DETECTING LONG TERM CHANGES IN VEGETATION COVER USING HISTORIC AERIAL PHOTOGRAPHS AND MODERN VRI DATA IN THE KENNEDY LAKE WATERSHED

by

Qiao Si Yuan

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ABSTRACT

Rivers and their associated floodplains produce a wide variety of ecosystem services. However, they are severely altered by human activities such as logging. Riparian vegetation plays an important role in contributing large woody debris to the streams, and the debris directly affects the physical character of the streams. Various vegetation types can have different impacts on the streams. Therefore, it is important to quantify and understand vegetation changes caused by logging. My objective is to assess vegetation changes after logging in Kennedy Lake watershed. Here, I combined historical aerial photography and modern Vegetation Resources Inventory data to quantify vegetation changes over time. Over the 60-year period, conifer abundance decreased by approximately 10% compared to its historical cover. Trees with heights from 30m to 40m experienced the largest decline in percent cover while trees with heights from 10m to 20m increased the most. Site productivity affected change in average tree height. The area with the highest site productivity decreased in average height whereas the average tree heights in areas with all other productivity classes increased. In contrast, average crown closure increased in area with very good site productivity and decreased in areas with lower productivities. Vegetation composition also varied in relation to site productivity classes. Very good site productivity was associated with more decrease in conifers, and increases in deciduous, conifer and deciduous mixed, and shrub and herb covers. My results indicate that historic logging activities had a large impact on vegetation today in the Kennedy Lake watershed, and understanding these patterns can guide potential restoration planning and watershed management.

KEYWORDS

Vegetation Changes, historical aerial photographs, land cover type, Kennedy Lake Watershed, conifer, deciduous, large woody debris (LWD)
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INTRODUCTION

Rivers and their associated floodplains produce a wide variety of ecosystem services (Tockner and Stanford 2002, Coast Information Team 2004), and they play a crucial role in resource provisioning and regulation of biophysical ecosystem processes (Brauman et al. 2007). Due to the significant economic value of products derived from floodplains, such areas have been severely altered in many parts of the world by flow control, agriculture and urban expansion (Tockner and Stanford 2002). Besides these alternations, human activities such as logging also impact the riparian zone by altering the vegetation composition and structure. Such changes are important to channel formation and riparian ecosystem functioning because different species of trees generally have different in-stream residence times (Naiman et al. 2010). For example, deciduous species do not persist as long in the channels as conifers do (Naiman et al. 2010, Hyatt and Naiman, 2001). In addition, woody debris size affects riparian ecosystems, as woody debris jams formed by large debris are more stable and can provide better refuge for stream biota from floods than jams formed by small woody debris (Naiman et al. 2010). Furthermore, riparian zones provide large woody debris that enters into the stream system and influences physical characteristics of streams (Naiman et al. 2010). Thus any changes in riparian vegetation can have an impact on biophysical processes (Naiman et al. 2010).

Understanding historical riparian condition enables monitoring of long-term changes
in rivers, assist in predicting potential future changes, and offer management options (Morgan et al. 2010). In British Columbia, historical logging after European settlement has greatly influenced the current status of riparian zones by removing channel-forming large woody debris close to the stream bank and altering vegetation composition (Warttig et al. 2001, Gergel et al. 2007, MacKinnon and Trofymow 1998), although it is not very documented precisely in my region of interest (Pearson 2010). Natural regeneration takes hundreds of years and the species composition needs to spend a long time to recover the pre-harvest condition (Poulin et al. 2000, Ministry of Forests 2002). This means that for a long period of time, the potential source of large wood debris entering the stream will be very different from historical sources in type, size and amount. One approach to documenting riparian vegetation prior to logging involves historical reconstruction using historical aerial photos. Such records can be compared with contemporary data to provide a long-term record of change in landscape (Morgan et al. 2010, Tomlinson et al. 2011). I utilized such records for my work in the Kennedy Lake watershed. Historical reconstruction was done by dividing the historical photos into plots and each plot was interpreted by experienced experts to obtain attributes such as dominant tree species. Modern data is available from Vegetation Resources Inventory (VRI). By comparing the attributes on the same plots, I could identify some changes and trends. In this study, I used this approach to address three primary research questions.
1. **HOW HAS THE AMOUNT OF VEGETATION TYPE COVER CHANGED OVER TIME?**

Riparian vegetation is a source of large woody debris input to streams. It enters the channel by various mechanisms such as windthrow, landslides and avalanches (Naiman et al. 2010). Sources of woody debris are grouped into three categories: deciduous, conifers, and shrub/herb. The relative abundance of conifers and deciduous trees along stream sides has high importance as conifers persist longer in streams (Gergel et al. 2007). Tracking the relative amount of different vegetation cover types (conifers vs. deciduous etc.) can help understand likely types and sources of large woody debris. I quantified the amount of vegetated cover types using historic and contemporary air photos. Comparing the same locations with historical and contemporary air photos allowed documentation of shifts cover types over time. I expected to see a general trend of decreases in conifer abundance and increases in deciduous and shrub/herb vegetation covers for two reasons. First, when logging took place, people likely selectively logged conifers for higher value wood. And secondly, since logging leads to secondary succession, generally speaking, colonizers tend to be vascular herbs and shrubs.

2. **HOW HAS THE SIZE OF POTENTIAL LARGE WOOD DEBRIS FROM THE RIPARIAN ZONE CHANGED OVER TIME?**

Large woody debris tends to persist longer in streams than smaller debris and thus has
a greater influence on sediment storage and bedform roughness (Naiman et al. 2010). Larger woody debris is also more stable and able to form woody debris jams which influence channel form (Naiman et al. 2010). Moreover, large woody debris delivered to streams creates a unique niche that is essential to riparian obligates. Hence, the size of the woody debris input has a large impact on stream channel characteristics (Naiman et al. 2010). Since DBH data was not available from photo interpretation, tree height was used to represent relative tree size. In order to examine the changes in size of potential large wood debris, I grouped forested polygons into five height classes to examine if the relative abundance of different size classes has changed over time. I compared the average height of trees in deciduous trees and coniferous stands between historical and current time periods and anticipated a shift towards shorter trees because the trees established after logging are younger than those growing there in historical time. In addition, I expected to see a decrease in average conifer height and an increase in average deciduous height because more conifers logged in historic time lead to young conifers in modern time bringing the modern average conifer height down, while fewer deciduous trees were logged historically and they continued to grow in height.

3. **HOW HAS THE RELATIVE COVER OF CONIFER, SHRUB AND DECIDUOUS CHANGED OVER TIME WHEN ACCOUNTING FOR SITE PRODUCTIVITY?**

Since conifer-dominated cover and deciduous-dominated cover are two groups that
are distinct in their residence time and function in streams, it is helpful to know how conifers, deciduous, and shrub cover vary in areas of different site productivities. Because site productivity is related to factors such as soil depth, nutrient and moisture content; higher site productivity usually means higher above-ground production (Keyes and Grier 1981). In the Pacific Northwest, many streams are salmon spawning habitat which also supply considerable amount of nutrient to adjacent forests (Helfield and Naiman 2001). Above-ground production includes wood and foliage (Keyes and Grier 1981); generally speaking, the higher the above-ground production, the more the wood is produced. To determine the changes, I calculated the percent of each type of vegetation cover controlling for site productivity. Because the tree volume is usually higher in areas with high site productivity, trees are likely to be preferably removed in these areas. Hence, I expected to see greater decreases in conifer cover where the site productivity is relatively high and an increase in shrub abundance. On the contrary, in areas where the site productivity is relatively low, I expected slighter decreases in the conifer abundance.

METHODS

Study site

The research area is located in the vicinity of the Kennedy lake watershed in Clayquote Sound, BC (Fig 1. and Fig 2.). The watershed covers approximately 55,013 hectares within Coastal western hemlock zone according to BEC classification and it is an extremely productive area (Mandrone Consultants Ltd 2002, Morgan 2009). The
major conifers in that area include western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), amabilis fir (*Abies amabilis*), yellow cedar (*Chamaecyparis nootkatensis*), and sitka spruce (*Picea sitchensis*) (Morgan 2009). The dominant deciduous tree in that region is red alder (*Alnus rubra*) (Morgan 2009). This area was logged extensively from 1950s to 1980s which resulted in huge degradation of the area’s forests and streams (Warttig et al. 2001, Parks Canada 2011). Logging roads in that area also negatively impacted sensitive floodplain area, and consequently, reduced suitable salmon spawning habitat (Warttig et al. 2001, Parks Canada 2011). Additionally, the historic harvest in Kennedy Lake watershed has caused severe alternation in large woody debris input into the streams (Warttig et al. 2001). Recent restoration plan in Kennedy flats has focused on removing small excessive woody debris from streams and moving large woody debris from areas of plenty to streams in deficiency (Warttig et al. 2001). After these problems were exposed, a series of restoration plans have been implemented to restore the local ecosystem (Warttig et al. 2001).
Historical vertical aerial photographs from 1937-1938 were selected in order to reflect the original diversity of the historic landscape. The original printed photos were scanned to a resolution of 1200 dpi, and further manual interpretation was processed digitally (Morgan 2009). Recent Vegetation Resources Inventory (VRI) data from 1996 were obtained from the Ministry of Forests, Lands and Natural Resource Operations. VRI is prepared using photo interpretation, ground sampling and statistical adjustment (Salkeld 2006). Attributes examined in this work are shown for site 7 as an example (Fig 3, Fig 4, and Fig 5), demonstrating polygon boundaries.
classification schemes and labels used in the historical interpretation.

**Classification Scheme**

Species 1: Leading Species  
Cw: Cedar, Western Red  
Hw: Hemlock, Western  
Ss: Spruce, Sitka  
Yc: Cedar, Yellow  
Hm: Hemlock, mountain  
Fd: Fir, Douglas  
Ba: Fir, Amabilis  
Pl: Pine, Lodgepole  
Pw: Pine, Western White  
Dr: Alder, Red,  
Mb: Maple, Bigleaf

![Fig. 3. Site 7 Each polygon labeled by the historical dominant species (height in meter)](image)

![Fig. 4. Site 7 Each polygon labeled by the height (in meters) of historical dominant species](image)
Statistical analyses

This study aims to detect the changes in the riparian vegetation in the Kennedy Lake watershed. The changes were quantified using data interpreted from historical aerial photographs and modern VRI data. Based on these data, bar graphs were constructed to illustrate the changes in percent of the landscape, in average height, and in percent of each vegetation type with respect to different independent variables.

Since I was interested in the changes in terrestrial vegetation cover, polygons that associated with water were excluded from analysis for historical and modern layers. The boundaries of the terrestrial polygons in these two layers were delineated differently (Fig 6), only the areas of overlap in both layers were used in further
Fig. 6. Comparison between historic and modern polygon delineation

1. **HOW HAS THE AMOUNT OF VEGETATION TYPE COVER CHANGED OVER TIME?**

I analyzed the attributes of both historic and modern layers describing vegetation cover types include conifer, deciduous, conifer and deciduous mixed, and shrub and herb. The shrub and herb classes were combined as they were not considered potential sources of large coarse woody debris. The changes in the percentage of the landscape occupied by each vegetation cover class were determined in two time periods.

2. **HOW HAS THE RELATIVE COVER OF CONIFER, SHRUB AND DECIDUOUS CHANGED OVER TIME WHEN ACCOUNTING FOR PRODUCTIVITY?**

To determine the changes in average tree height over time (of the dominant trees), I grouped heights into 5 classes ($ht \geq 40m$, $30m \leq ht < 40m$, $20m \leq ht < 30m$, $10m \leq ht < 20m$, $1m \leq ht < 10m$). Because conifers and deciduous trees have different residence times in
stream, I also compared the changes in tree height for conifer and deciduous classes separately. I took the average of the dominant tree height across those conifer-dominated polygons and another average across those deciduous-dominated polygons for both time periods. Conifer and deciduous mixed cover is not considered in this analysis because it is unclear which cover type dominates.

3. **HOW HAS THE RELATIVE COVER OF CONIFER, SHRUB AND DECIDUOUS CHANGED OVER TIME WHEN ACCOUNTING FOR SITE PRODUCTIVITY?**

Site productivity data was mapped in the historic geo-data, and I assumed site productivity estimates remained constant over time. Since polygon boundaries in the historic and modern layers were not identical, I used paired points to spatially link the attributes in the two layers together. There were only 12 polygons with very poor site productivity rendering the sample size is too low to be included in this analysis. Using GIS, to put one point in each polygon (with poor, medium, good or very good site productivity) resulting in 479 total points, each of which was then assigned historic and modern attributes from the appropriate associated polygons. Points gained null values (either blank or -9999) after attribute extraction were deleted and 417 points left because they are located outside of a raster pixel. In order to obtain the effect of stratified random sampling and to get a balanced ANOVA analysis, I used excel to randomly choose 25 points from each site productivity classes, for a total of 100 points, for further analysis. Average dominant tree heights and average crown closures for four site productivity classes were determined for both historic and modern polygons to compare changes in height and crown closure according to site
productivity.

I also compared the historic and modern tree composition in areas of different site productivities. Because of the different polygon delineation methods applied for the two layers, I used GIS to ensure that the total area of each site productivity class is the same for both time periods. I overlaid one layer on the other, creating smaller polygons, in order to enable each polygon has site productivity, historic and modern tree type and correct shape area. Unknown site productivity class is unclassified in the original data mainly due to the inability to identify the productivity caused by the shadow. The total area of polygons within each site productivity class was determined to represent the percentage of each tree type composition.

To test if the tree height and the crown closure were significantly different in historic and modern time at the stand-level, I used SAS software to carry out two paired T tests, using alpha level 0.05.
RESULTS

Fig. 7. Changes in different Vegetation cover types from historic 1930’s to 1996 in 6,622 hectare of riparian areas within the Kenned Lake watershed

In the 1930s, the landscape was predominantly covered by conifers. Deciduous trees, conifer & deciduous mixed, and shrub & herb only made up to less than 1.5% in total. Over time, the percent of land covered by coniferous trees decreased (by approximately 9%) whereas all the other vegetation types increased in percent cover. The amount of increases in deciduous and conifer & deciduous mixed cover types are much higher than that in shrub & herb cover.
Changes in height of dominant trees across the Kennedy Lake landscape subset.

Trees with height between 30m to 40m experienced a greatest decrease (more than half) in abundance, and trees with height between 10m to 20m experienced a largest increase (more than two folds). Despite the fact that trees taller than 40m increased a little, the amount of landscape dominated by shorter trees increased, and generally the landscape shifted from dominated by taller trees to shorter trees.

Fig. 9. Changes in average tree height of dominant conifer and deciduous trees from historic to modern time.
There is a slight increase (0.8m) for coniferous species and decline (3.0m) for deciduous species from average tree height of 525 historic polygons to that of 1355 modern polygons across the Kennedy Lake landscape subset.

![Graph showing changes in average tree height for leading species in relation to site productivity classes of the 100 random points](image)

**Fig. 10.** The changes in average tree height for the leading species in relation to site productivity classes of the 100 random points.

Only trees on areas with very good site productivity decreased in average tree height. The average tree heights on areas with other three site productivity classes all increased. At stand level, using point data, the height of the dominant tree cover in areas with poor, medium, good and very good site productivities have increased by 5 meters ($P=0.08$), 2 meters ($P=0.42$), 3 meters ($P=0.53$) and decreased by 17 meters ($P<0.0001$), respectively.
The crown closure decreased for poor, medium, and good site productivity classes. But it increased for very good site productivity class. At the stand level, using point data, the crown closure in areas with poor, medium, good and very good site productivities decreased by 2 meters \((P=0.43)\), 8 meters \((P=0.07)\), 10 meters \((P=0.04)\), and increased by 4 meters \((P=0.24)\), respectively.
Fig. 12. The composition of vegetation classes for various site productivity classes in historical time in polygons where the 100 random points are located

Fig. 13. The composition of tree types for various site productivity classes in modern time in polygons where the 100 random points are located

By comparing fig 13 and 14, there is an increase in shrub & herb, deciduous trees and mixed trees on the landscape across all site productivity classes; the percent of
conifers decreased in areas with all site productivity classes, and the biggest decrease is in area with very good site productivity.

DISCUSSION

This paper documents the important changes in vegetation cover from historic to modern time which likely include a shift from conifers to deciduous trees, from large to small size classes, as well as greater conifer establishment on areas with high site productivity and higher probability of deciduous tree establishment on areas with low site productivity. Understanding these changes helps us to better characterize the landscape dynamic and to better manage the watershed in the future.

1. HOW HAS THE AMOUNT OF VEGETATION COVER TYPES CHANGED OVER TIME?

Across the whole landscape, conifer is the only vegetation cover type that experienced about a 10 percent decrease in its cover. The covers of all of the other types (deciduous, conifer & deciduous, and shrub & herb) increased slightly. Conifer cover decreased less than my expectation. My results show vegetation cover shifting from conifer to deciduous, conifer and deciduous mixed, or shrub and herb. These results are generally consistent with other studies in areas where logging has been the main disturbance (Palik and Pregitzer 1992, Leahy et al. 2003). It also supports the idea that logging activities in riparian zones often remove conifers and consequently favour the establishment of deciduous trees and shrubs (Ministry of Forests, 2002). However,
other works have shown larger changes in conifer cover than mine; for example, work
done by Leahy et al. suggested that their study area has shifted from a conifer
dominated area (75% conifer) to an area almost equally covered by conifer and
deciduous trees period from pre-settlement to present-day (Leahy et al 2003, Labbe et
al. 2013). Nonetheless, this inconsistency could be caused by historic data limitation.
The historic data interpreted from the 8 historical aerial photos only covered part of
the entire watershed; therefore, the results obtained from this analysis may not reflect
the actual total changes of the whole area. Even though, my result still shows a
decrease in conifer abundance, which is likely caused by logging preference to more
valuable conifers. Kennedy Lake Watershed is dominated by species such as Western
red cedar and yellow cedar that have a very high market value, and they are likely to
be the ones logged first (Committee, 2006).

2. HOW HAS THE SIZE OF POTENTIAL LARGE WOOD DEBRIS FROM THE

RIPARIAN ZONE CHANGED OVER TIME?

Generally speaking, there is a tendency of an increasing area with short trees and less
with tall trees. Despite the fact that the percent of landscape with trees taller than 40
meters has increased, that with trees with height of 30 meters to 40 meters decreased
by more than half over time. The portion of the landscape with very tall trees
increased may be due to some old, not very commercially valuable deciduous trees
could grow with a release in resources after logging. Kennedy and Spies’ work also
suggests that medium-sized cover type has the highest probability of transitioning to
large trees (Kennedy and Spies 2004). The reason for the large drop in the area with trees in the 30 to 40 meters height class could be that these good-sized trees were harvested in early days, and the trees regenerated afterwards have not yet reached that height. The area of trees with heights from 10 to 20 and 20 to 30 meters both increased and the area of trees with heights from 1 to 10 meters decreased. That is very likely since historic old growth lacking of understory with that height and modern regeneration reaching understory competition stage excluding the lower layer. Over the entire landscape, the average height of dominant conifers increased by less than 1 meter and the average height of dominant deciduous trees decreased by 3 meters. Although the general trends of incense and decrease were the same as my expectation, the change is not as big as I had expected. It is unlikely that the average height of conifers barely changed given the extensive logging activities occurred historically. The reason for this minimal change might be because the result is based on the average of the dominant tree height. Therefore, only the tallest were taken into account, and it could not represent the trees in lower canopy layers.

3. HOW HAVE THE AVERAGE HEIGHT, CROWN CLOSURE, AND RELATIVE VEGETATION COVER CHANGED OVER TIME WHEN ACCOUNTING FOR SITE PRODUCTIVITY?

The changes in average tree height seems to be related to site productivity. Looking at historic data, tree height increases as site productivity increases. This is reasonable because the better the site productivity, the more resources available for trees to grow.
Average tree height in areas with very good site productivity in modern time is less than that in historic time. The result can be ascribed to selectively logging the tallest and biggest trees. There were probably fewer trees logged on sites with lower productivity; hence, the trees continued to grow which contribute to the increase in average tree height.

Average crown closure is quite the opposite; crown closure on areas with very good site productivity increased over time, whereas crown closure on areas with lower productivity decreased. In historic time, the average crown closure on medium, good and very good site productivity was about the same, which indicates that these areas have probably all reached old growth stage. In modern time, however, the average crown closure in area with very good site productivity is higher than those in all other site productivity classes. Although the crown closure on very good site productivity has increased, the height of the crown may not be the same. Area with good site productivity promotes rapid regeneration, hence a large number of trees. Crown closure in areas with other site productivity classes decreased because the understory regeneration has not yet reached the crown and there is still gap in between.

Relative vegetation cover changed in areas in all site productivity classes. Historic vegetation cover was relatively homogeneous and almost exclusively dominated by conifers, whereas in modern time, although areas with different site productivities are still dominated by conifers, conifer and deciduous mixed and deciduous also make up to some fraction of the total landscape. More specifically, the higher the site productivity, the higher proportion of deciduous or deciduous and conifer mixed
found in a particular site productivity class. This general pattern is in agreement with my hypothesis that conifers would decrease and other cover types increase in modern time. Furthermore, areas with very good site productivity witnessed the most increase in other vegetation covers largely due to the removal of high-quality conifers historically. The type of vegetation regenerating after logging is worth noting because some studies have indicated that disturbances caused by logging promotes conifer establishment and other studies suggests that the deciduous species surviving logging disturbances proliferated (Leahy and Pregitzer 2003, Haugo et al. 2010). These contrasting ideas may have developed because results are context specific, depending on the specific study area and species. In the Kennedy Lake watershed, species such as red alder may regenerate quickly after clear-cut in some areas because of its high ability for seed dispersal.

**Limitation**

Although this study provides a reasonable reconstruction of how vegetation cover in Kennedy Lake Watershed has changed over time, it may not reflect the comprehensive changes across the entire landscape simply because the historic information is limited to the historic photos available. In addition, historic data and modern data were collected using different methods, one with aerial photo interpretation only and other with both photo interpretation and inventory; therefore, bias to some extent may exist. In this study, I only considered the dominant tree cover type. Later studies can take a closer look at the dominant tree species and the
co-dominant tree species as well, which may explain what conifer species experienced the most decrease and what deciduous species increased the most. Moreover, further studies can also be done on the vegetation changes along the stream edge as the neighboring trees contributes the most to the coarse woody debris in streams.

**Implications**

This study helps to reconstruct the historic landscape and to document and understand post-logging regeneration trends. Understanding how historic riparian vegetation looked like and how natural regeneration patterns occurred in riparian zones provides useful guidelines for long-term restoration planning (Ministry of Forests 2002, Charron et al. 2008). Although my study did not show a dramatic decrease in the overall conifer percentage, it shows a fairly remarkable decrease in the percent of area with tree from 30 to 40 meters in height and a substantial decrease in average tree height from the 1930’s to now. Since riparian zones are generally areas that have the highest productivity, it is very likely that coniferous vegetation close to the rich riparian zone decreased a fair amount in height and quantity. That may have a detrimental impact on hydrological and ecological processes, because conifer trees having longer residence time in streams can affect the channel dynamic. Long lasting coarse woody debris is very important for such area with high and unique value of spawning habitat (Poulin et al. 2000). Based on my study, I suggest that future land use planning should take riparian vegetation into account because the vegetation there
is usually of high quality and plays an important role in contributing to the coarse woody debris in streams. In addition, I suggest that future restoration plans should take pre-logging condition and the changes in vegetation into account. The pre-logging condition derived from historical aerial photographs can serve as a target for restoration as it represents the original state, and the changes in vegetation over time can offer insights on what measurements should be taken (Poulin et al. 2000).

This study has shown a decrease in large conifers and an increase in deciduous trees over the landscape; it suggests that conifer abundance needs to be increased to restore historic vegetation. Increasing conifer abundance can be achieved through practices such as conifer release (Ministry of Forests 2002). The large decrease in tree height in areas with very good site productivity indicates that sites with good site productivity (likely to be along the streams) have undergone more logging than other sites. Hence, extra attention should be paid to these areas with high site productivity in restoration planning. Moreover, long-term monitoring systems should be set up to observe the changes in habitats with high ecological value and large human-induced disturbance.

CONCLUSION

The Kennedy Lake watershed has important biological and ecological values, but the historic logging activities have severely degraded and altered the riparian vegetation. Through reconstructing the historic landscape by aerial photographs, my study has demonstrated a decrease in conifer cover and height, as well as an increase in deciduous, shrub and herb abundance. The changes in average dominant tree height
and the averages crown closure, and the species composition are also shown to be related to site productivity classes. The reconstructed historic landscape and the changes in vegetation cover provide important suggestions to future restoration planning. Restoration should focus on increasing conifer abundance and size, as well as recovering the vegetation in the most productive areas.

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