# CHAPTER 14.

## Use of Forest Inventory Data to Document Patterns of Yellow-Cedar Occurrence, Mortality, and Regeneration in the Context of Climate

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## BACKGROUND

Yellow-cedar (*Callitropsis nootkatensis*) has great cultural and economic value but has experienced widespread mortality for about 100 years in southeast Alaska (Hennon and Shaw 1997). The tree mortality, known as yellow-cedar decline, appears as dense concentrations of dead yellow-cedar trees (fig. 14.1), which are readily detectable by aerial survey or other forms of remote sensing. Yellow-cedar decline occurs primarily in unmanaged forests on wet soils where trees of various sizes and ages die and remain standing long after death. The cause of yellow-cedar decline appears to be freezing injury of shallow fine roots when they are not protected by snow in late winter or spring (Hennon and others 2012, Schaberg and others 2008). The Forest Service Forest Health Protection team has developed a fairly complete distribution map for yellow-cedar decline; it occurs in more than 2,000 locations totaling over 500,000 acres (Lamb and Winton 2010). Producing maps and geographic information system layers for healthy yellow-cedar forests has proven more difficult, however, because cedar trees are not easily distinguished from hemlocks and other trees in mixed-species forests. Thus, there is no reliable information on the current distribution of healthy yellow-cedar forests to place the decline issue into some spatial context.

*Figure 14.1—Yellow-cedar decline results in more than 70-percent mortality of yellow-cedar, which can be detected by aerial surveys and other forms of remote sensing. Evaluating healthy yellow-cedar forests requires the use of inventory data. (Photo: USDA Forest Service)*

## METHODS

We used Forest Inventory and Analysis (FIA) and other inventory plot data and personal field observations in selected areas to produce a coarse distribution map of yellow-cedar forests for southeast Alaska. For this coarse map, entire watersheds were designated as having yellow-cedar if yellow-cedar was present in an inventory plot or was observed there. We overlaid the map of dead cedar forests generated from the forest health detection aerial survey to determine how yellow-cedar decline fits into the general distribution of the tree.

We also analyzed FIA inventory data on the occurrence of live, dead, and regenerating yellow-cedar by elevation classes to evaluate our observations that the tree is dying at low elevations but thriving and regenerating at higher elevations in the region. We calculated ratios of live trees to dead trees and live trees to live saplings using a 5-inch diameter threshold to separate trees and saplings, and then charted these ratios by elevation to explore trends of how yellow-cedar populations may be changing by elevation. Results that relate numbers of yellow-cedar trees to elevation used FIA plots that were measured between 1995 and 1998; there were 625 forested plots with yellow-cedar trees in that inventory. For information about net change of yellow-cedar in the region, we used 307 of these plots that were remeasured from 2004 through 2008.

## RESULTS

The map showing the occurrence of yellow-cedar in southeast Alaska (fig. 14.2) is the most detailed view of yellow-cedar's natural range within the region. Yellow-cedar is present throughout most of southeast Alaska, but there are areas where it is rare or absent. For example, yellow-cedar is apparently missing from large areas in the northeastern portion of the panhandle, even though there is abundant

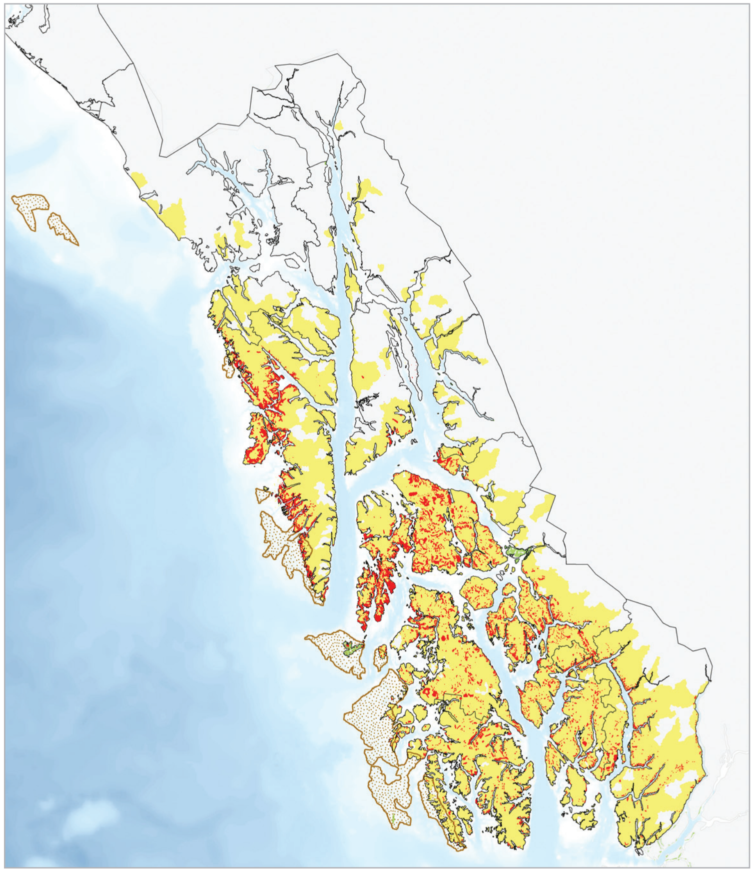

*Figure 14.2—Occurrence map of yellow-cedar in southeast Alaska (yellow) from Forest Inventory and Analysis and other inventory data and several personal observations, and the distribution of yellow-cedar decline (red) mapped during forest health aerial detection surveys. Note that yellow-cedar decline occurs within most, but not all, of the range of yellow-cedar in southeast Alaska. The speckled areas along the outer west coast of the region indicate glacial refugia during the late Pleistocene Epoch (Carrara and others 2007) and may represent the origins for yellow-cedar for subsequent Holocene migration.*

suitable habitat present in the form of bog and forested wetland complexes. This regional map of yellow-cedar is useful for a variety of purposes; for example, it has already been used to illustrate where yellow-cedar is present as a resource for bark and wood collection by native people near each of the villages or towns. Also, we used this map as the basis for sampling in a new regionwide population genetics study for yellow-cedar.

Overlaying the yellow-cedar decline on this map reveals that the intensive mortality problem covers only part of yellow-cedar's regional distribution. Yellow-cedar decline is present in the southern and northwestern portions of the panhandle, but yellow-cedar growing in the northeastern portion of the panhandle appears to be free of the intensive mortality.

Although yellow-cedar can be found from shoreline forests to timberline in southeast Alaska, inventory data reveal that the abundance of this tree peaks at mid-elevation range (fig. 14.3). Tree death and regeneration of yellow-cedar show somewhat of a departure by elevation from this pattern of live trees. The ratio of dead trees to live trees was greatest at lower elevation and then diminished upslope, but the ratio of live trees to live saplings showed the opposite relationship, with a greater proportion of regeneration at higher elevations (fig. 14.4).

Overall, change in net live tree biomass of yellow-cedar between the 1995–98 and 2004–08 inventories showed an increase of 0.61 percent, which was not significantly different from 0 ($p = 0.4064$). Average annual mortality of trees greater than 5 inches diameter at breast height (d.b.h.) was 0.30 percent (standard error = 0.04 percent). Average annual harvest rate was 14 percent of average annual mortality, for a total tree death rate of 0.34 percent. Total number of live yellow-cedar trees greater than or equal to 5 inches d.b.h. did not show significant change in biomass between the 1995–98 and 2004–08 inventories ($p = 0.7443$).

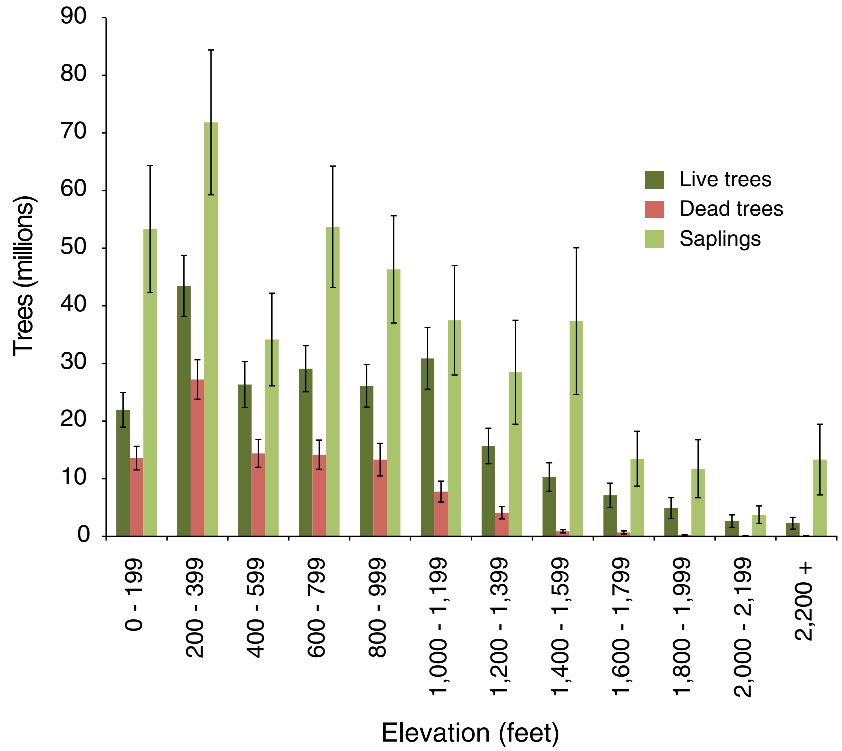


*Figure 14.3—Numbers of yellow-cedar trees (live trees ≥ 5 inches diameter at breast height [d.b.h.], dead trees ≥ 5 inches d.b.h., and live saplings < 5 inches d.b.h.) by elevation. Lines at end of bars represent ± standard error.*

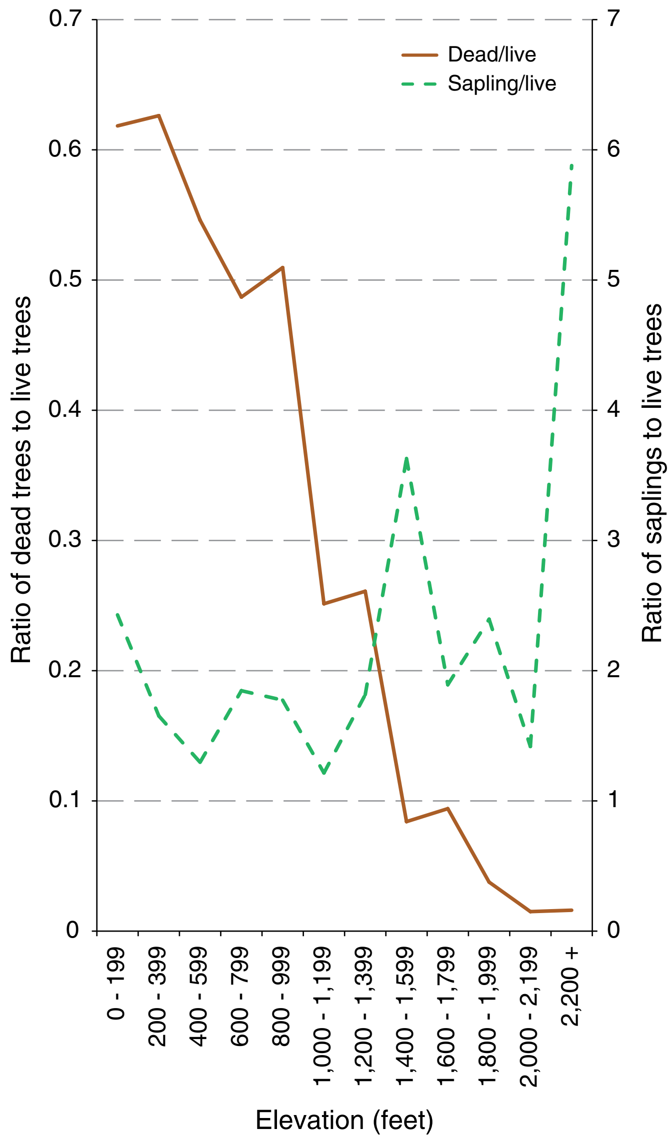


*Figure 14.4—Ratio of yellow-cedar dead trees to live trees and live saplings to live trees for 200-foot elevation classes from Forest Inventory and Analysis inventory plot data.*

## INTERPRETATION

The general occurrence of yellow-cedar in southeast Alaska may be the result of long-term climate change in the region combined with yellow-cedar's low reproductive capacity. We hypothesize that yellow-cedar survived the late Pleistocene Epoch in forested refugia along the outer western coast of the panhandle when most of the region was covered by ice sheets (Carrara and others 2007). Yellow-cedar likely began to colonize much of southeast Alaska during favorable climate conditions in the last 4,000 years, but our data suggest that the species is still actively migrating toward the northeast. This scenario may explain the absence or rarity of the tree in the northeast portion of southeast Alaska. The above-mentioned population genetics study based on our yellow-cedar map is designed to evaluate this hypothesis. Yellow-cedar also grows farther to the northwest in Prince William Sound. Populations are so small there that we were able to produce a map of the tree's range there by observations from a boat (Hennon and Trummer 2001).

The pattern of yellow-cedar decline within the general distribution of yellow-cedar is consistent with our interpretation that seasonal snow depth is a controlling factor for yellow-cedar decline. The lowest snow zone on a regional snow map shows a remarkably close association with yellow-cedar decline (Hennon and others 2008). Areas with more annual accumulation of snow are generally those that have healthy yellow-cedar populations. Snow protects yellow-cedar from the proximal injury leading to tree death—freezing injury of shallow-growing fine roots in late winter (Schaberg and others 2008).

Yellow-cedar death in FIA plots is more common at low elevations. This is consistent with the same finding from aerial surveys, where the acreage of yellow-cedar decline mapped was clearly skewed toward lower elevations (Lamb and Winton 2010). The association of yellow-cedar decline with lower elevations is consistent with the role of snow in protecting yellow-cedar from the freezing scenario mentioned above.

Tree species that show different elevational patterns of occurrence among live trees, dead trees, and regeneration may be considered relatively unstable with regard to climate. More stability for a tree species would be exhibited by a pattern where live trees, dead trees, and regeneration had similar elevational trends. Yellow-cedar appears to be a species in flux, however, as our data indicate the trees are dying at low elevation, surviving as live trees at mid-elevation, and regenerating at higher elevation. Thus, under the recent-past and current climate, yellow-cedar populations appear to be shifting to higher elevations.

The relatively low rate of recent tree mortality is interesting given the large acreage of dead yellow-cedar in southeast Alaska. Our reconstruction of yellow-cedar mortality through the 1900s shows that tree death peaked during the 1970s and 1980s (Hennon and Shaw 1994). We have observed recent mortality in specific areas, despite the fairly low regional mortality rate. Although pollen records clearly show that tree species migrate over time in response to climate, little is known about the process of migration. The long-term occurrence of yellow-cedar is not well known because the species was omitted from the classic pollen profile studies conducted in the region (Heusser 1960). Spatially differentiated mortality and regeneration could occur either gradually or in pulses. If mortality is caused by the combination of low snow cover and spring freezing, both episodic events, then mortality would occur in pulses. However, yellow-cedar trees may take a long time to die after they are injured, as root damage from weather can have cumulative effects on tree growth and health (Beier and others 2012). These possibilities suggest that monitoring needs to be long term to capture temporal variability as well as spatial variability.

These findings can contribute to development of an adaptive strategy for the conservation and management of yellow-cedar (Hennon and others 2012). Continued analysis of inventory plot data for yellow-cedar habitat preferences would aid in the construction of a high-resolution distribution map. A distribution map could be combined with aerial surveys of dead cedar and snow modeling to partition the landscape of coastal Alaska into areas that are unsuitable and suitable for yellow-cedar. Inventory plot data should be queried to evaluate successional trends in forests impacted by yellow-cedar decline to project the future composition and productivity of these forests. Inventory data could also be used to document the resource (e.g., diameter classes and volume) of dead yellow-cedar that might be available for salvage recovery on the roughly 500,000 acres of yellow-cedar decline.

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