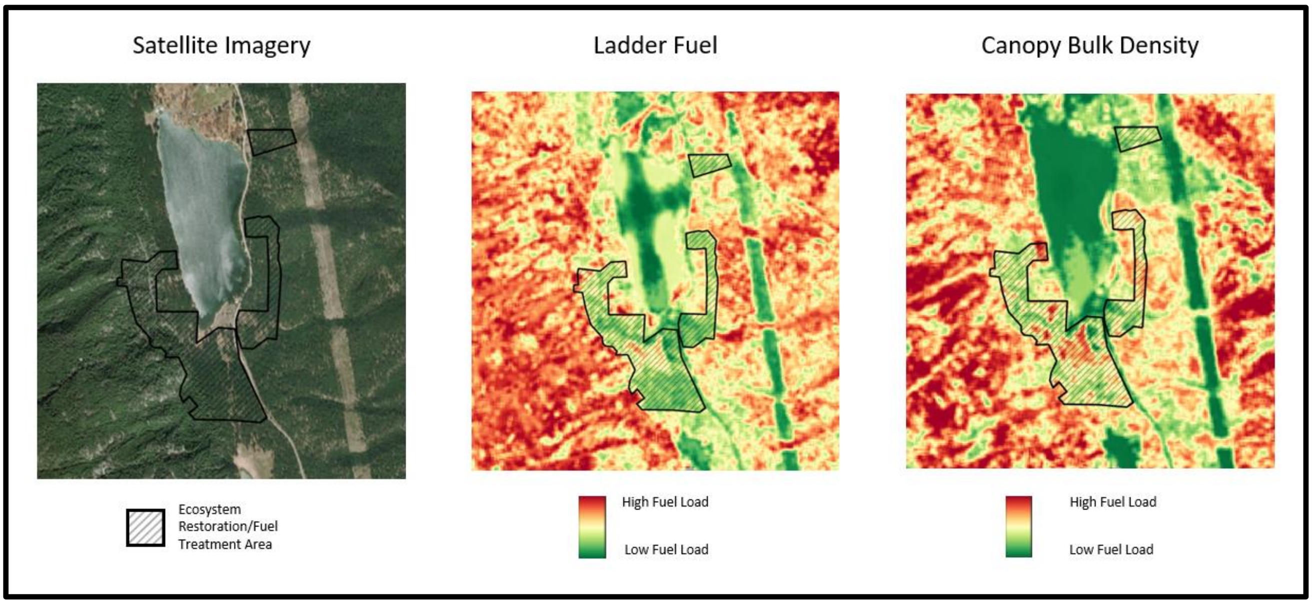

Figure 2- Comparison of modelled fuel metric products for a known fuel treatment site in the study area. All three maps display the same area with the black hashed boundary indicating an area that has been thinned and pruned for fire risk reduction. The map on the left indicates the inability to differentiate the treated area from the untreated areas in the satellite imagery, whereas the Ladder Fuel and Canopy Bulk Density maps indicate the subsequent ability to distinguish the areas of increased and decreased fuel load (i.e., treated vs. untreated) with the ALS derived products.

8. Web Mapping Platform

One of the main priorities of this work has been to promote community capacity building by providing information accessibility, research methods transparency, and direct collaboration. With that in mind, a suite of web mapping tools have been developed to provide a comprehensive GIS decision support platform to the community. The platform provides user-friendly access to important spatial data visualizations, enables community-directed management planning, and facilitates co-development of management solutions.It encourages discourse regarding management objectives by providing a means for translating technical data directly to the solution seeker in a way that is accessible and useful. The web map tool is essentially a multi-part story map, made in Arc GIS online that functions as both as a data sharing outlet/communication network and a decision support platform for fire risk mitigation and general forest management planning.

9. Conclusion

Ongoing work continues with the community to utilize the results of the ALS fuel modelling and integrate them into current and future management planning. In addition, further development and design refinement of the web mapping platform continues in collaboration with the community to continually improve the ability to leverage the results of this study towards tangible managment objectives, as well as build the internal capacity of the community.

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