Understanding Geospatial Data Products for Assessing Landscape Fire Severity and Effects: MTBS products and future directions
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Overview
The Monitoring Trends in Burn Severity Project (MTBS; www.mtbs.gov) was initiated as a partnership between the United States Geological Survey (USGS) and United States Forest Service (USFS) to develop a comprehensive fire atlas for the United States that includes fire perimeter polygons and fire severity raster data for all fires greater than a specific size threshold (1,000 ac in the western US, and 500 ac in the eastern US). With the development of this database, there is increasing interest in utilizing it for both scientific research and applied management. As with any derived data, however, there are limitations to its utility based on how it was constructed and how it should be applied; it is critical that both scientists and managers understand these limitations to maximize the utility of the dataset without compromising the outcomes. The purpose of this brief is to 1) review the products available and explain the development process used to create them, 2) highlight limitations and best practices for using these products, and 3) suggest the next steps to be taken in the evolution of these products.

Summary Points:
- MTBS produces fire perimeter polygons and both classified and continuous (index-based) burn severity raster data
- Polygon perimeters include unburned islands, overestimating area burned
- Classified burn severity maps use subjectively-interpreted classification thresholds unique to each fire; these thresholds have no ecological relevance
- Classified burn severity maps should not be used for quantitative spatial or trend analysis; they lack the necessary accuracy and consistency
- A more objective approach to classification is proposed that utilizes field validation data to develop consistent thresholds for each ecoregion

A Brief History of MTBS
MTBS evolved from the joint National Park Service (NPS) and USGS Burn Severity Mapping project, begun in the late 1990s to map wildfire effects across the National Park system and establish methodology for monitoring fire effects utilizing spaceborne data. Two primary products of this initial effort were 1) the Composite Burn Index (CBI), which is a field methodology for quantifying total fire effects within a 30-meter square plot (to match the spatial resolution of Landsat satellite sensor data), and 2) the Normalized Burn Ratio (NBR) which is a spectral index that differentiates healthy, green vegetation from dry, dead vegetation and charcoal in a post-fire Landsat scene. Subsequent research found that subtracting a post-fire NBR scene from a pre-fire NBR scene to produce the differenced NBR (dNBR) was more strongly correlated to CBI-based field observations of burn severity than the single, post-fire NBR scene for most ecosystems. Additional research found that a relativized version of dNBR (RdNBR) that measures post-fire live vegetation cover relative to pre-fire cover better accounted for heterogeneity in pre-fire fuels and was more accurate for delineating higher severity fire effects in ecosystems with lower fuel loads.

MTBS mapped wildfires in the United States back to 1984 to correspond to the launch of Landsat 5. Additionally, many prescribed and agricultural fires (but not all) were mapped because the burn scars were visible on the Landsat scenes. Currently, there is an approximately 1.5 to 2-year lag for new fires to be included.

What are the data products and how are they created?
There are two primary spatial data products created by MTBS: 1) fire perimeter polygons (distributed as an ESRI shape file and including a fire centroid point), and 2) burn severity raster datasets (including the continuous NBR, dNBR and RdNBR indices, and a classified map of five burn severity classes within each fire perimeter). Fire perimeters are initially acquired from the fire GIS team, local resources, and historical databases that were digitized. They are reviewed for quality control and an analyst corrects errors by digitally editing fire perimeters using post-fire Landsat scenes. These perimeters often include unburned fingers and unburned islands within the fire perimeter.

The NBR, dNBR and RdNBR continuous data rasters are created through an automated process. NBR is very similar to the Normalized Difference Vegetation Index (NDVI) that is used to monitor vegetation greenness in that both are ratio equations, but NBR uses different wavelengths of light acquired by different Landsat bands. Just like with NDVI, the NBR, dNBR, and RdNBR are unitless indices. The values for an NBR raster are constrained between -1000 and 1000 (the ratio value of -1 to 1, multiplied by 1000). The dNBR and RdNBR have a greater range, but the observed values are generally -500 to 1500. These values are meaningless ecologically unless tied to observed field metrics of severity through post-fire field data collection.

The above are all relatively objective, semi-automated data products. This is <u>not</u> the case for the classified burn severity data maps. The classified burn severity maps are the most subjective product created by MTBS. A geospatial analyst produces them by visually assessing the Landsat images (often including both the dNBR and false color composite images) and a histogram of the dNBR values. The analyst draws from any knowledge they have of the fire and the ecosystem, and looks for natural breaks or steps in the continuous data that might be displayed in the histogram (Figure 1). The analyst then subjectively assigns threshold values to delineate each of the five primary classes: increased greenness, unchanged, low, moderate and high burn severity.

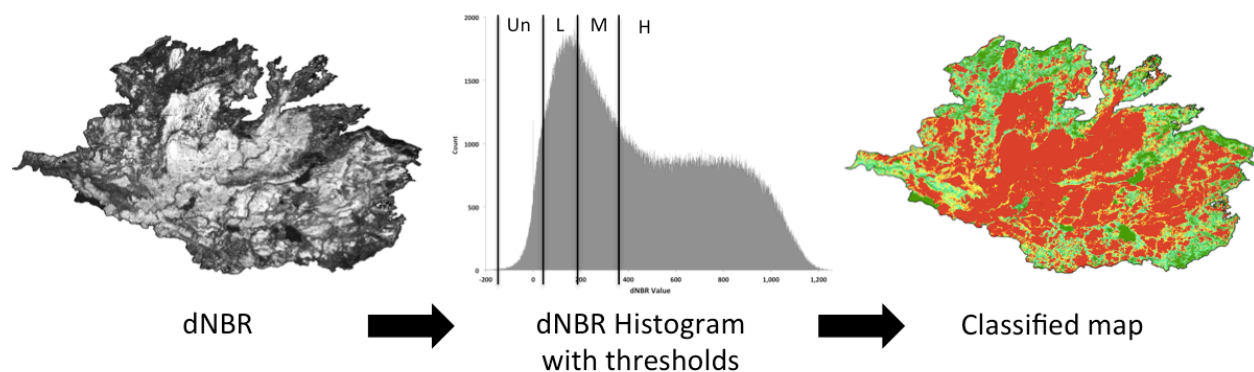dNBR → dNBR Histogram with thresholds → Classified map

Figure 1. Example showing the raw dNBR raster, the thresholds for a fire applied to a histogram of the dNBR, and the resulting burn severity classification map.

The analyst also creates an "offset value" for both dNBR and RdNBR. This value is derived from a relatively homogenous area of unburned vegetation outside of the fire perimeter. It is the "offset" due to phenological differences between pre- and post-fire scenes, and is meant to be used to normalize dNBR and RdNBR for phenological differences. However, it is not actually applied to the dNBR and RdNBR products; it is expected that users will apply the offset when they download the data, as applying this offset will improve classification accuracy.

How accurate are these data products?
The fire perimeter data is relatively accurate; the primary error is an overestimation of area burned associated with unburned fingers and islands included in the fire perimeter. The representativeness of dNBR and RdNBR has been explored in numerous research articles, and varies considerably by ecosystem. Users should seek out either research articles or one of the many comprehensive reviews on the relationship between dNBR/RdNBR and different field observations of burn severity or local knowledge. Generally, however, dNBR and RdNBR are a relatively good proxy to predict immediate and 1-year post-fire changes in above-ground biomass (e.g., crown consumption) and litter consumption due to fire for most forested and rangeland ecosystems in the western US, as well as much of the coniferous forests in the eastern US.

The classified burn severity data product lacks the fine-scale accuracy that is required to compare fires quantitatively over space and time, and should not be utilized for trend analysis. Overall, it is a good visual representation of burn severity across a fire, and can be useful for getting a sense of general distributions of burn severity and planning for post-fire activity. The thresholds between classes are selected subjectively on a fire-by-fire basis, however, so there is considerable variability in the thresholds selected across fires even within the same location and forest type (Figure 2) and these thresholds have no ecological meaning to potential users. For example, a user interested in wildlife habitat might wish to know where there is a certain amount of tree mortality or loss of canopy cover associated with a fire. Ecologically-based thresholds would define this on a per-ecoregion basis (e.g., a dNBR threshold of 500 might be associated with a specific conifer type experiencing 80 percent tree mortality or greater based on field data from numerous fires). **The current thresholds assigned to each MTBS fire, however, do not have that ecological association, and are not comparable across fires.** While the 'increased greenness' class almost always has dNBR thresholds of -970 and -150, meaning that the 'unchanged' class almost always utilizes -150 to define the low threshold. The other three severity thresholds, however, which discriminate unchanged from low, low from moderate, and moderate from high, are highly variable.
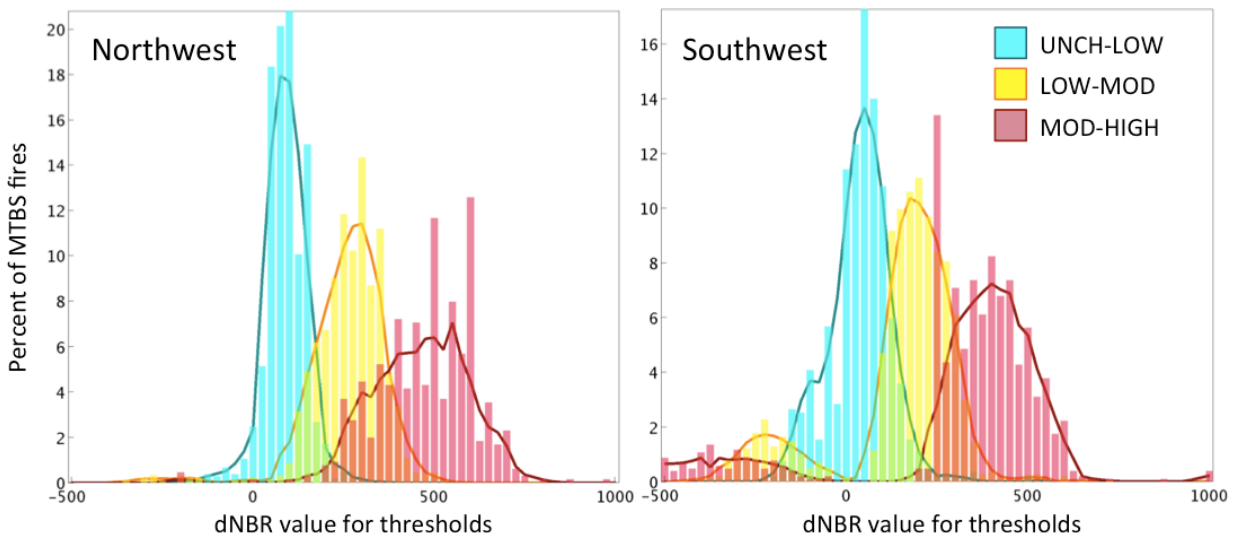

Figure 2. Histogram examples of the wide distribution of classification thresholds from two different Geographic Areas. The dNBR values for each threshold represent the value used to split between two classes: unchanged-to-low (cyan), low-to-moderate (yellow), and moderate-to-high (red). Bin size is 25, y-axis represents percent of MTBS fires with thresholds in that bin for the specific Geographic Area.

Because of this variability, the current classified MTBS products cannot be utilized to compare proportions of severity across space and time with any degree of accuracy or ecological relevance. They fail to pass a simple "lawsuit test" – if a research study using these data was presented in a court of law in response to a lawsuit over a forest management plan, for example, the data are too flawed for the study to hold up under rigorous examination.

How do arbitrary thresholds compare to ecological thresholds from field data?
One way to assess whether arbitrary thresholds misrepresent burn severity across fires is to compare them with thresholds that have been developed based on field ecological metrics like changes in biomass or tree mortality. Such metrics have not been widely developed yet. One example comes from the North Cascades region of Washington State, where thresholds developed from extensive field work links dNBR and RdNBR to a specific ecological metric: percent tree mortality resulting from the fire. Cansler and McKenzie (2012) identified thresholds that divide dNBR and RdNBR into classes where Low Severity includes 0-19% tree mortality, Moderate Severity includes 20-59% tree mortality, and High Severity includes 60-100% tree mortality; these thresholds also correspond to CBI values used in other regions and studies.

When these ecologically- and statistically-based thresholds are compared to the ones utilized by MTBS for fires in the same region, we can see the differences between MTBS classifications and an ecologically-based classification. Cansler and McKenzie (2012) published ecologically-based thresholds for a greater North Cascades study area based on over 600 field validation plots. Figure 3 shows two fires for the North Cascades where the MTBS classified severity maps (based on visually-determined thresholds) are significantly different than the severity maps classified using Cansler and McKenzie's ecologically-based thresholds.
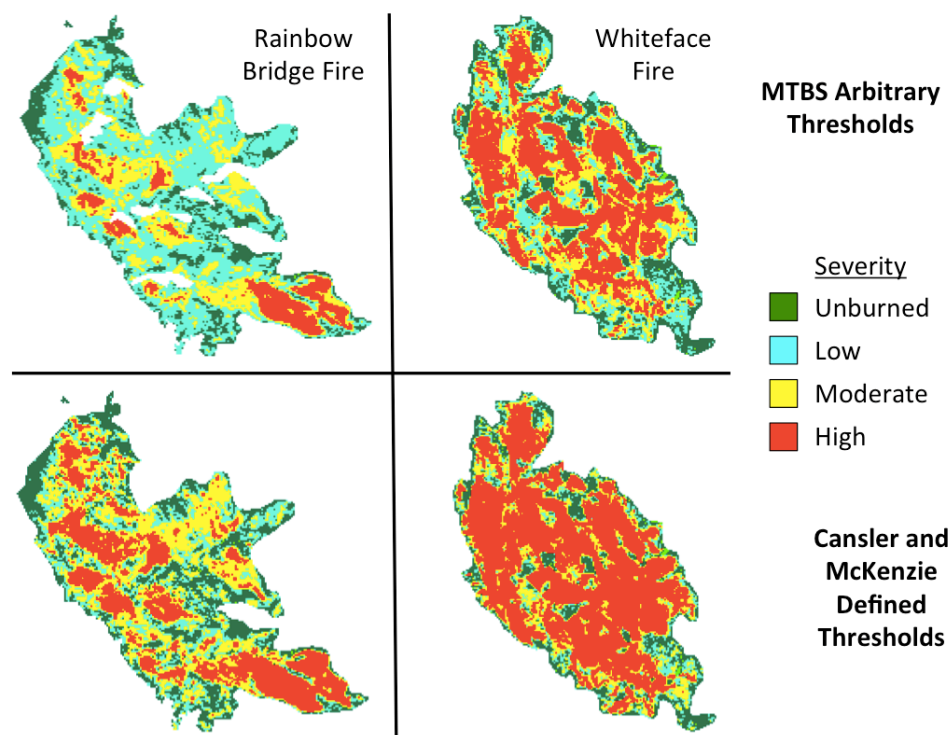

Figure 3. There are clear differences in the classified burn severity maps between arbitrary thresholds assigned by MTBS (top) and the ecologically-based thresholds identified by Cansler and McKenzie (bottom) for two fires in the North Cascades of Washington State.

What are the Next Steps? How do we move forward?
To be able to utilize MTBS data in a consistent, ecologically-linked, and scientifically-defensible manner, classified data needs to be consistent across space and time (i.e., an apples-to-apples comparison). For this to occur, thresholds need to be identified for burn severity classes that are based on field measurements of ecological change. This alignment of class thresholds and ecological metrics could occur at broad ecoregion levels at the coarsest spatial scale, but would also align well with the objectives of LANDFIRE if thresholds were defined for the finer-scale Biophysical Settings (BpS) utilized as the basis for the LANDFIRE product development (and would subsequently apply to other LANDFIRE products, such as Existing Vegetation Type). The rationale for this is that Fire Regime characteristics are defined at the BpS level, and burn severity is a fire regime characteristic. Once these thresholds are defined nationally for each ecoregion of BpS model, they could be utilized to re-classify the raw dNBR and RdNBR outputs to create a new classified data product from MTBS (Figure 4).

CLASSIFICATION FRAMEWORK

1. Identify existing field data by ecoregion/BpS model ← E.g., CBI, FIA, other post-fire field assessments

2. Fill spatial gaps in field data ← New field data collection

3. Identify key ecological metrics & thresholds used by management ← E.g., ΔCanopy Cover, ΔBasal Area, ΔBiomass, %Mortality, etc.

INPUT: Existing automated MTBS products: dNBR and RdNBR

4. Quantify relationships between thresholds and severity indices ← E.g., Δ Biomass = (dNBR/RdNBR)$a + b$

Apply 'offset' values to dNBR & RdNBR to normalize for inter-annual variability in phenology

5. Set classification thresholds based on ecological transitions ← Base on VDDT or other S&T models (ΔBiomass = Conversion from Late-Closed to Late-Open successional state)

6. Apply thresholds and classify by BpS model or ecoregion

OUTPUT: New classified burn severity maps based on field-validated ecological metrics and S&T model thresholds
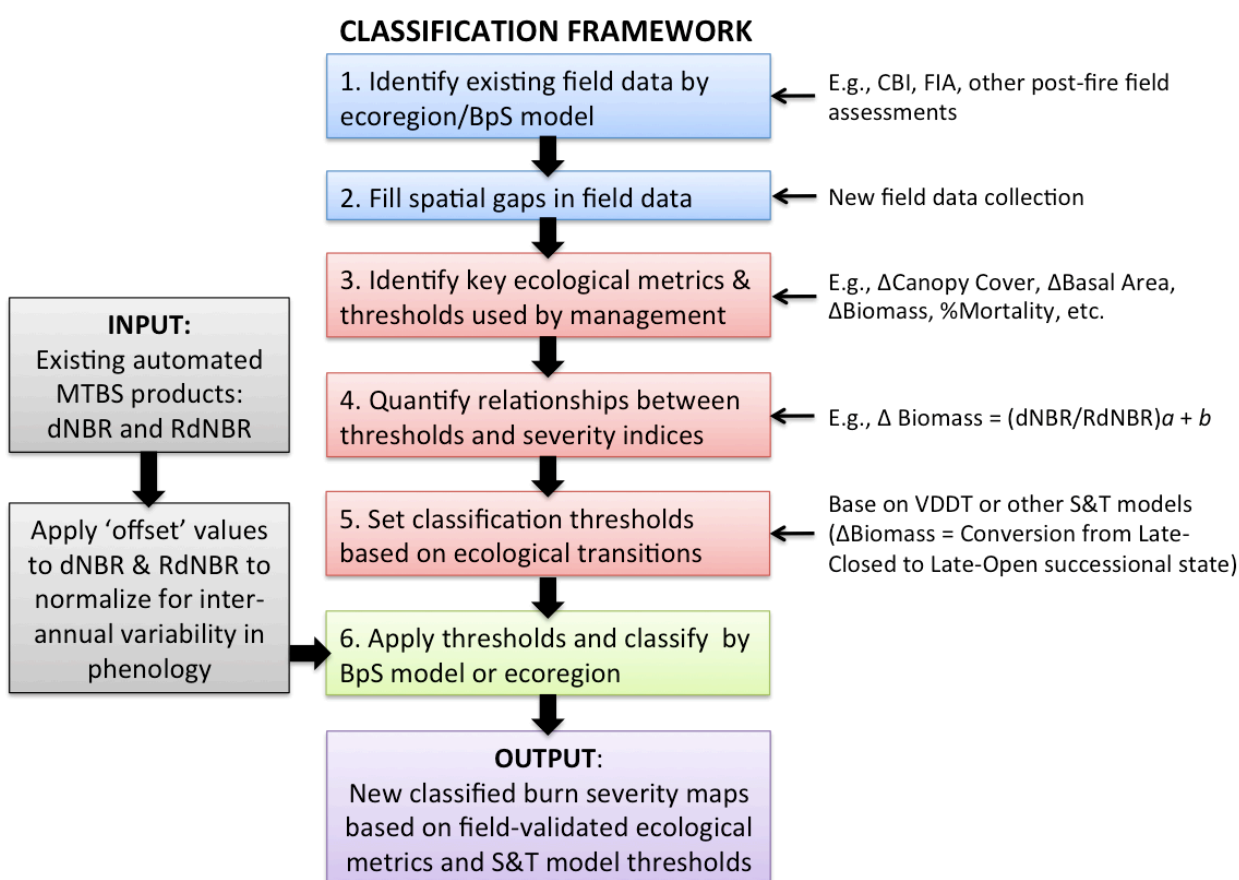
Figure 4. Suggested framework and workflow for developing a national set of thresholds that is congruent with existing LANDFIRE products and can be applied to create a more consistent and accurate MTBS classified severity product that is linked to ecological thresholds.

Such a product (both the thresholds and the re-classified data) would require identification of key ecological metrics that are critical to land management planning. For example, some researchers have utilized Percent Change in Canopy Cover (ΔCC) as a metric, while others have looked at Percent Change in Basal Area (ΔBA) or Percent Change in Biomass (ΔBM). Different metrics are likely to be applied in different ecoregions and depending on needs. One potential route to defining thresholds is utilizing the framework of State and Transition models,

such as those embedded in the LANDFIRE-Vegetation Dynamics Development Tool (VDDT) products, where severity thresholds for each BpS/EVT model are defined by what magnitude of change results in a transition to a new successional state (Figure 5). Thus, the final product would ideally include a cross-walk table to understand which ecological metrics were utilized in classification, and provide alternative thresholds and equations for classification based on other metrics, which users could apply themselves to the raw dNBR or RdNBR data.
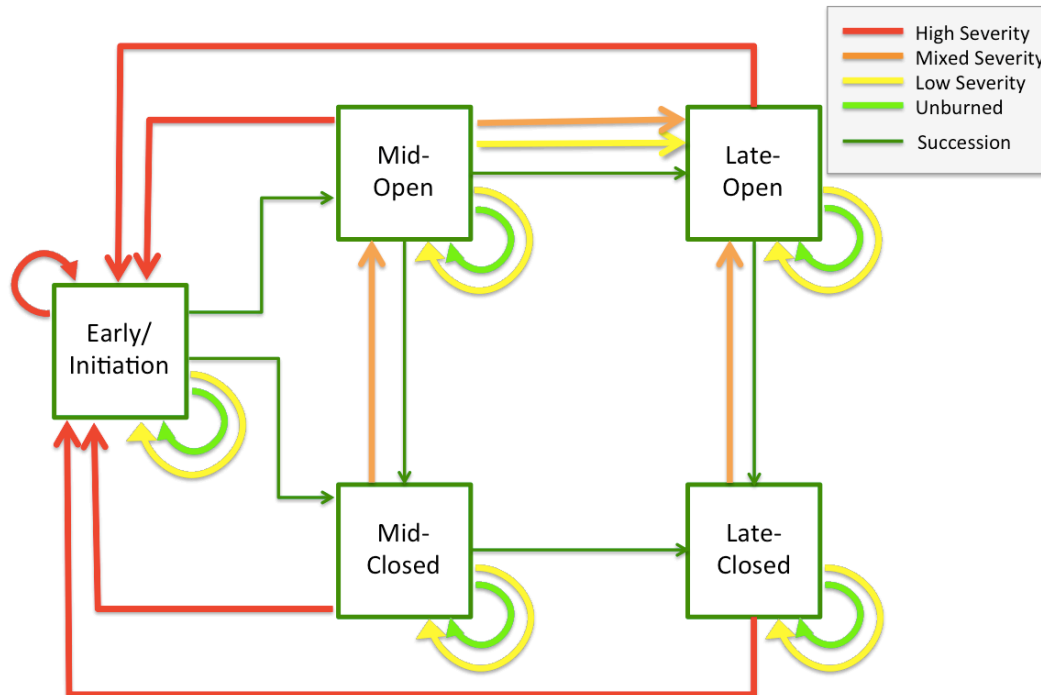

Figure 5. Conceptual diagram of the role of state and transition models in defining burn severity, modified from a VDDT S&T model.

Finally, field data are the foundation of such a development process. There are two existing data sources that could be utilized in order to minimize new, expensive field data acquisition. These include Composite Burn Index (CBI) plots used to field validate dNBR throughout the US, and the Forest Inventory and Analysis (FIA) program run by USFS. Both protocols include measurements of tree mortality, canopy cover, and other ecological information. While CBI plots are generally installed one year post-fire, FIA plots are re-read at regular (~5 year) intervals, such those that burned in the intervening period could be utilized to define thresholds. In the Pacific Northwest region of USFS, FIA plots are being revisited one-year post-fire regardless of the normal re-visit schedule specifically to collect post-fire data. Additionally, there are several regional datasets that could supplement these two national datasets.

Summary
MTBS products can provide considerable information for wildland fire and natural resource management, but these products have limitations. The classified burn severity product in particular is not appropriate for quantitative assessment of spatial and temporal trends due to the highly variable thresholds that are not currently linked to ecological metrics. Development of consistent, ecologically based thresholds is key to robust monitoring of trends in burn severity.

Reference
Cansler, C.A., and D. McKenzie. 2012. How robust are burn severity indices when applied in a new region? Evaluation of alternate field-based and remote-sensing methods. *Remote Sensing* 4: 456-483.