Spruce Beetle (*Dendroctonus rufipennis)* Infestation for the Copper Plateau Ecoregion, Alaska

By

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Introduction

The study area, for this project, is the Copper Plateau ecoregion of Alaska which is 1,723,701 hectares in size (figure 1). The ecoregion has elevation ranges from 139 meters to 1017 meters (figure 2). Spruce trees (*Picea* spp.) are the dominate terrestrial conifer vegetation covering the landscape of the Copper Plateau. The ecoregion contains spruce trees that range from 0 to 206 square feet of basal area per acre (USFS 2019) (figure 3). The area of spruce trees by basal area classes is listed in table 1.

Spruce beetle (*Dendroctonus rufipennis* Kirby) is a widely distributed North American endemic bark beetle (Coleoptera: Curculionidae: Scolytinae) (Sherriff, Berg et al. 2011). *D. rufipennis* host species are spruce trees (*Picea* spp.). That is, *D. rufipennis* attacks and kills spruce trees from Arizona to Alaska. The life cycle of *D. rufipennis* is labeled as bivoltine (one generation every two-years) (Fairweather, McMillin et al. 2006). In addition, *D. rufipennis* is also known to carry the infection vector for the blue stain fungus. The blue stain fungus (genera *Ophiostoma* and *Ceratocystis*) is also a primary mortality agent affecting spruce trees (Hagle, Gibson et al. 2003).

After a spruce tree is attacked by *D. rufipennis* tree mortality usually occurs two or more years after initial attack. Therefore, when detecting infestations of *D. rufipennis* from aerial surveys a lag time is likely to occur. This lag time is compounded by both the time that occurs for the spruce trees to die, thus being ocularly detected from an airplane, and the bivoltine life cycle of *D. rufipennis.*

D. rufipennis outbreaks often occur in spruce stands that are growing on poor soils, over mature, weakened or stressed by other causal agent such as diseases (i.e. root rot) or physically damaged by wildfire, drought, flooding, wind-throw or avalanches (van Driesche, Laforest et al. 2019). Tuffly (2012) concluded that when plant defenses are compromised and populations of deleterious insects are present in sufficient numbers; then, the likelihood of infestation is exacerbated.

It has been estimated that global average air temperatures are rising by 1° C to 5° C (Williams and Liebhold 2002). Forrest (2016) states that warmer air temperatures can speed up insect development and thus change voltinism from two-years to one. Moreover, Sherriff, Berg and Miller (2011) suggest that warmer temperatures greatly facilitates *D. rufipennis* outbreaks in south central Alaska. Finally, Williams and Liebhold (2002) have documented that two endemic bark beetles (*Dendroctonus frontalis* and *Dendroctonus ponderosae*) populations have shifted to higher elevations and higher latitudes due to warmer air temperatures. This may be an indication that in the next few decades *D. rufipennis* populations in Alaska will surge; subsequently, increasing the mortality of spruce trees over the landscape.

Over the past 25-years optical multispectral data from both the LandSat project and the Moderate Resolution Imaging Spectroradiometer (MODIS) project (NASA 2019) have been a mainstay in assessing and quantifying the status of vegetation over large landscapes. Optical multispectral data is plague by any phenomena that alters optical reflectance. Some of the main reflectance altering phenomena are: clouds, atmospheric aerosols, and sun angles.

In the Copper Plateau ecoregion, clouds and varying sun angles are the biggest deterrent to optical multispectral data. The Google Earth Engine (GEE) Application Programming Interface (API) has partly resolved the cloud issue with optical multispectral data. That is, using the computing power of Google's

® massive computers coupled with the GEE API users can write computer programs that can search the LandSat and MODIS data archive, for an area of interest, and over a particular time period, for optical multispectral data that is relatively cloud free. This can produce imagery that is relatively cloud free but from different time periods. Finally, the GEE API can concatenate the cloud free imagery from varying time periods into a single comprehensive scene for the area of interest.

However, obtaining cloud free imagery from different time periods exacerbates the sun angle issue. Sun angles produce shadows over the landscape. Shadows mask the true optical reflectance properties of the object of interest. Furthermore, in the northern latitudes, of the Copper Plateau, sun angles differ greatly from season to season. Consequently, classifying optical images from different time periods in the Cook Inlet may intensify image anomalies due to varying sun angles over the study area.

Synthetic Aperture Radar (SAR) relies on microwaves to collect information. Microwaves are not influenced by clouds, atmospheric aerosols, or sun angles (SERVIR 2019). The Sentinel-1 Copernicus (ESA 2018) satellite collects data in the C-band. The C-band has wavelengths that are from four to eight centimeters in size (Moreira, Prats-Iraola et al. 2013).

The long wave length of the SAR C-band is relative to the size of forest canopy elements (i.e. leaves, branches, and stems) (Fernandez-Ordonez, Soria-Ruiz et al. 2009). Optical multispectral remotely sensed data has a much smaller wavelength (i.e. 0.4 – 2.5 micrometers). The small wave length of the optical remotely sensed data is sensitive to plant pigments (Fernandez-Ordonez, Soria-Ruiz and Leblon 2009). Concluding, that SAR data is better at identifying forest structure; whereas, optical remotely sensed data is a better tool for identifying forest condition (Fernandez-Ordonez, Soria-Ruiz and Leblon 2009).

Methods

A two-year time period spatial analysis was conducted for the Copper Plateau ecoregion of Alaska (EPA 2013) (figure 1). The purpose of this study was to assess and evaluate the spatial and temporal extent of the spruce beetle (*Dendroctonus rufipennis* Kirby) infestation. The time periods assessed were 2017 and 2018.

Two Aerial Detection Surveys (ADS) spatial data sets were provided by USFS (2019). One data set was for 2017 (figure 4) and the other was for 2018 (figure 5). These ADS data identified forest mortality coupled with the causal agents for selected areas in the United States on an annual basis.

The Copper Plateau ecoregion of Alaska is 1,723,701 hectares in size. The Copper Plateau ecoregion could not be modeled using the same methods as the Cook Inlet ecoregion (Alaska) for the following reasons. First, the 2017 ADS data for the Copper Plateau ecoregions identified only one-hectare infested with spruce beetles out of 71,640.72 hectares surveyed (figure 4). Second, the 2018 ADS data for the Copper Plateau ecoregions identified 20.5 hectares infested with spruce beetles out of 316,106.4 hectares surveyed (figure 5). Therefore, with such scant ADS data a direct and reasonable spatial model could not be generated. Consequently, an alternative modeling approach was required.

An indirect modeling method for *D. rufipennis* was required. That is, instead of directly modeling *D. rufipennis* via the ADS data a viable alternative was to model areas of potential forest disturbance. A breath of literature has been written with respect to forest disturbance and endemic insect infestations. Therefore, directly modeling forest disturbance in the Copper Plateau ecoregions will serve as an indirect model for *D. rufipennis* infestation.

Synthetic Aperture Radar (SAR) imagery from Sentinel-1 (ESA 2018) for the years 2017 and 2018 was collected from UAF (2019) for the entire Copper Plateau ecoregion. The time period of the SAR data collection was Julian day 232 to 240 (i.e. eight-day time window). For 2017 ten SAR Single Look Complex (SLC) images were acquired and for 2018 eight SLC were needed. The SAR data was processed using the Sentinel Application Platform (SNAP) (ESA 2019) software. In addition, the methods used to process the SAR data are outlined in SERVIR (2019). SAR output data was two polarizations (VV and VH). The intensity values from the cross-polarization data, VH, for each year was standardized from 0 to 20000 figure 6 and figure 7 for 2017 and 2018, respectively. The SAR data had a ground sample distance (GSD) of 15-meters.

SAR data are not influenced by clouds, darkness, or snow (SERVIR 2019). This is due to the fact that the Sentinel-1 (ESA 2018) SAR satellite collects active remotely sensed data in the form of microwaves. Sentinel-1 microwaves are broadcasted in the C-band with a wavelength from four to eight centimeters in size (Moreira, Prats-Iraola, Younis, Krieger, Hajnsek and Papatjanassiou 2013). The long wave length of the SAR C-band is relative to the size of forest canopy elements (i.e. leaves, branches, and stems) (Fernandez-Ordonez, Soria-Ruiz and Leblon 2009). Optical remotely sensed data has a much smaller wave length (i.e. 0.4 to 2.5 micrometers). The small wave length of the optical remotely sensed data is relative to plant pigments (Fernandez-Ordonez, Soria-Ruiz and Leblon 2009). Concluding that SAR data is better at identifying forest structure; whereas, optical remotely sensed data is a better tool for identifying forest condition (Fernandez-Ordonez, Soria-Ruiz and Leblon 2009).

Bitemporal (i.e. imagery from two time periods) SAR data can be used to identify forest disturbance and or deforestation (SERVIR 2019). Moreover, the Sentinel-1 cross-polarization VH backscatter data has been very useful in identifying forest structure (SERVIR 2019). This is due to the fact that the Sentinel-1 cross-polarization VH SAR backscatter data is well suited in the identification of horizontal and vertical forest structure elements (SERVIR 2019).

Subtracting the 2017 standardized Sentinel-1 cross polarization VH backscatter from the 2018 data identifies or highlights areas that have experienced forest disturbance between the one-year time period. That is, if an area of forest in 2017 was healthy and vigorously growing; then, the cross-polarization VH backscatter intensity would be relatively high. However, if tree mortality occurred in 2018 then the VH backscatter intensity will be lower than 2017 for the same area. Concluding, when subtracting the 2017 data from the 2018 data lower VH backscatter intensity values indicate disturbance and high values illustrate forest growth. Therefore, directly modeling forest disturbance with the SAR data can indirectly model potential *D. rufipennis* infestations.

Results

Contained in figure 8 are the four risk categories for the Copper Plateau ecoregion derived from the SAR data. Table 2 summarizes the risk categories by area. Table 3 summarizes the rick categories by spruce basal area loss.

Discussion

It is well known that forest disturbance such as flooding, snow or wind damage, and drought play a critical role in the likelihood of infestation by *D. rufipennis*. It is also common knowledge that the average air temperatures are rising. In addition, many entomologists have indicated that due to increased annual air temperatures *D. rufipennis* life cycle is changing from bivoltine to univoltine. Finally, it has also been documented that endemic bark beetle populations are shifting to higher elevations and higher latitudes due to increased annual air temperatures. Putting all these elements together paints a picture that *D. rufipennis* population numbers and spatial extent in the Copper Plateau will likely increase in the coming years.

When forest parameter data (i.e. areas of mortality) are scant; then modeling risk is difficult. The SAR VH cross-polarization is a very useful tool in assessing and quantifying forest disturbance. SAR data is not influenced by sunlight, clouds, or atmospheric aerosols as is optical remotely sensed data. Therefore, SAR data can be quickly acquired, processed, and assessed at almost any time of the year for a very low cost. Moreover, SAR data has proven to be a tremendous and an efficient asset in the mapping and quantification of forest disturbance over the landscape in remote areas such as the Copper Plateau ecoregion.

Conclusion

It is suggested that an annual or biannual forest assessment using SAR data could be implemented for the Copper Plateau ecoregion so that forest disturbances (i.e. *D. rufipennis* infestations) can be directly monitored over time and space. Modeling forest disturbance over time and space will directly inform foresters, entomologists, and resource managers on the magnitude and change over time of the *D. rufipennis* infestation. Thus, providing the critical information needed to lessen spruce mortality due to *D. rufipennis* in the Copper Plateau ecoregion.


Copper Plateau Ecoregion
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
141°0'0"W
64°0'0"N
63°0'0"N
62°0'0"N
61°0'0"N
60°0'0"N
Copper Plateau
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
148°0'0"W
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
N
W
E
S
25 12.5 0 25 50 75 100
Kilometers
Document Name: figure1b_copper
Date: 5/31/2019
Map created by M. Tuffly of
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Figure 1.

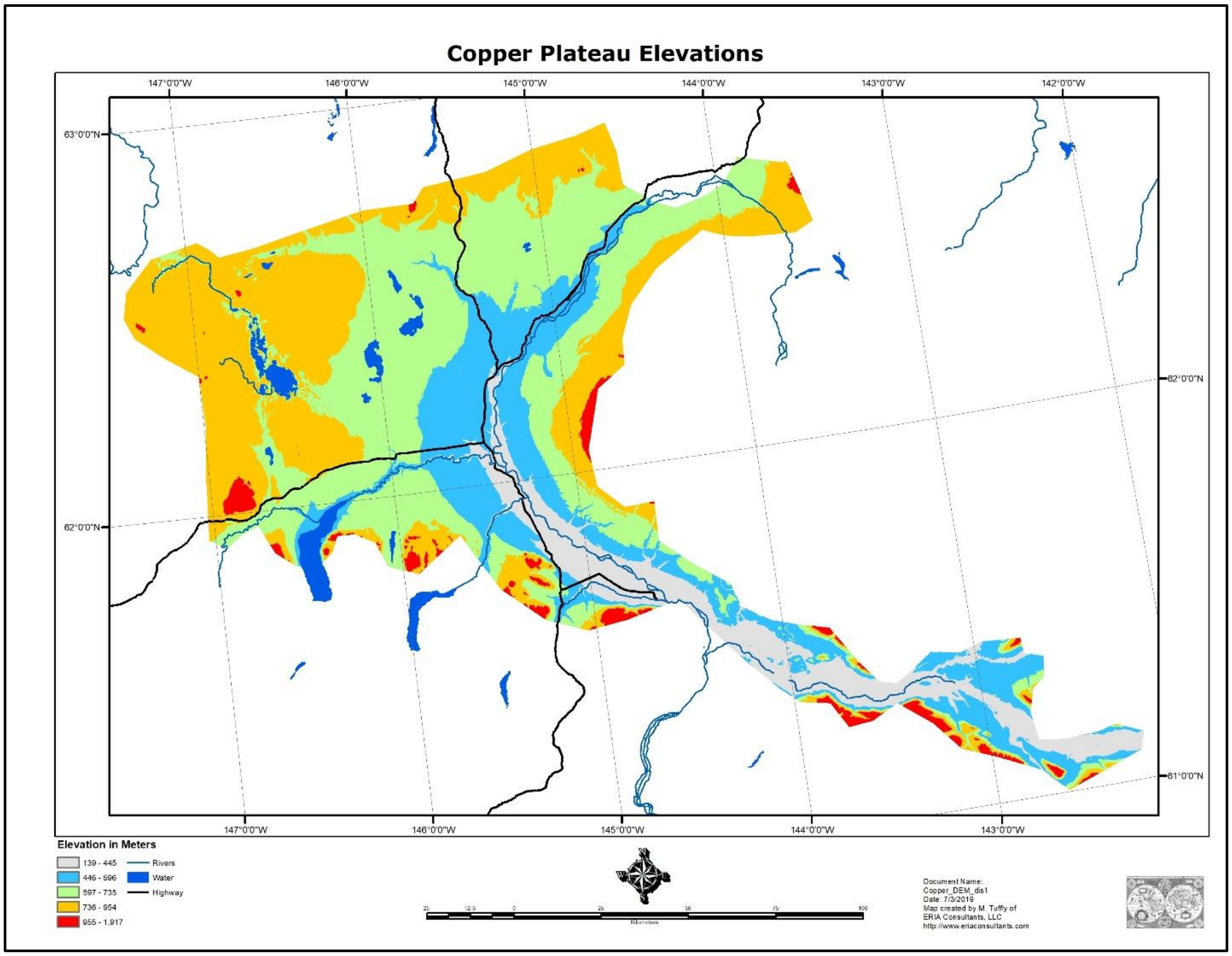
Copper Plateau Elevations
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
63°0'0"N
62°0'0"N
61°0'0"N
Elevation in Meters
139 - 445
446 - 596
597 - 735
736 - 954
955 - 1,917
Rivers
Water
Highway
Document Name:
Copper_DEM_dis1
Date: 7/3/2019
Map created by M. Tuffy of
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Figure 2.

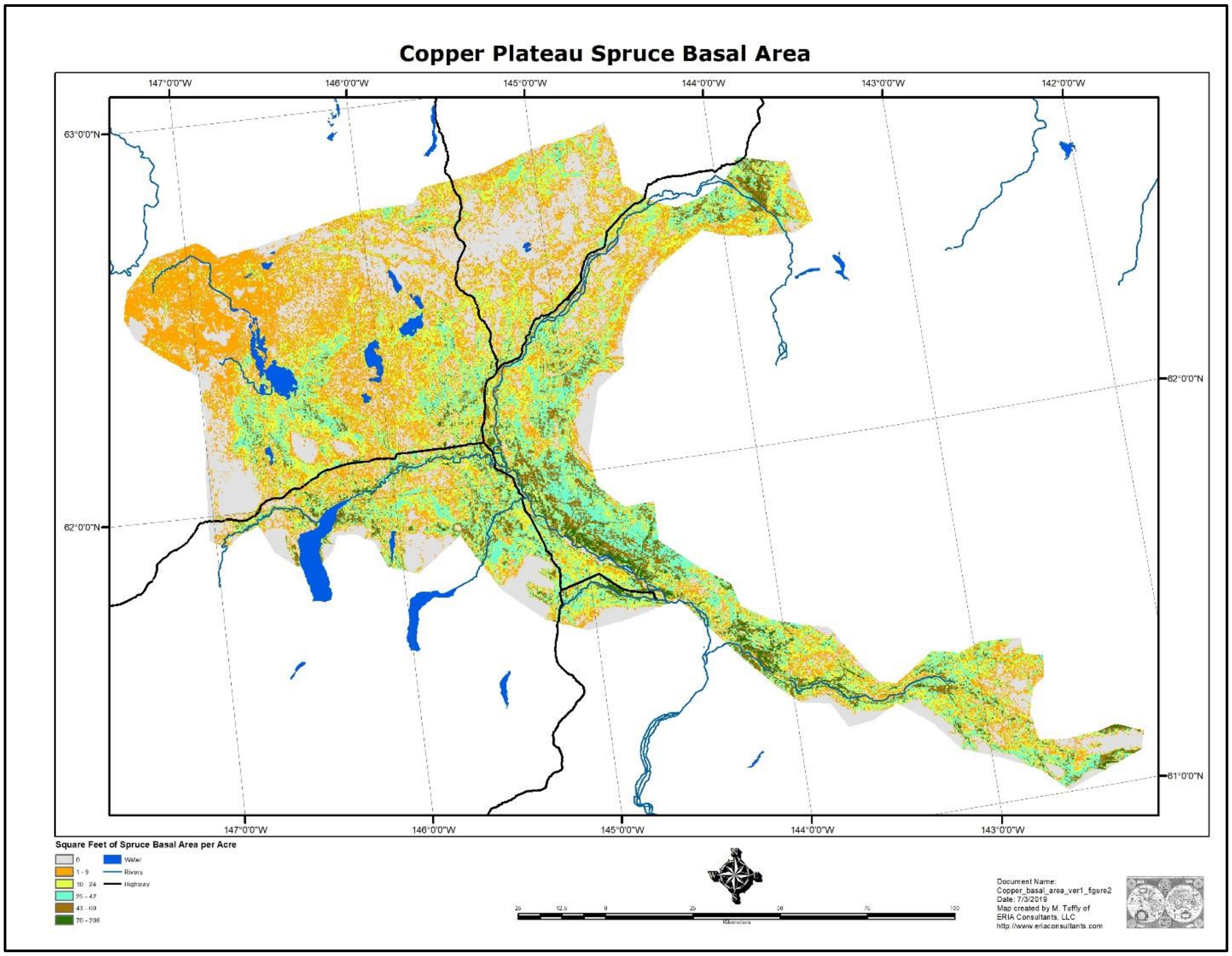
Copper Plateau Spruce Basal Area
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
63°0'0"N
62°0'0"N
61°0'0"N
Square Feet of Spruce Basal Area per Acre
0
1 - 9
10 - 24
25 - 42
43 - 69
70 - 206
Water
Rivers
Highway
Document Name:
Copper_basal_area_ver1_figure2
Date: 7/3/2019
Map created by M. Tuffly of
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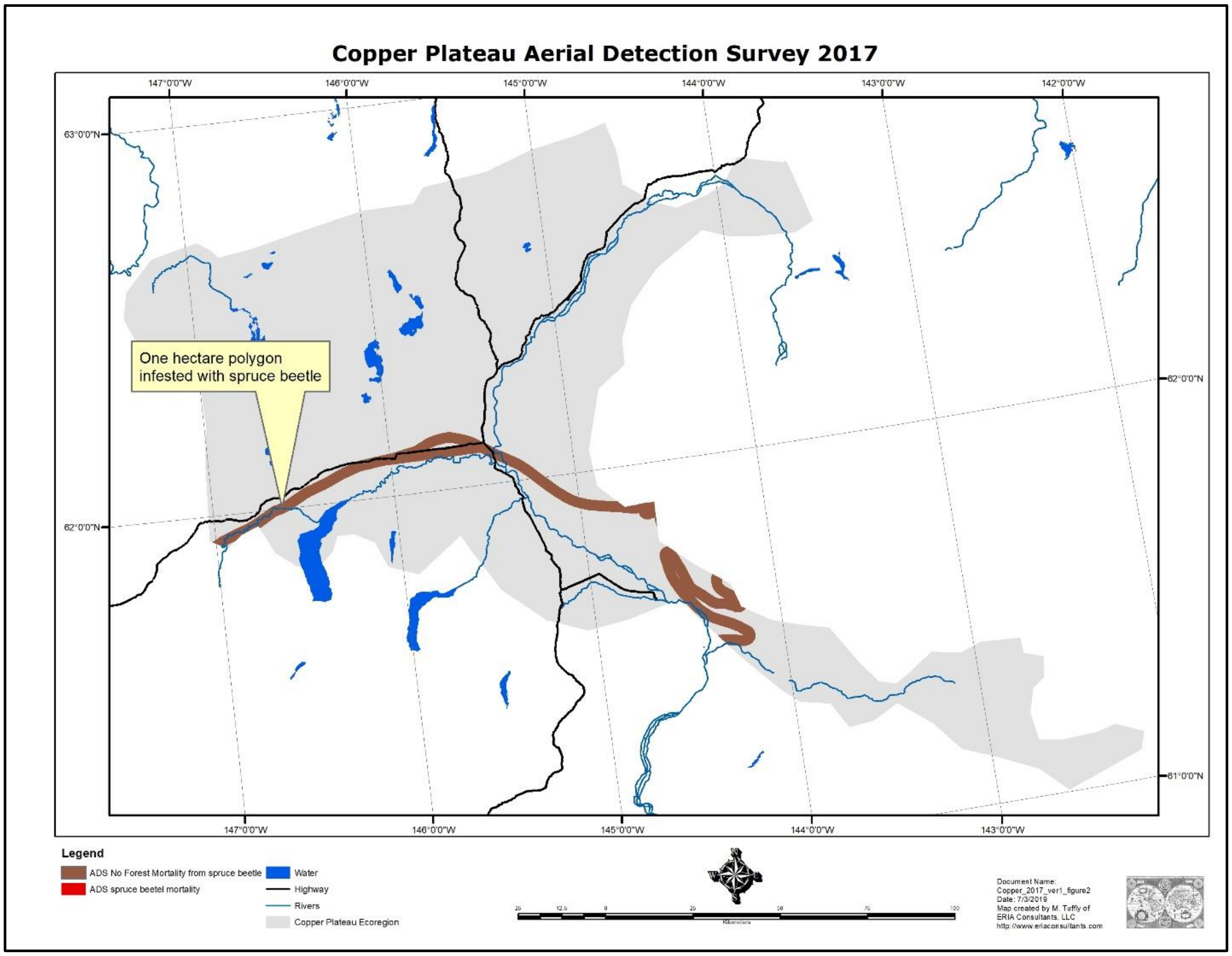
Figure 3.


Copper Plateau Aerial Detection Survey 2017
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
63°0'0"N
62°0'0"N
61°0'0"N
One hectare polygon infested with spruce beetle
Legend
ADS No Forest Mortality from spruce beetle
ADS spruce beetel mortality
Water
Highway
Rivers
Copper Plateau Ecoregion
Document Name:
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Date: 7/3/2019
Map created by M. Tuffly of
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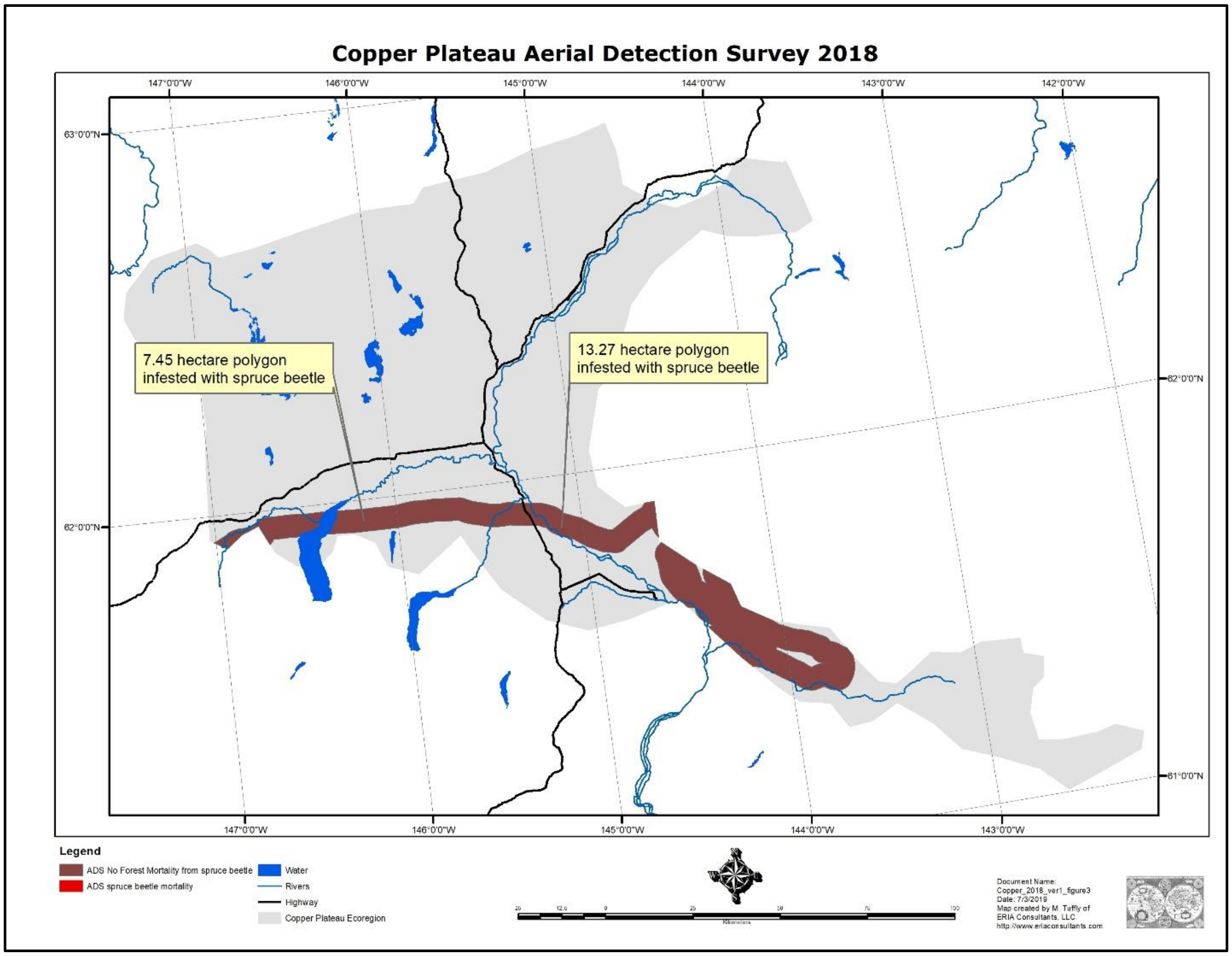
Figure 4.


Copper Plateau Aerial Detection Survey 2018
7.45 hectare polygon infested with spruce beetle
13.27 hectare polygon infested with spruce beetle
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
63°0'0"N
62°0'0"N
61°0'0"N
Legend
ADS No Forest Mortality from spruce beetle
ADS spruce beetle mortality
Water
Rivers
Highway
Copper Plateau Ecoregion
Document Name:
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Date: 7/3/2019
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Figure 5.

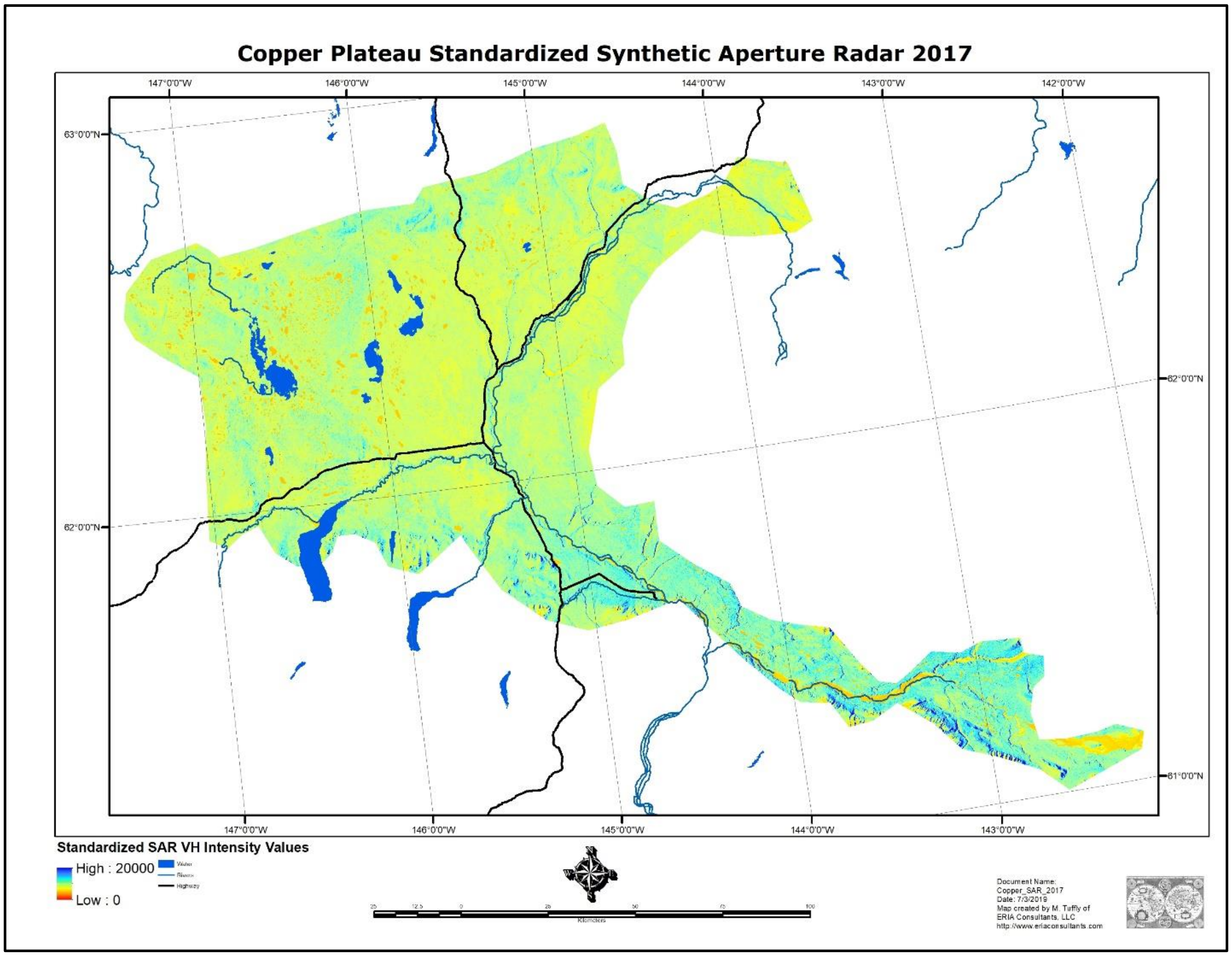
Copper Plateau Standardized Synthetic Aperture Radar 2017
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
63°0'0"N
62°0'0"N
61°0'0"N
Standardized SAR VH Intensity Values
High : 20000
Low : 0
Document Name:
Copper_SAR_2017
Date: 7/3/2019
Map created by M. Tuffly of
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Figure 6.

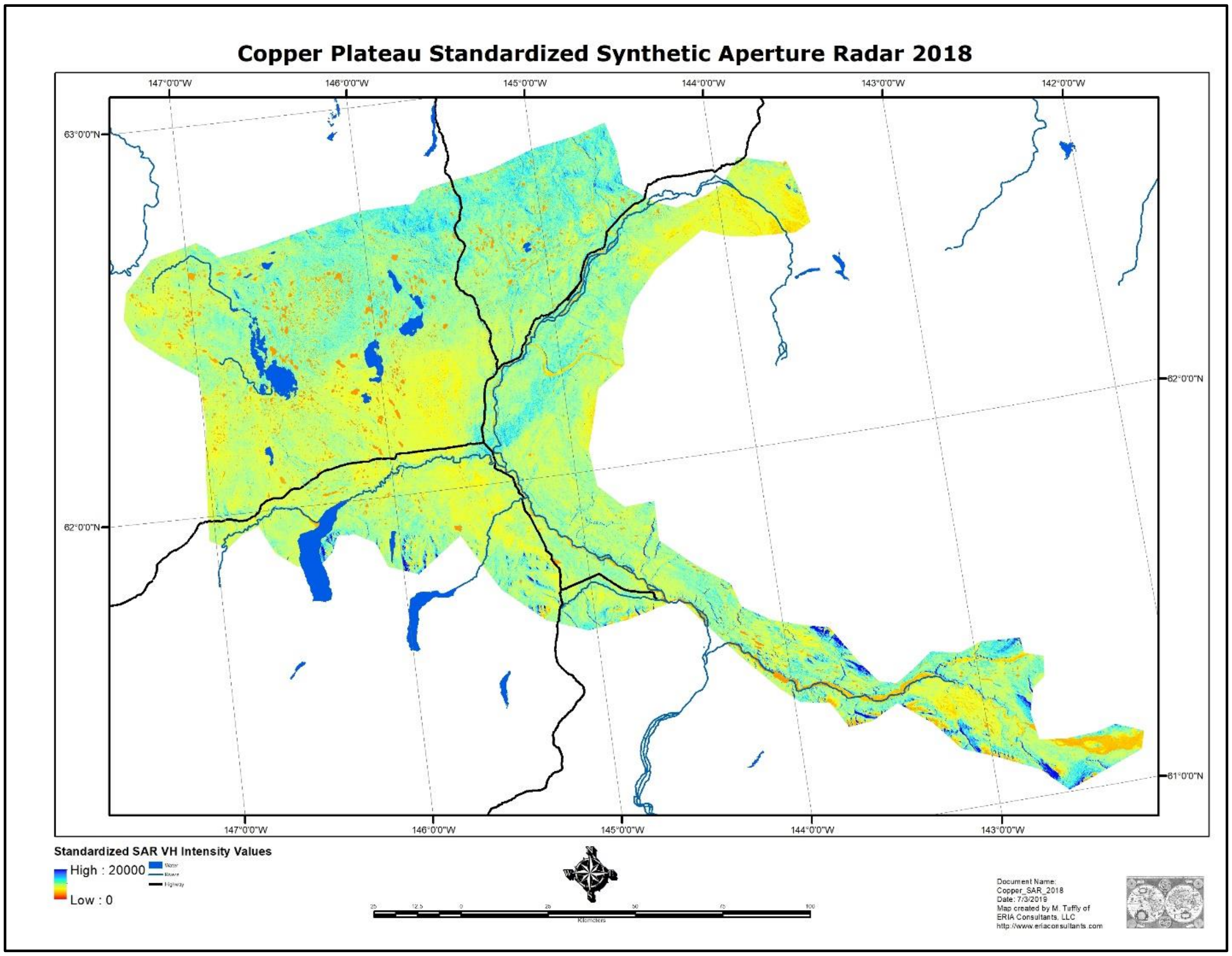
Copper Plateau Standardized Synthetic Aperture Radar 2018
147°0'0"W
146°0'0"W
145°0'0"W
144°0'0"W
143°0'0"W
142°0'0"W
63°0'0"N
62°0'0"N
61°0'0"N
Standardized SAR VH Intensity Values
High : 20000
Low : 0
Water
Rivers
Highway
Kilometers
Document Name:
Copper_SAR_2018
Date: 7/3/2019
Map created by M. Tuffly of
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Figure 7.

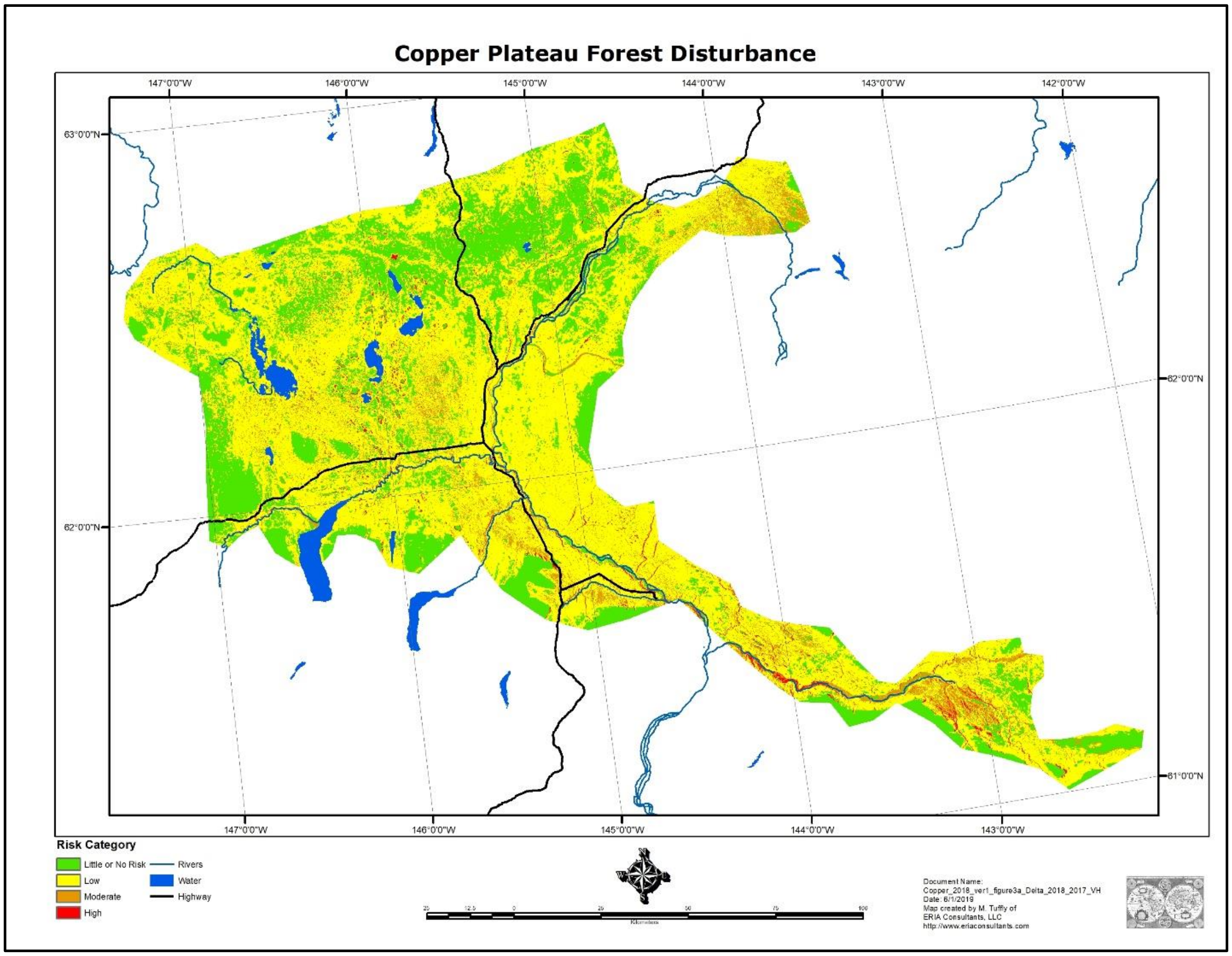

Figure 8.

Table 1. Spruce Basal Area Distribution.

Square Feet Basal Area Per Acre	Hectares	Percent Area
0	473,420.78	27.47
1 to 9	467,839.34	27.14
10 to 24	365,864.30	21.23
25 to 42	274,885.10	15.95
43 to 69	118,616.30	6.88
70 to 206	23,075.18	1.34
Total	**1,723,701.00**	**100.00**

Table 2. Risk Categories.

Risk Category	Hectares	Percent of Ecoregion
Little or No	442,908.74	25.70
Low	1,063,813.19	61.72
Moderate	148,428.70	8.61
High	21,146.72	1.23
Water	47,403.65	2.75
Total	**1,723,701.00**	**100.00**

Table 3. Basal Area Loss by Risk Category.

Square Feet of Basal Area per Acre	Risk Category	Hectares	Percent Area	Percent by Basal Area Class
0	Little or No	473,421.00	27.47	27.47
1 to 9	Little or No	1,431.52	0.08	
1 to 9	Low	403,756.00	23.42	
1 to 9	Moderate	55,016.80	3.19	
1 to 9	High	7,635.30	0.44	27.14
10 to 24	Little or No	919.88	0.05	
10 to 24	Low	309,339.08	17.95	
10 to 24	Moderate	48,837.32	2.83	
10 to 24	High	6,772.04	0.39	21.23
25 to 42	Little or No	658.40	0.04	
25 to 42	Low	237,653.60	13.79	
25 to 42	Moderate	31,353.44	1.82	
25 to 42	High	5,220.32	0.30	15.95
43 to 69	Little or No	600.64	0.03	
43 to 69	Low	100,277.44	5.82	
43 to 69	Moderate	13,819.84	0.80	
43 to 69	High	3,918.40	0.23	6.88
70 to 206	Low	18,330.64	1.06	
70 to 206	Moderate	3,112.72	0.18	
70 to 206	High	1,626.64	0.09	1.34
Total		**1,723,701.01**	**100.00**	**100.00**

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