POPULATION STATUS, THREATS AND PERSISTENCE OF YELLOW-CEDAR IN ALASKA—INFORMATION SYNTHESIS

Prepared for

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INTRODUCTION

Concerns over the widespread mortality of yellow-cedar (*Callitropsis nootkatensis*) led to a petition to list the species as endangered or threatened under the Endangered Species Act (ESA). The U.S. Fish and Wildlife Service (FWS), which has management authority over native plants, was petitioned on 24 June 2014 by the Center for Biological Diversity (Anchorage, AK), The Boat Company (Poulsbo, WA), Greater Southeast Alaska Conservation Community (Sitka, AK), and Greenpeace (Sitka, AK). In their 90-day finding issued on 10 April 2015, FWS found that the petition provided substantial scientific or commercial information indicating that listing may be warranted (U.S. Fish and Wildlife Service 2015; 80 FR 19259). The 90-day finding initiates a status review by FWS, which will culminate in a 12-month finding on whether listing is warranted. A Species Status Assessment was initiated in spring 2017, with a proposed rule due in 2019.

This synthesis of available information on yellow-cedar has been prepared at the request of the Alaska Department of Fish and Game's (ADFG) Threatened, Endangered, and Diversity (TED) Program. Through the TED program, ADF&G coordinates the State of Alaska's response to ESA issues, and this synthesis will provide the most recent information necessary for the State of Alaska's comments to the FWS regarding yellow-cedar status.

The existing literature, including peer-reviewed publications and unpublished reports, was reviewed and compiled into a comprehensive bibliography (Appendix A). The review included studies of yellow-cedar throughout its range, but primarily within Alaska. In addition, telephone interviews were conducted with several yellow-cedar researchers (Appendix B), and their input was incorporated into the synthesis. Updated information presented at the recent symposium (Yellow-Cedar Biology, Ecology, and Emerging Knowledge, Juneau, AK, 24-25 October 2017) has also been included. The synthesis specifically addresses the 5 factors that are the basis for making a listing decision under section 4(a)(1) of the ESA:

A. the present or threatened destruction, modification, or curtailment of its habitat or range
B. overutilization for commercial, recreational, scientific, or educational purposes
C. disease or predation
D. the inadequacy of existing regulatory mechanisms
E. other natural or manmade factors affecting its continued existence

TAXONOMY AND NAMING

Yellow-cedar is a member of the Cupressaceae (cypress) family, which includes junipers, cypresses, and false-cedars. Like most species in this family, yellow-cedar has small scale-like leaves and lacks distinct buds enclosed by bud scales. The other *Cupressaceae* that occur in Alaska are western redcedar (*Thuja plicata*), common juniper (*Juniperus communis*) and creeping juniper (*J. horizontalis*).

Yellow-cedar was named by its discoverer, David Don, as a member of the genus *Cupressus*. It was later reclassified as *Chamaecyparis* (Spach 1842) and eventually transferred to the genus *Callitropsis* (Oersted 1864), but both genus names were in use until recently (early 2000s). The currently accepted scientific name is *Callitropsis nootkatensis*; the specific epithet reflects the original discovery of the species in Nootka Sound. The common name yellow-cedar is used in most recent scientific publications by U.S. researchers. According to naming convention, the hyphen is required because the species is not a true cedar. The common name officially accepted by the U.S. Forest Service (FS) is Alaska-cedar, although greater acreage and volume of the species occur in British Columbia. Several other common names are, or have previously been, in use for the species, including Nootka cedar, canoe-cedar, and Alaska yellow-cedar. In Canada, the species is commonly called yellow-cedar, yellow cypress or sometimes simply cypress. Alaska native names include xáay (Tlingit), sgahláan (Haida), and walh (Tsimshian). These spellings vary somewhat among sources, since the languages are traditionally unwritten (information in this paragraph is largely from Hennon et al. 2016).

RANGE AND DISTRIBUTION

The natural range of yellow-cedar extends along the Pacific Coast from northern California as far north as Prince William Sound in Alaska, spanning 20° of latitude and covering approximately 56,000 km^2 (Buma et al. 2016; Hennon et al. 2016). The distribution is mainly coastal, with the bulk of the population in British Columbia (BC) and Southeast (SE) Alaska. Yellow-cedar is widely distributed in most of SE Alaska, except in the northeastern portion around Hoonah (on Chichagof Island), Admiralty Island, the Juneau area, and Lynn Canal (Hennon et al. 2012; Hennon et al. 2016). Yellow-cedar does occur in this region, but the species is absent or rare over large areas of apparently suitable habitat (Barrett and Christensen 2011;

Hennon et al. 2016; Krapek et al. 2017). The relative rarity of yellow-cedar in the northeastern panhandle of SE Alaska may indicate that the species is still in the process of migrating into the area from Pleistocene glacial refugia in the outer coastal area (Buma et al. 2016; Hennon et al. 2006; Krapek 2016; Krapek et al. 2017). Two small, disjunct populations are known to occur in interior areas of Oregon and British Columbia (Hennon et al. 2016).

Within Alaska, yellow-cedar occurs at elevations from sea level to near timberline, with the peak of abundance at mid-elevation (Barrett and Christensen 2011; Caouette et al. 2016; Hennon et al. 2016). This pattern of distribution varies from the southern part of the range, where yellow-cedar is most abundant at relatively high elevations, to its northern extent, where the species occurs at lower elevations, down to sea level (Harris 1990).

ECOLOGY OF YELLOW-CEDAR

Yellow-cedar is a slow-growing, long-lived species; mature trees are commonly 500–750 years old (Laroque and Smith 1999), and some individuals may live for over 1,000 years (Harris 1990; Hennon et al. 2016; Krapek et al. 2017). The wood is extremely decay-resistant, and dead trees (snags) typically remain standing for up to 80–100 years (Hennon et al. 1990c; Kelsey et al. 2005). Natural regeneration of yellow-cedar is constrained by factors including limited cone production, low seed viability and germination rates, and vulnerability of seedlings to freezing injury (Hennon et al. 2016). Seed dispersal distances are short, seedlings are never abundant, and their density in a stand is closely related to the basal area of mature yellow-cedar (Hennon and Shaw 1994).

Yellow-cedar is rarely seen in pure stands; it typically grows in mixed forests with other conifers, including Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), mountain hemlock (*T. mertensiana*) and shore pine (*Pinus contorta*). In Alaska it occurs predominantly in the western hemlock–yellow-cedar forest series, but is also found in the mixed conifer, mountain hemlock, western hemlock, shore pine, and other series (Hennon et al. 2016). The species typically reaches its highest relative abundance (as proportion of stand) on relatively poorly drained, shallow, nutrient-poor soil (Martin et al. 1995; Hennon and Shaw 1997; D'Amore and Hennon 2006; D’Amore et al. 2009), where there is less competition from more rapidly growing species. On these marginal sites, yellow-cedar develops a network of shallow, fine roots, promoting uptake of nutrients when they are available (D'Amore et al. 2009). Yellow-cedar is capable of growing more rapidly and attaining greater size on more productive sites, but it is not a strong competitor with the other conifer species that usually dominate these sites (Klinka 1999; Hennon et al. 2016).

YELLOW-CEDAR DECLINE

Dieback of yellow-cedar (yellow-cedar decline) has been occurring at least since the 1880s (Hennon et al. 1990b) and was first reported in SE Alaska in 1909 (Beier et al. 2008). Areas of mapped decline extend from approximately northern BC to Chichagof Island in SE Alaska (D'Amore and Hennon 2006; Buma et al. 2016; Hennon et al. 2016). Yellow-cedar decline has not been detected in forests further south or north within the species' range (Hennon and Trummer 2001; Oakes et al. 2015; Hennon et al. 2016). Barrett and Christensen (2011) noted that producing maps and GIS layers for healthy yellow-cedar forests has proven difficult, because aerial surveys and other forms of remote sensing cannot easily distinguish healthy cedar trees from hemlocks and other species in mixed-species forests. They stated that there was no reliable information on the current distribution of healthy yellow-cedar forests, to put the decline issue into spatial context. However, recent mapping efforts have greatly increased understanding of the overall distribution of yellow-cedar in SE Alaska (Ellenwood 2015).

Research on the cause of tree death began in 1981 (Shaw et al. 1985), but the mechanism was not well understood until the last decade or so (D'Amore and Hennon 2006; Schaberg et al. 2008, 2011; D'Amore et al. 2009; Hennon et al. 2016). Potential biotic causes that were studied and ruled out, as summarized by Hennon et al. (2006) included higher fungi (Hennon 1990; Hennon et al. 1990a); oocmycetes (Hamm et al. 1988; Hansen et al. 1988); insects (Shaw et al. 1985); nematodes (Hennon 1986), viruses and mycoplasmas (Hennon 1999); and bears (Hennon et al. 1990a). Several early studies noted that decline occurred mainly on sites with saturated soil (Hennon et al. 1990c; Hennon and Shaw 1994; Johnson and Wilcock 2002). D'Amore and Hennon (2006) concluded that yellow-cedar decline was not associated with soil acidity, or with concentrations of aluminum (Al) or calcium (Ca) or the Al:Ca ratio. The same study found that soil saturation was not directly linked to the occurrence of yellow-cedar decline, but that an indirect relationship appeared likely. Highly saturated soils were associated with low canopy cover, resulting in wider variation in both air and soil temperatures, and potentially leading to early dehardening of roots followed by freezing damage. The following description of the current generally accepted mechanism of yellow-cedar decline is taken mainly from Hennon et al. (2016), with other sources as noted.

On poorly drained sites, yellow-cedar has shallow fine roots, an adaptation for nutrient uptake. These fine roots are less cold hardy compared with roots of other species (Schaberg et al. 2005; Grossnickle and Russell 2006) and tend to lose hardiness early in spring at relatively low temperatures (Hawkins 1993; Puttonen 1994; Grossnickle and Russell 2006). These adaptations allow yellow-cedar roots to begin taking up nutrients early in spring when soil thaws, but make them vulnerable to damage if temperatures in the upper soil horizon drop below about -5°C (Schaberg et al. 2005; 2008). Tree death may follow rapidly, but more typically requires 10–15 years and several root-freezing events, particularly for mature trees (Hennon et al. 2016). Late-winter cold periods with the potential to cause freezing injury occur during most winters in SE Alaska (Beier et al. 2008, Hennon et al. 2016).

Throughout much of yellow-cedar's range in Alaska, snow cover has historically been adequate to protect these shallow roots from freezing damage during periods of cold weather. Since approximately 1900, the climate of Southeast Alaska has warmed, resulting in more early thaws and reduced snow cover (Beier et al. 2008; Hennon et al. 2012, 2016). However, the periods of freezing weather in late winter are caused by cold fronts originating east of the coastal mountains (Beier et al. 2008; Hennon et al. 2012, 2016), and their frequency has not changed over the past century (Beier et al. 2008, Hennon et al. 2016). In areas with little or no snowpack, periods of cold weather in late winter may result in freezing injury to roots and eventual tree mortality (Beier et al. 2008; D'Amore et al. 2009; Hennon et al. 2012, 2016; Buma et al. 2016). Based on examination of growth rings of yellow-cedar at several sites in Southeast Alaska, Beier et al. (2008) found decreased growth of yellow-cedar in years with thaw-freeze events, suggesting freezing damage to roots. In a study covering the entire range of the species in Alaska, Caouette et al. (2016) found that dead yellow-cedar tended to occur at lower-elevation sites, while live trees, seedlings, and saplings were found at higher elevation sites, where snow cover was presumably deeper.

ESA LISTING FACTORS

The following sections review the available literature on yellow-cedar that is relevant to each of the 5 factors used by FWS in evaluating petitions. In the 90-day finding, FWS found that the petition presented sufficient information indicating that listing may be warranted for yellow-cedar based on Factors A, B, and E.

FACTOR A—HABITAT DESTRUCTION, MODIFICATION, OR CURTAILMENT

Spatial Considerations

The degree to which yellow-cedar populations have been affected by habitat change varies widely across the species' extensive range. Mortality is widespread in some regions, while healthy stands persist in others, and even severely affected stands include some healthy trees. In some areas of SE Alaska where yellow-cedar thrived prior to the end of the Little Ice Age (approximately 1880), the habitat has been modified by a changing climate, apparently resulting in conditions that are no longer optimal for the species. Over much of this region, winter temperatures are typically around 0°C, so relatively small changes in temperature can determine whether precipitation falls as rain or snow. In most years, brief periods of much colder weather occur during late winter (Beier et al. 2008), when yellow-cedar roots may have already dehardened. If snow cover is lacking during these cold spells, soil temperatures may drop below -5°C, potentially resulting in freezing damage to roots.

Weather records are available for SE Alaska since approximately 1900. Since then, winter temperatures at some locations have warmed just enough to cause precipitation to fall as rain rather than snow. These areas match up well with areas where yellow-cedar decline has occurred over this period. In SE Alaska, the spatial pattern of yellow-cedar decline was closely associated with the lowest snow zone, based on a regional snow accumulation model (Hennon et al. 2006, 2008). Using the same model, Beier et al. (2008) reported that in 4 zones of snow accumulation, 79% of yellow-cedar decline occurred in the lowest snow accumulation zone, and 94% occurred in the lowest 2 zones. Buma et al. (2016) reported that mortality was most likely in areas where the mean winter (coldest 3 months) temperature was near 0°C. Yellow-cedar forests appear healthy in areas of Alaska with high annual snow accumulation, including the northeastern panhandle, Glacier Bay forelands, and Prince William Sound (Hennon and Trummer 2001).

Yellow-cedar decline is also not known to occur south of approximately 51° N (Westfall and Ebata 2014), where late-winter weather is rarely cold enough to result in soil temperature below -5°C.

Within mapped areas of yellow-cedar decline, approximately 70%–80% of the basal area of yellow-cedar is typically dead (D'Amore and Hennon 2006; Oakes et al. 2014; Barrett and Pattison 2017). Patches with lower concentrations of dead trees may exist within these mapped areas, but are difficult to distinguish from healthy forests from the air or on aerial photographs (Hennon et al. 2016) and are likely to be mapped as healthy. Affected stands typically include a mixture of long-dead, recently dead, dying, and surviving trees; suggesting that mortality has been occurring for many years and is continuing (Hennon and Shaw 1997; Hennon et al. 2012). Most mature yellow-cedar trees, whether alive or dead, established and grew to canopy status during the Little Ice Age (Hennon and Shaw 1994; Hennon et al. 2006; Beier et al. 2008). Because of the highly decay-resistant properties of the wood, dead yellow-cedar trees (snags) often remain standing for 80–100 years (Hennon et al. 1990c, 2016; Kelsey et al. 2005). A snag classification system based on retention of foliage, twigs, and branches (Hennon et al. 1990c; Stan et al. 2011) allows the age (i.e., time since death) of standing dead trees to be estimated. Older snags are often found on the wettest portion of a site, while more recently dead or dying trees are on better-drained areas at the perimeter of the affected stand, indicating a slowly spreading pattern along a hydrology gradient (Hennon et al. 1990c). The surviving trees, released from competition, generally show good growth in the post-decline stage (Beier et al. 2008).

There is considerable disagreement about the spatial extent of yellow-cedar decline, due at least in part to the use of different survey methods. The areas occupied by the species are vast and largely inaccessible, so estimates necessarily rely on sampling and estimation. Aerial surveys, where observers sketch areas of decline from an aircraft, tend to yield coarse outlines that include areas with varying degrees of decline. Interpretation of aerial photographs can give more precise boundaries, but likely fails to identify areas of decline in low-volume forests (Hennon et al. 2016). Aerial surveys may also underestimate the occurrence of healthy yellow-cedar, which are difficult to distinguish from other species. However, Hennon and Wittwer (2013) reported that high-resolution map layers for selected areas, derived from aerial photo interpretation, aligned strongly with the mapping based on aerial surveys. Ground-based studies based on plot data from the FS's Forest Inventory and Analysis (FIA) program have provided more detailed information (Barrett and Pattison 2017), but may have some biases due to the limited number of plots and inaccessibility of some portions of the species' range (Bidlack et al. in press). For example, since 2005 the FIA surveys have not covered wilderness areas managed by the FS (Hennon et al. 2016, T. Barrett, pers. comm.), where some extensive areas of decline are known to exist (Oakes et al. 2014).

Several studies, using different approaches, have estimated that 175,000–275,000 ha in Alaska are affected by yellow-cedar decline, generally with >70% of the basal area dead (Wittwer 2004; Hennon et al. 2012, 2016; Buma et al. 2016; Barrett and Pattison 2017). This represents approximately 7-8% of the total area of yellow-cedar forest (i.e., forest with a substantial yellow-cedar component) in the state (Ellenwood et al. 2015; Buma et al. 2016). More recent studies, not yet published, indicate that the area affected by decline is closer to 12% of yellow-cedar forest in Alaska (B. Buma, pers. comm.). The studies do not agree completely on how the affected areas are distributed spatially. In particular, Barrett and Pattison (2017) state that only 4,000–12,000 ha (68% CI) within the previously mapped decline area had over 70% of the basal area of yellow-cedar in snags. However, they found large areas with declining yellow-cedar outside the previously mapped boundary, so their estimate of the total area of decline in Alaska (175,000 ha) was similar to those of other studies. In a range-wide study of yellow-cedar decline, Buma et al. (2016) found that mortality was concentrated in the northern half (10° of latitude) of the species' range, but was absent in the small populations at the extreme northern edge. In some areas (56–57° N), the percentage of yellow-cedar forest affected was as high as 17%. However, large areas of coastal forest in Alaska currently lie outside the range of yellow-cedar decline (Hennon et al. 2016), and mortality of yellow-cedar is very low in these stands (Hennon and Trummer 2001; Oakes et al. 2015).

Hennon et al. (2006, 2008) examined the spatial pattern of yellow-cedar decline at three scales. At the largest scale (based on aerial surveys), the distribution of mortality was closely associated with the zone of lowest snow accumulation. At the mid-scale, mapped polygons with decline were concentrated at lower elevation (below 150 m), with moderate decline between 150 and 300 m, and low amounts of decline above 300 m. Decline occurred on all slope aspects, but was found more frequently on south and southwest facing slopes. At the fine scale (small watershed), the decline was more common on sites with saturated soils, greater daily temperature fluctuations (associated with low canopy cover), and lower snowpack. The complex spatial pattern of yellow-cedar decline appears to result from a combination of a broad-scale mortality driver (lack of snow combined with late-winter cold spells) with heterogeneity in finer-scale factors that may increase or decrease the probability of tree deaths.

Barrett and Pattison (2017) concluded that yellow-cedar in Alaska is not undergoing range contraction, because very few of the FIA plots they examined contained snags but no live trees. In their study, a live tree was defined as one with any live branch above breast height. However, Bidlack et al. (in press) point out that this criterion (i.e., 100% mortality) for range contraction may be inappropriate, since 10-35% of trees typically remain alive (by the above standard) even in severely affected stands where significant impacts on regeneration and future stand composition can be expected.

Temporal Considerations

There is general agreement that elevated mortality of yellow-cedar began around 1880–1900 and continued at least into the 1990s, peaking in the 1970s and 1980s (Hennon and Shaw 1994). Barrett and Pattison (2017) concluded that no major mortality or decline was observed over the course of their study (1995–2013). However, other researchers have reported evidence of additional decline more recently (Oakes et al. 2014; Mulvey et al. 2015a,b; Dubois and Wurtz 2017; B. Buma pers. comm.).

Predicting the extent and rate of future yellow-cedar decline depends largely on using regional climate models to predict winter temperatures and snow accumulation. Some models predict that by 2070 approximately 75% of yellow-cedar forests in Alaska will experience mean winter temperatures above -2°C (B. Buma pers. comm.), while the corresponding figure over the species' entire range is 50% (Buma et al. 2016). Current temperature and snow patterns suggest that this will result in loss of snowpack in these areas. If periods of cold weather occur in late winter in areas with little or no snow, yellow-cedar roots may be damaged by freezing. No modeling currently exists, however, to predict changes in the occurrence of late-winter cold spells (Buma et al. 2016). As climate has warmed over the past century, the frequency of these cold spells has not changed appreciably (Beier et al. 2008). Some recent modeling assumes that late-winter cold spells will eventually become less common as the climate continues to warm; if so, the risk of freezing injury will be reduced even in snow-free areas, and populations of yellow-cedar may rebound in areas that have experienced decline (B. Buma, pers. comm.).

FACTOR B—OVERUTILIZATION

Prior to the 1990s, only small quantities of yellow-cedar were harvested on the Tongass National Forest, as most logging occurred on high productivity, low-elevation sites where the species is not common. Since the late 1990s, harvesting has been occurring on a wider range of sites, including some lower-volume stands with a substantial component of yellow-cedar (Hennon et al. 2016). Until recently yellow-cedar was considered the most commercially valuable tree species harvested in Alaska (Carstensen and Christensen 2008; Hennon et al. 2016). Regulations allow the export of unprocessed yellow-cedar from federal lands, unlike other wood species. Most yellow-cedar is exported to Asia, particularly Japan, where it is in high demand and brings premium prices (Hennon et al. 2016). Other tree species from federal lands may be shipped unprocessed to the lower 48 states, but not overseas. Western redcedar also has a relatively high value, whereas the value of spruce is substantially lower, and hemlock has negative value (i.e., its current selling price does not offset the cost of harvesting). Changes in the Asian market since 2016 have resulted in decreasing prices for yellow-cedar, which is currently less valuable than red cedar (B. Kleinhenz, pers. comm. [October 2017 workshop]).

Estimates of the proportion of yellow-cedar in the growing stock on timberlands in coastal Alaska range from 6% (Berg et al. 2014) to 10% (Hennon et al. 2016, based on 2008 FIA data). The percentage of redcedar is likely somewhat lower; FIA data from 2000 indicated that yellow-cedar constituted 9% of the net volume of growing stock, while 6% consisted of redcedar (van Hees 2003). Given the high value of these relatively uncommon species, in some instances they may be specifically targeted for timber sales. On federal lands, timber sales cannot legally be advertised unless they are expected to be profitable, so relatively large amounts of the more valuable species are needed to compensate for the essentially valueless hemlock. Carstensen and Christensen (2008) stated that sales of redcedar and yellow-cedar drive most timber sales in the central and southern Tongass National Forest, because of their high value relative to other species. The authors stated that as of 2008 only about 10% of cuts occurred above 1000 feet elevation, but that the pattern was changing rapidly, partly because yellow-cedar is concentrated at higher elevations. This report was listed in the 90-day finding as one of the sources supporting Factor B (overutilization). According to the petition, the percentages of yellow-cedar and redcedar in the timber harvest from the Tongass exceeded their proportions in the growing stock, but this statement was based on data obtained prior to 2002. Although the Tongass National Forest contains approximately 80% of the timberland in SE Alaska, timber harvests on National Forest lands accounted for an average of only 20% (range 11.6–24.9%) of the total Alaska timber harvest during 2002–2011 (Zhou 2013). In 2015, sales from National Forest lands represented 22% of total timber sales in Alaska (Marcille et al. 2017). Sales from the Chugach National Forest are included in these totals, but nearly all (>99%) of the timber sold from National Forests in Alaska comes from the Tongass.

The overall timber harvest in Alaska decreased from 1,033 million board feet (MMBF) in 1990 to 268.3 MMBF in 2001 (Halbrook et al. 2009, as cited in Berg et al. 2014). From 2002 to 2011, the total harvest varied between 117.9 and 276.1 MMBF (Zhou 2013), with the harvest for 2011 recorded as 175.3 MMBF (Berg et al. 2014; Zhou 2013). By 2015 the total statewide timber harvest had declined to 136.4 MMBF (Marcille et al. 2017). Yellow-cedar constituted approximately 1% of the total Alaska timber harvest in 2011 (Berg et al. 2014) and 1.2% in 2015 (Marcille et al. 2017).

Based on FIA plot data, Barrett and Christensen (2011) found that net live tree biomass of yellow-cedar did not change significantly between the 1995–1998 and 2004–2008 inventories. They estimated the average harvest rate of trees >5 inches in diameter at 0.04%, while natural mortality was 0.3%. Van Hees (2003) stated that average annual growth exceeded annual mortality for the Alaska cedar-hemlock (ACH) forest type, but did not present data for individual tree species.

Based on the data available, yellow-cedar is probably not over-represented in the total timber harvest from Southeast Alaska; i.e., the species makes up a lower percentage of the harvest than of the growing stock of timber. However, this does not necessarily mean that the species is not being overutilized; overutilization is assumed here to mean that the harvest exceeds the mean annual growth (increase in growing stock). A simplified calculation to determine whether overutilization is occurring in a given year would require the following information:

- current growing stock of yellow-cedar in Alaska (cubic feet)
- annual net growth rate of yellow-cedar (percent)
- total timber harvest (cubic feet)
- proportion of yellow-cedar in harvest (percent)

We found it difficult to obtain the needed data in consistent units that would allow accurate estimation of all these quantities. Sample calculations, based on the most appropriate information we were able to obtain, are shown in Table 1. Updated, accurate data would be required in order to determine whether yellow-cedar is being harvested at an unsustainable level (overutilized). In particular, an accurate estimate of the annual percentage growth rate of yellow-cedar is needed. The preliminary value below is based on an annual growth rate of 0.4% for Alaska-cedar hemlock forest (van Hees 2003), and the assumption that the growth rate for the slow-growing yellow-cedar is half of that for mixed forest with the faster-growing hemlock. Discussion at the symposium in October 2017 indicated that the numbers in this preliminary table were reasonable. However, more accurate data could be obtained from industry and agency sources if needed to update the estimates.

Table 1. Annual growth and harvest of yellow-cedar in Alaska. Growing stock and annual growth rate from van Hees (2003); total timber harvest 2002–2011 from Zhou (2013); total timber harvest 2015 and proportion of yellow-cedar in harvest from Marcille (2017).

	Growing stock of yellow-cedar (K cu ft)	Annual growth rate (%)	Annual growth (K cu ft)	Total timber harvest (K cu ft)[1]	Proportion of yellow-cedar (%)	Harvest of yellow-cedar (K cu ft)	Net growth (growth – harvest) (K cu ft)
Average 2002–2011	1,930,000	0.2	3,860	15,708	1.2	189	3,671
2015	1,930,000	0.2	3,860	11,367	1.2	136	3,724

[1] Harvest rates were reported in board feet, and were multiplied by 12 to convert to cubic feet.

FACTOR C—DISEASE OR PREDATION

As noted previously, diseases and insect pests are not primary causes of yellow-cedar decline (Hennon et al. 2006). Yellow-cedar wood is defended against insects and pathogens by high levels of secondary compounds, which also give the wood its distinctive color and odor (Hennon et al. 2016). These compounds are also present in the needles, but at lower concentrations in young foliage, leaving it more vulnerable to herbivory by insects and mammals (Hennon et al. 2016). Bark beetles (*Phloesinus* spp.) are frequently found in yellow-cedar stands that are suffering from decline (Hennon et al. 2016; Mulvey et al. 2015a) and may accelerate tree mortality (Mulvey et al. 2015b). A shoot blight fungus (*Kabatina thujae*) can damage and even kill young seedlings, but apparently does not affect mature trees (Hennon et al. 2016). A root disease fungus (*Armillaria* sp.) is commonly found on dead or dying yellow-cedar (Hennon 1990; Mulvey et al. 2015a), but does not damage healthy trees (Hennon et al. 2016). Some specialized fungi are able to attack the heartwood of live yellow-cedar and cause significant decay, but little is currently known about the extent of mortality from this cause (Hennon et al. 2016). Many fungi can attack yellow-cedar sapwood, which does not contain high concentrations of defensive compounds, but these fungi occur mainly in trees that have been killed by other causes (Hennon 1990; Hennon et al. 2016).

Brown bears (*Ursus arctos*) can cause significant damage to mature yellow-cedar trees, by stripping bark to feed on the sugary phloem tissue (Hennon et al. 2016). In some locations with high densities of bears, up to half the trees may be scarred (Hennon et al. 1990a), but there is no evidence that bear damage contributes to yellow-cedar decline (Hennon et al. 2016).

Browsing by Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) may be limiting regeneration of yellow-cedar in both healthy and declining forests in some areas with high densities of deer (Martin et al. 1995; Martin and Baltzinger 2002). In a planting trial on Prince of Wales Island, over 95% of yellow-cedar seedlings were damaged or killed by deer (Hennon et al. 2016). In the same study, no browse damage was recorded at a site near Juneau, where deer densities were lower and winter snow cover protected seedlings for part of the winter. Oakes et al. (2014) noted that the relatively high abundance of yellow-cedar seedlings and saplings in plots in the Glacier Bay area may have been partially due to their location at the northern limit of distribution for Sitka black-tailed deer.

FACTOR D—INADEQUACY OF EXISTING REGULATORY MECHANISMS

The petition to list yellow-cedar as endangered or threatened asserts that failure by the United States (U.S.) government and the international community to adequately regulate greenhouse gas emissions is resulting in climate change, which places yellow-cedar at ever-increasing risk of extinction. As reviewed under Factor A, yellow-cedar decline does appear to be related to climate change, specifically reduced snow cover due to warmer winter temperatures. However, the decline began at the end of the Little Ice Age (around 1880), well before the onset of human-caused climate change. In addition, freezing damage to roots occurs only when lack of snow cover in late winter coincides with a period of cold weather. The warming climate in Southeast Alaska has resulted in decreased snowpack at some locations, but the frequency of late-winter cold spells has not changed (Beier et al. 2008). These periods of freezing temperatures are caused by high pressure fronts originating from the arctic mainland, (Beier et al. 2008), and no modeling currently exists to predict how their frequency may change in response to future climate change (B. Buma, pers. comm.). The potential effects of climate on yellow-cedar were reviewed under Factor A—Habitat Destruction, Modification, or Curtailment.

The petition also states that existing regulations governing the management of National Forest lands do not adequately protect yellow-cedar from over-harvesting. While there is evidence that yellow-cedar is targeted for harvest within the Tongass National Forest, it does not appear that, overall, the species is being harvested at an unsustainable level. The available information on the balance between harvest and growth rates of yellow-cedar was reviewed under Factor B—Overutilization.

FACTOR E—OTHER NATURAL OR MANMADE FACTORS

Limitations to regeneration were mentioned in both the petition and the 90-day finding as a potential additional factor affecting the continued existence of yellow-cedar. Yellow-cedar is a long-lived species with a defensive life-history strategy that does not depend on prolific reproduction. Even in healthy stands, natural regeneration is limited by irregular seed crops, low cone production, low rates of seed viability and germination, short dispersal distance, poor competitive ability, and preferential browsing by wildlife (Hennon and Shaw 1994; Krapek and Buma 2015; Hennon et al. 2016; Krapek 2016). In the plots studied by Hennon and Shaw (1994), seedlings were never frequent, and their density closely tracked basal area of mature yellow-cedar in the stand. Most seedlings were <3 years old, and saplings were rare in stands with moderate-to-high basal area. They found that poor reproduction was independent of yellow-cedar decline, with relatively good reproduction in some severely affected stands. In contrast, Oakes et al. (2014) documented lower abundance yellow-cedar of seedlings in stands affected by decline, compared to healthy forests. The same study found decreased importance value (sum of density, frequency, and total basal area) of yellow-cedar saplings in declining stands. Barrett and Christensen (2011) reported that the ratio of live saplings to live trees was highest at elevations above 2,000 ft, suggesting that regeneration was more successful at higher elevations. In some cases, it appears that limited regeneration capacity after decline may result in successional change toward a community with reduced importance of yellow-cedar (Oakes et al. 2014).

A related question is the extent to which yellow-cedar may be able to expand into currently unoccupied locations, thus compensating for areas of habitat that may have become unsuitable due to changes in climate. Within the northeastern portion of the Alaska Panhandle, large areas of apparently suitable habitat are currently not occupied by yellow-cedar (Barrett and Christensen 2011; Krapek et al. 2017). Yellow-cedar most likely colonized its current range from glacial refugia in the southwestern part of the Panhandle, and this migration is apparently not yet complete, due to the species' limited seed dispersal and capacity for regeneration (Hennon et al. 2006; Barrett and Christensen 2011; Krapek et al. 2017). A recent study in the Juneau area concluded that the sampled stands had established during a period of favorable conditions during the Little Ice Age, with limited migration since that time (Krapek et al. 2017). The authors concluded that the rate of northward migration of yellow-cedar is not sufficient to offset the northward spread of yellow-cedar decline.

Several authors have discussed possible management approaches to promote long-term survival of yellow-cedar in Alaska. To reduce impacts from harvesting, it may be possible to meet some of the demand by salvaging dead wood from decline-affected stands. Due to the extreme decay resistance of yellow-cedar heartwood, it remains comparable in quality (strength, decay resistance, etc.) for decades after death (Green et al. 2002; Kelsey et al. 2005; Hennon et al. 2007 [all cited in Hennon et al. 2016]). Wood from older (more than 25 years after death) snags, however, lacked the distinctive color and odor of wood from live trees (Kelsey et al. 2005 [cited in Hennon et al. 2016]). Some decline-affected stands contain mainly smaller trees that may not be worth salvaging; cost-effective salvage logging would probably require roads to areas with high concentrations of relatively large, recently dead yellow-cedar (Hennon et al. 2016).

Opportunities exist to promote regeneration of yellow-cedar in post-harvest stands (Hennon et al. 2012). Most timber harvesting in SE Alaska has occurred on productive sites with relatively deep, well-drained soils. Yellow-cedar is capable of thriving on these sites, but must be actively managed (e.g. planting, thinning) or it will be outcompeted by western hemlock and/or Sitka spruce. In addition, it may be possible to establish yellow-cedar in areas of suitable habitat that are currently unoccupied through assisted migration (planting). For example, a planting trial near Yakutat resulted in first-year survival of over 90% of yellow-cedar seedlings (Hennon et al. 2012). Whether on post-harvest sites or new areas, the main potential barriers to artificial regeneration are competing species, browsing by deer, and spring freezing injury (Hennon et al. 2006).

CONCLUSIONS

The current extent of yellow-cedar decline, if conditions were stable, would not indicate a serious threat to survival of the species. Depending on the source of information, between 8 and 12% of the species' range in Alaska is affected by decline, with 20–30% of trees (by basal area) surviving in most affected areas. However, recent research indicates that decline is continuing to occur, with new areas of decline being discovered and additional mortality in stands that have already been affected. Climate models predict that additional areas, particularly at higher elevations and in the northern part of the range, are likely to be affected in the future (Oakes et al. 2015; Buma et al. 2016; Hennon et al. 2016). Recent modeling predicts that by 2070, 75% of yellow-cedar's range in Alaska will experience winter temperatures above -2°C (B. Buma, pers. comm.), potentially exposing roots to freezing injury if periods of cold weather occur in late winter. No climate modeling currently exists to predict the future occurrence of these cold spells; their frequency has not changed as the climate has warmed over the past century. In addition, because of variation in microsite characteristics, the distribution of yellow-cedar decline is patchy even within areas exposed to the combination of minimal snowpack and late-winter cold periods. Thus, although it appears likely that the extent of yellow-cedar decline will increase substantially over the next 50–100 years, exact prediction is difficult due to the uncertainties associated with climate models and the spatial distribution of microsites providing conditions where yellow-cedar may persist. Healthy stands of yellow-cedar exist in areas where the conditions that cause root freezing damage are not expected to occur (e.g., the extreme southern and northern portions of the species' range) and healthy individuals persist in even severely affected stands.

Levels of timber harvest are an important consideration in assessing the current and future status of yellow-cedar in Alaska. Currently, yellow-cedar has been harvested on only about 6% of the land area within the Tongass National Forest (D. D'Amore, pers. comm.). There is some evidence that yellow-cedar may be over-represented in the timber harvest from National Forest lands, which has accounted for approximately 20% of the total Alaska harvest in recent years. However, it does not appear that yellow-cedar makes up a disproportionate share of the total statewide timber harvest. Preliminary calculations suggest that the current harvest is well below the sustainable level (i.e., relative to annual growth), but this estimate should be revised with updated input data. If the extent of yellow-cedar decline increases over time, the total annual growth will presumably decrease, which would decrease the harvest levels that can be sustained. To assess whether overutilization is a potential threat to yellow-cedar in Alaska, more complete data will be required regarding standing stocks, annual growth rates, and annual harvest rates on both publicly and privately owned forest lands. In particular, additional information is needed about the 80% of Alaska's timber harvests that occur on privately and state-managed lands. Another important consideration is the extent to which management policies and practices are directed toward ensuring harvests are sustainable. For example, the Constitution of the State of Alaska directs that all of the state's renewable resources be managed on the sustained yield principle.

The future status of yellow-cedar in Alaska will be affected by the species' limited regeneration capacity and the potential for range expansion. Recent research suggests that natural regeneration is minimal in many post-decline stands, resulting in successional change toward communities with reduced importance of yellow-cedar (Oakes et al. 2014). This suggests that stands that have been affected by decline may remain lacking in yellow-cedar indefinitely.

Successful yellow-cedar regeneration has been reported in many harvested forests, however (Hennon et al. 2016). The factors that promote or limit regeneration on harvested sites are not yet well understood, and may include a temporal component (e.g., periods of favorable or unfavorable environmental conditions (Hennon et al. 2016). Browsing by Sitka black-tailed deer can significantly reduce the success of yellow-cedar regeneration in some areas.

Yellow-cedar appears to have migrated into its current range from glacial refugia along the coast, and seems likely to continue migrating northward and eastward. However, migration appears to be episodic, as well as limited by short seed dispersal distances, and therefore is unlikely to offset the expansion of areas affected by decline (Hamann and Wang 2006; Krapek et al. 2017).

Overall, there seems to be a consensus among yellow-cedar researchers that extirpation of the species is not expected in the foreseeable future (50–100 years). Although the causes of the decline phenomenon are now better understood, and several research programs have provided a great deal of information about the species, predicting the future of the species in Alaska will depend on several key questions:

- As the climate in the region continues to change, what additional areas within yellow-cedar's current range will experience snow-free winters?
- How will the frequency and spatial distribution of late-winter cold periods change over time?
- How much yellow-cedar is being harvested each year from all Alaska timber lands, and how does this harvest compare to annual growth?
- To what extent is yellow-cedar recovering (through regeneration or release) in post-decline stands?
- What factors limit or promote regeneration of yellow-cedar in post-harvest stands?
- Can timber harvests be managed to reduce or avoid the harvest of live yellow-cedar?
- What management practices could be employed to increase regeneration of yellow-cedar after harvesting, or to promote the establishment of the species in currently unoccupied areas that will provide suitable habitat in the future?

APPENDIX A.   BIBLIOGRAPHY OF ALASKA YELLOW-CEDAR LITERATURE

We compiled a bibliography of published and unpublished literature that pertains to the distribution, abundance, use, and management of yellow-cedar, primarily in Alaska. Of primary interest were sources pertaining to the 5 factors used by USFWS to make a listing determination for a species (Table A1).

Literature for this bibliography was collected from a variety of sources including ABR's literature databases and library, TreeSearch (the USFS search engine and publications repository), the UAF Goldmine catalog, and various academic search engines (most notably Google Scholar). Additional items were found through a manual search of cited literature in reports and published papers. Citations and electronic documents were entered into an EndNote database (version X7; Clarivate Analytics, Philadelphia, PA).

Sources that we were able to obtain and evaluate as relevant for this review are listed in **bold** typeface. Sources that we have not evaluated are listed in regular typeface. If sources were relevant to one or more of the 5 ESA listing factors, we noted the factor(s) below the citation.

Table A1. Factors to be used as the basis for deciding whether to list a species as threatened or endangered, under section 4(a)(1) of the Endangered Species Act.

ESA Factor	Description
A	the present of threatened destruction, modification or curtailment of its habitat or range
B	overutilization for commercial, recreational, scientific, or educational purposes
C	disease or predation
D	the inadequacy of existing regulatory mechanisms
E	other natural or manmade factors affecting its continued existence

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APPENDIX B. LOG OF INTERVIEWS WITH YELLOW-CEDAR EXPERTS

Table B1. Record of interviews conducted with experts on Alaska yellow-cedar. All interviews were conducted over the phone by Susan C. Bishop of ABR, Inc.

Interviewee	Affiliation	Date of Interview
Tara Barrett	USDA Forest Service, Pacific Northwest Research Station, Wenatchee, WA	10/02/2017
Allison Bidlack	University of Alaska Southeast, Alaska Coastal Rainforest Center	9/15/2017
Brian Buma	University of Alaska Southeast, Department of Natural Sciences	10/06/2017
Dave D'Amore	USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Juneau, AK	10/2017
Paul Hennon	USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Juneau, AK (retired)	9/20/2017
Lauren Oakes	Stanford University	9/26/2017