1   **Yellow-Cedar Blue Intensity Tree Ring Chronologies as Records of Climate, Juneau,**

2   **Alaska, USA**

3

4   Gregory C. Wiles*[1,3], Joshua Charlton[1], Rob J.S. Wilson[2,3], Rosanne D. D'Arrigo[3], Brian Buma[4],

5   John Krapek[5], Benjamin V. Gaglioti[3,6], Nicholas Wiesenberg[1] and Rose Oelkers[3]

6

7   [1]Department of Earth Sciences, The College of Wooster, Wooster, OH, USA

8   (gwiles@wooster.edu, jcharlton19@wooster.edu, nwiesenberg@wooster.edu; Tel: 330-263-

9   2298, FAX: 330-263-2249); [2]School of Earth and Environmental Sciences, University of St.

10   Andrews St Andrews, UK. (rjsw@st-andrews.ac.uk); [3]Tree Ring Lab, Lamont-Doherty Earth

11   Observatory Palisades, NY 10964, USA (rdd@ldeo.columbia.edu, bengaglioti@gmail.com and

12   roelkers91@gmail.com); [4]Department of Integrative Biology, University of Colorado, Denver,

13   1151 Arapahoe, Denver, CO 80204, USA (brian.buma@ucdenver.edu); [5]Department of Natural

14   Sciences, University of Alaska Southeast, Juneau, Alaska 99801, USA (jpkrapek@gmail.com);

15   [6]Water and Environmental Research Center, Institute of Northern Engineering, University of

16   Alaska Fairbanks, Fairbanks, AK 99775.

17

18   *Corresponding author

19

20

21

22

23

24

25

26

27

28

29

30

31

32 **Abstract**

33 This is the first study to generate and analyze the climate signal in Blue Intensity (BI) tree-ring

34 chronologies from Alaskan yellow-cedar (Callitropsis nootkatensis D. Don; Oerst. ex D.P.

35 Little). The latewood BI chronology shows a much stronger temperature sensitivity than ring-

36 widths (RW), and thus can provide information on past climate. The well-replicated BI

37 chronology exhibits a positive January-August average maximum temperature signal for 1900-

38 1975, after which it loses temperature sensitivity following the 1976/77 shift in northeast Pacific

39 climate. The positive temperature response appears to recover and remains strong for the most

40 recent decades although the coming years will continue to test this observation. This temporary

41 loss of temperature sensitivity from about 1976 to 1999 is not evident in RW or in a change in

42 forest health, but is consistent with prior work linking cedar decline to warming. A confounding

43 factor is the uncertain influence of a shift in color variation from the heartwood/sapwood

44 boundary. Future expansion of the yellow-cedar BI network and further investigation of the

45 influence of the heartwood/sapwood transitions in the BI signal will lead to a better

46 understanding of the utility of this species as a climate proxy.

47 **Key words:** Yellow cedar, blue intensity, tree rings, dendroclimatology, Alaska

48

49

50

51

52

1. Introduction:

53

54 Climate-driven, abiotic stresses are emerging as a major driver of forest decline in North

55 America (Cohen et al., 2016; Buma et al., 2017). Forest decline is defined as the loss of tree

56 vigor and eventual mortality triggered by complex biotic and abiotic factors (Manion and

57 Lachance 1992). Abiotic forest decline is a complex disorder driven by various non-living

58 physical stresses, including climate change, on a forest stand that results in growth decline and

59 can lead to mortality. Affected trees may recover once the stresses are removed. Identifying the

60 response of ecosystems to varying rates of climate change is a challenge as species may respond

61 linearly or non-linearly to anthropogenic warming as well as to the natural internal climate

62 dynamics of the North Pacific (Krapek et al., 2017). In the coastal northeast Pacific, of particular

63 interest are the Pacific related decadal fluctuations (ie., the Pacific Decadal Oscillation; PDO)

64 that dominate many aspects of the climate and ecosystems and have persisted for increasingly

65 long intervals over the observational record since CE 1900 (Boulton and Lenton, 2015; Gaglioti

66 et al., 2019). This decadal variability is superimposed on contemporary warming and has been

67 observed throughout the Little Ice Age (~CE 1250-1850; Wilson et al., 2007).

68 Decadal shifts have been recognized in climate data, climate indices and biological time

69 series (Overland et al., 2008). Determining the causes of shifts in North Pacific climate has been

70 an ongoing challenge, in part due to the large number of both instrumental and proxy time series

71 available, all of which capture different aspects of climate system on various timescales (ENSO,

72 decadal and century-scale warming). Efforts to extract the decadal signal from sea surface

73 temperature data suggest that in addition to the positive shift in PDO in 1975/76, a negative shift

74 occurred in 1998/99, although it may be too early to label this episode as a "regime shift" (Ding

75 et al., 2013; McAfee, 2014, 2016; Wills et al., 2018).

76   Here we examine the climate response of a well-replicated tree-ring chronology of

77   yellow-cedar (*Callitropsis nootkatensis* D. Don; Oerst. ex D.P. Little) composited from three

78   sites near Juneau, Alaska (Table 1, Fig. 1). Yellow-cedar is an economically and culturally

79   important species, which grows along the northwest coast of North America (Oakes, 2018;

80   Hennon et al., 2016). The wood is strong and resistant to decay, used for canoe paddles and in

81   carvings, and its inner bark is utilized for fiber in weavings. The three sites composited in this

82   study have had limited evidence of cultural modification with the exception of one of them,

83   Cedar Lake, which shows evidence of bark stripping on a few trees that have been utilized over

84   the past few decades to a century. Our three sites have been discussed in previous publications

85   including analyses of ring-width data (RW) from Cedar Lake (Beier et al., 2008) and

86   investigations of forest ecology at all three sites (Krapek et al., 2017). Krapek and Buma (2017)

87   showed that the timing of yellow-cedar establishment in these stands occurred during cool/wet

88   intervals of the Little Ice Age and that cedar could not colonize where other species out-

89   competed this long-lived, slow growing and slow migrating species.

90   Yellow cedar has been the subject of intense study primarily because of the phenomenon

91   of widespread decline of this species in southeastern Alaska, which is relatively well understood.

92   In the early 1980s, foresters (led largely by the National Forest Service in Juneau, Alaska) ruled

93   out various pathogens and other abiotic factors (Hennon et al. 2006, 2012, 2016; Schaberg et al.,

94   2008). The current leading hypothesis for the decline has been factors related to warming

95   temperatures. Earlier spring snowmelt, and the associated shift in the transition from snow to

96   rain, both lead to a loss of spring snowpack, which can contribute to freezing of rootlets and to

97   decline. Snowpack provides insulation from cold surface air temperatures, protecting vulnerable

98   small roots from frost events especially when shallow root dehardening occurs in wet soils

99   (Schaberg et al., 2008, 2011; Hennon et al. 2012, 2016). Extensive work has been done testing

100   this hypothesis and exploring the forest dynamics and ecology associated with the decline

101   (Oakes et al., 2014, 2015; Krapek and Buma, 2017; Krapek et al., 2017) driven by concerns of

102   species loss and determination of whether the species is endangered (Buma et al., 2017; Barrett

103   and Pattison, 2017, Bidlack et al., 2017).

104   Dendroclimatic studies of RW in southeast Alaska have shown that the growth response

105   of yellow-cedar can be spatially and temporally complex (Beier et al., 2008; Wiles et al., 2012)

106   and, in general, results have not been promising for climate reconstruction. Beier et al. (2008)

107   analyzed RW from declining cedar sites in southeast Alaska and from the healthy stand at Cedar

108   Lake, one of our study sites. At Cedar Lake, they noted a general decrease in RW over the past

109   several decades, whereas at sites that were experiencing substantial decline and tree death,

110   farther to the southeast of Juneau, a reduced-competition growth release in surviving trees was

111   detected. Another RW study examined two healthy yellow-cedar stands in Glacier Bay National

112   Park and Preserve (Wiles et al., 2012). This latter work showed a marked nonstationary response

113   to climate with a notable shift in temperature sensitivity from positive (more growth with warmer

114   temperatures) to negative (less growth with warmer temperatures) after CE 1950, presumably as

115   warming occurred (Wiles et al. 2012). Wiles et al. (2012) also documented decreased radial

116   growth for decades but without any visible evidence of decline in the crowns of the trees.

117   Similarly, Hennon et al. (1990) observed a decrease in RW, sometimes for decades, prior to

118   noticeable decline in the outward appearance of the trees.

119   In a regional study examining yellow-cedar health across its entire range (Buma et al.,

120   2017) identified a critical threshold of mean winter temperatures above 0°C as snow turns to rain

121   (Buma et al., 2017) and rootlets become more susceptible to frost damage. Once winter

122   temperatures sufficiently warm, frosts may be less frequent and snowpack will not be as crucial a

123   factor in protecting root systems. This appears to be the case at the southern range of yellow-

124   cedar (Buma, 2018) in Washington and Oregon where healthy stands are flourishing. This

125   previous work provides a context for the present study, as our sites are entering the zone where

126   mean winter temperatures are between -2° and +2°C as mapped by Buma et al. (2017) and are

127   thus susceptible to future decline as warming proceeds.

128   Previous dendroclimatic investigations along the Gulf of Alaska (GOA) have used tree

129   rings from coastal sites for climate reconstruction focusing primarily on mountain hemlock RW

130   (*Tsuga mertensiana* (Bong.) Carr.; Barclay et al., 1999; D'Arrigo et al., 2001; Wilson et al.,

131   2007; Wiles et al. 2014). More recently BI records are showing promise for generating robust

132   climate reconstructions along the GOA (Wilson et al., 2017) and in the Yukon (Wilson et al, in

133   press). Thus far, BI chronologies for the GOA have only been developed for mountain hemlock

134   (Wilson et al., 2017). Wilson et al. (2017) used the delta BI (dBi; latewood BI (LBi) subtracted

135   from the earlywood BI (EBi) values) parameter to reconstruct climate, noting the stronger

136   relationship between summer temperature and dBi than with LBi or EBi for mountain hemlock.

137   Here we present the first BI tree-ring series for yellow-cedar and examine the strength

138   and stability of its climate signal. Both RW and LBi chronologies for yellow-cedar were

139   examined for their potential for climate reconstruction and our results are interpreted within the

140   context of the yellow-cedar decline outlined above (Buma et al., 2017; Hennon et al., 2016). We

141   generated ring-width (RW) and blue intensity (BI) measurements to document the climate

142   response over the past several centuries. Latewood blue intensity (LBi) is a similar tree-ring

143   measurement to maximum latewood density (MXD). BI measurements, in general, reflect the

144   combined hemi-cellulose, cellulose and lignin content in the latewood which are key components

145   of relative density (Björklund et al., 2014; Rydval et al., 2014). The utility of LBi as a summer

146   temperature proxy has been shown to improve climate reconstruction from multiple high

147   elevation and high latitude sites (Björklund et al., 2014, 2015; Campbell et al., 2007; Dolgova,

148   2016; Rydval et al., 2014, 2017; Wilson et al., 2014) and the use of dBi from the Gulf of Alaska

149   (Wilson et al., 2017). Significantly, blue intensity is a much less expensive parameter to generate

150   than MXD. One downside however, is that LBi chronologies generally require a larger sample

151   size than MXD to generate a robust mean chronology (Björklund et al., 2014; Wilson et al.,

152   2014, 2017).

153

154   **2. Methods**

155   Trees were cored at the aforementioned three sites near Juneau: Cedar Lake, Bridget Cove and

156   East Glacier (Fig. 1). The sites range in elevation from 110 to over 480 m (Table 1). For the

157   Cedar Lake site, cores and ring-width data were obtained from other researchers (Beier et al.,

158   2008; Krapek et al., 2017) and combined with our collections from the summers of 2016 and

159   2017 (Charlton et al., 2017). The tree cores were immersed in acetone for 72 hours to remove

160   resins in the wood (Rydval et al., 2014; Fuentes et al., 2018), then glued onto wood mounts and

161   sanded to a high polish. An Epson V850 pro scanner, using an IT8.7/2 calibration card in

162   conjunction with SilverFast scanning software was used to scan the samples at a resolution of

163   2400 dpi. Scanning was done with a nonreflective black box covering the scanner window. BI

164   measurements were made using CDendro 8.1 and CooRecorder 8.1 (Larsson, 2016). Previously

165   generated ring-width chronologies facilitated calendar dating, and COFECHA (Holmes, 1983)

166   was used as a final quality control for the dating of the RW and LBi measurements.

167   Since BI measurements are color based, discoloration of the wood presents challenges.

168   One is the presence of a heartwood/sapwood boundary, which can cause a color shift in some

169   species that may impose a trend bias in the BI series (Björklund et al., 2014; 2015). In most of

170   the yellow-cedar cores we did not observe a strong color difference, although a subtle change

171   was noted in some series that might be enough to influence the measured values. To investigate

172   potential color change, we counted the number of rings at the transition from heartwood to

173   sapwood where we were able to discern the transition; counts ranged from 16 to 50 years in the

174   ~10% of samples in which we could detect the transition. The blue intensity parameters that

175   were evaluated included: LBi, earlywood BI (EBi) and the derived dBi (McCarroll et al., 2002;

176   Björklund et al., 2014, 2015; Rydval et al., 2014; Wilson et al., 2017). In our yellow cedar series,

177   EBi and LBi values are highly correlated with one another (r=0.82 for 1900-2014). The

178   application of dBi in the case of such a strong inter-correlation can lead to a loss in climate signal

179   (Björklund et al. 2014). The uniform density between the earlywood and latewood illustrated in

180   this high correlation is consistent with known wood properties that make the yellow cedar

181   desirable for its smoothly carved surfaces (Hennon et al., 2016). Given the high correlation

182   between the early and latewood measurements, and our strong results for our climate analyses

183   using LBi, we focused herein on only the LBi and RW signals from yellow-cedar for this paper.

184   We combined the individual series from the three sites into a regional master chronology

185   based on the strong correlations and coherent low frequency features among the sites. The

186   combined final RW and LBi chronologies are well replicated and both incorporate 179 series

187   from 113 trees. Although individual sites have trees that date back to CE 1114 (East Glacier;

188   Table 1) we examine the combined record back to CE 1400 based on a critical Expressed

189   Population Signal (EPS) of >0.85 (Fig. 2a; Wigley et al, 1984). The EPS is a measure of how

190   well a sample of tree-ring data (ie., number of tree ring series) represents an ideal population.

191   We followed the methodology of Wilson et al. (2017) in processing the ring-width and

192   LBi records into chronologies. Tree-ring series were standardized using the signal-free (SF), age

193   dependent spline (ADS) approach described in Melvin et al. (2007), and Melvin and Briffa

194   (2008, 2014; Fig. 2a). We used the signal free software RCSigFree, a freeware program

195   developed at the Tree-Ring Lab of the Lamont-Doherty Earth Observatory

196   (http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software) that is based on the

197   program ARSTAN (Cook, 1985). The SF approach was used because of the complex growth

198   trends recognized in the individual tree ring series; both Wilson et al., (2017; in press) and

199   Buckley et al. (2018) similarly used SF standardization with favorable results.

200   The RW and LBi series were best correlated with GOA monthly maximum temperatures

201   (Tmax, CRU TS4.01; Harris et al., 2014; Fig. 3). The temperature series was calculated by

202   averaging gridded data from within the coordinates 56° - 62° N, 130° - 140° W (Fig. 1) for the

203   CE 1900-2014 interval. We used the Tmax for analyses because of its stronger correlation with

204   the tree-ring record than with mean or minimum monthly temperatures. Wilson et al. (2017), in

205   their investigation of BI and RW series for mountain hemlock (using dBi), used mean monthly

206   temperatures from stations within 57° - 61° N, 134° - 153° W, a broader region than our study, as

207   they analyzed multiple sites across a larger swath of the GOA. Although we obtained marginally

208   better results with maximum temperatures from this larger area, we chose to use a more

209   restricted area to better represent the region surrounding our sampling sites (Fig. 1). It is difficult

210   to assess the temperatures at the tree-ring sites relative to the meteorological stations and we

211   have no records of frost frequency at the individual sites. January (coldest month) Tmax values

212   correlated at 0.95 (N=96 years) with temperatures at the Juneau station, near sea level south of

213   the study sites. However, the Tmax series is about 6˚C colder than Juneau values, which may be

214   closer to the actual temperatures at the sites up to 480 meters in elevation.

215   To assess the temporal stability of the tree-ring series and Tmax we performed running

216   correlations between series using 15-year and 31-year windows. To account for autocorrelation

217   in the series we examined correlations between the first differenced data. We also compared

218   running correlations between the yellow-cedar latewood BI series (YCLBi) and a published tree-

219   ring based temperature reconstructions for the Gulf of Alaska (Wiles et al., 2014).

220

221   **3. Results**

222   The RW series at the three sites span a common period of CE 1400-1975 (prior to a divergence

223   of the LBi and RW series; Fig. 2a) and correlate between 0.65 and 0.81 with one another,

224   whereas the three sites for LBi, correlations ranged from 0.39 to 0.53 (Table 2). The lower

225   correlation among the LBi series is consistent with our observations of mountain hemlock BI

226   along the GOA (Wilson et al, 2017), white spruce (*Picea glauca (Moench) Voss*) in the Yukon

227   (Wilson et al., in press), and scots pine (*Pinus sylevestris L.*) in Scotland (Ryvdal et al., 2014).

228   As is found here, these cited studies found a weaker common signal among BI series relative to

229   the RW, but a stronger climate signal in the BI than the RW. This paradox is not well understood

230   at the present time.

231   The final chronologies were created by combining the three individual sites into one RW

232   and one YCLBi regional series (Fig.2). The two series correlate with one another at 0.49 for the

233   period of overlap between 1400 and 1975 CE (Fig. 2a) after which they diverge. The RW and

234   YCLBi series match well with the exception of intervals in the mid 1500s, early to mid 1600s

235   and after about CE 1970 (Fig. 2a). About 1975, the YCLBi record strongly decreases and the

236   RW series declines marginally and then generally increases through recent decades (Fig. 2; Table

237   3). Comparisons of RW and YCLBi series with Tmax from the CRU gridded dataset were made

238   for the "dendroclimatic year" that consists of March through December of the previous year of

239   growth and January through October of the year of growth (Fig. 3). For the YCLBi, the strongest

240   correlations (Pearson two-tailed) were with mean January through August (J-A) maximum

241   temperatures at 0.64 for 1901-1975 (p<0.00001), with a 1st differenced correlation of 0.71 (1902-

242   1975; p<0.00001; Fig. 3a). After 1975, there is a marked decrease in correlation and loss of

243   significance (r=0.21 p>0.34) for the non-transformed series with a 1st differenced correlation of

244   0.33 (p=0.14, also not significant) for the 1976-1999 interval (Figs. 3b, 4a). For the 2000-2014

245   interval, the correlation increases to 0.71 (p=0.004) with an increase in the 1st differenced data

246   correlation to 0.64 (p=0.01) (Fig. 4b) comparable to the pre-1975 relationship (Fig. 3c). RW was

247   positively correlated with temperature (J-A) prior to 1976 (r=0.30, p<0.01) and after that time

248   correlations with maximum temperatures are not significant (Fig. 3a).

249   A principal result of our analyses is that the YCLBi is more sensitive to, and thus

250   provides a much stronger proxy for maximum temperatures (January-August average) than RW.

251   Furthermore, decadal variations in climate along the GOA as inferred from the YCLBi record

252   appear nonstationary, especially during the climatic shift in the mid to late 1970s. This noted so-

253   called 1976/77 regime shift in the North Pacific is well-documented in terms of the physical and

254   biological changes that occurred in the region (Ebbesmeyer et al., 1991; Mantua et al., 1997;

255   Trenberth and Hurrell, 1994; Newman et al., 2016). In southeast Alaska, this shift brought

256   warmer temperatures with less snow but higher precipitation as rain (Wendler et al., 2017). The

257   loss of sensitivity in YCLBi to maximum temperature after this shift is consistent with the

258   hypothesis that warming decreases snowpack, thus potentially exposing the shallow roots to frost

259   (the decline hypothesis). This dropoff in correlation also corresponds with a peak of cedar

260   mortality in the late 1970s to the early 1980s elsewhere in southeast Alaska (Hennon et al., 2016;

261   Hennon and Shaw, 1994). The apparent recovery in climate signal after the 1999 negative shift

262   in climate discussed in Ding et al. (2013), analyzed in McAfee (2016) and reported by Wills et

263   al. (2018) is marked here by a strengthening in correlation with Tmax and is also consistent with

264   the decline hypothesis. A recovery of climate sensitivity with respect to Tmax after 1999 appears

265   to be strongest in the year-to-year, high frequency response (differenced data; Fig. 4b). It also

266   appears that the lower frequency (decadal) response is also in recovery, although this finding is

267   preliminary (Fig. 4).

268

269   **4. Discussion**

270   To explore these changes in climate response further we compared our new YCLBi series

271   with a published climate reconstructions based on ring widths (GOARW; Wiles et al., 2014).

272   This record is derived from coastal mountain hemlock sites along the Gulf of Alaska. The

273   GOARW record sustains a strong positive relationship with mean temperature throughout the

274   post 1976/77 regime shift (a so-called "divergence-free" reconstruction; Wiles et al., 2014). This

275   "divergence-free" series was constructed to minimize the effect of the changing climate response

276   of mountain hemlock RW recognized at some elevations along the southern Alaskan coast

277   (Jarvis et al., 2013; Wiles et al., 2014). As discussed above, the YCLBi record correlates best

278   with maximum average (January-August) temperatures, which is similar to the response of the

279   GOARW series that has been used to reconstruct mean February-August temperatures (Wiles et

280   al., 2014). Thus, the two compare favorably (Fig. 5a), with the YCLBi record correlating with

281   the GOARW (Wiles et al., 2014; Fig. 5a) series at 0.43 (p<0.00001) for the interval 1400-1975

282   (Fig. 5a). The 31-year running correlations of these two series show generally good agreement

283   except for the 1976-1999 interval (Fig. 5b). Correlations are strongest for the 1670-1930 period

284   (Fig. 5b). Subsequently, there is a dramatic drop after 1975 (not significant (r = -0.19) for the

285   1976-1999 interval) and then a marked recovery in correlation between the two series after 1999

286   (r = 0.70 (p< 0.05); Table 3; Fig. 5b), which persists to the present (2014). First differenced

287   transformations (detrended) agree better for that interval (1976-1999); however, they also do not

288   match well in the mid 1600s (Fig. 5b).

289   A similar comparison was made with the YCLBi and the Gulf of Alaska dBi (GOAdBi)

290   series of Wilson et al. (2017; Table 3). Similar to the GOARW the GOAdBi series shows no

291   signs of divergence. Many of the same tree-ring sites included in the GOAdBi series are also

292   incorporated into the GOARW reconstruction, however GOAdBi also include dBi series that

293   responded strongly to June-September mean temperatures. The comparison of the pre-1976,

294   1976/99 and 2000/14 intervals yielded consistent but somewhat stronger correlations (Table 3) as

295   those of the YCLBi and GOARW comparisons. The two series agree especially well for the

296   2000/14 interval with a correlation of 0.80 for the non-transformed series and 0.82 for the first

297   differenced series, both highly significant (p<0.01; Table 3).

298   Taken together, the changing climate response and comparison of the YCLBi series with

299   the Tmax series (Fig.4), and the GOARW (Fig.5) and GOAdBi (Table 3) reconstructions suggest

300   that yellow-cedar may have crossed a temperature threshold about 1976 (Fig. 3), which then

301   altered the interannual climate response of the species for about 20 years. The negative trend in

302   the YCLBi series for this interval may now be in recovery as suggested by the strong positive

303   response to Tmax in recent decades. As noted, the late 1970s and early 1980s also represent a

304   peak wave of recent yellow-cedar mortality in southeast Alaska (Hennon et al., 2016). The 1976

305   threshold shift may have led to multiple years of successive injury altering climate sensitivity,

306   although mortality has not been observed at our sites. Furthermore, in the course of the analyses

307   we did not observe any evidence of injury in the wood such as traumatic resin ducts. Importantly,

308   yellow-cedar freezing injury is classified as a "forest decline" because it often takes multiple

309   freezing events and years of injury before eventual mortality.

310   The correspondence of YCLBi change with the mid-1970s regime shift from a

311   dominantly negative to dominantly positive PDO caused strong warming in coastal regions in

312   southeastern Alaska and thus a reduction in snowpack is consistent with the decline hypothesis.

313   This possible threshold crossing is likely associated with the physiological limits of yellow-

314   cedar, wherein its sensitivity to temperature becomes decoupled (D'Arrigo et al. 2004; Ohse et

315   al. 2012). Wang et al. (2014) documented an analogous divergence between temperature and RW

316   in five species from southeastern China, also in response to the 1976-77 regime shift. To our

317   knowledge, the Juneau YCLBi results presented here are the first tree ring studies to suggest the

318   effects of this relatively recent phenomenon on yellow-cedar populations in southeastern Alaska.

319   The favorable comparisons of the YCLBi series with the GOARW tree-ring series (Fig.

320   5a) prior to 1976 and then again after 1999 also suggest that the changes documented in yellow-

321   cedar in recent decades are unprecedented at least since CE 1400 (Fig. 5a; Table 3). Our results

322   indicate, therefore, that decadal shifts in addition to century-scale warming should be considered

323   when assessing the climate response of yellow-cedar. The strong coherence between the series

324   additionally, suggests that the conditions forcing the divergence after 1976 were likely not

325   experienced since at least 1400 CE. Furthermore, with the caveat that in some of our samples we

326   detected a change in color in the heartwood-sapwood transition, the temporary loss of climate

327   signal (between 1976-1998) suggests that the divergence here at least to some degree has

328   recovered.

329   Previous work has focused on the secular warming since the Little Ice Age as a dominant

330   driver in cedar decline and this is clearly consistent with the data. However, decadal shifts

331   superimposed on this warming can also be instrumental in changing growing conditions and

332   subsequent stresses. For southeast Alaska, a ~1.1°C warming during the period 1976-1999

333   relative to the previous 1951-1975 interval (Hartmann and Wendler, 2005) occurred. At the time

334   of this shift, the amount of annual snowfall decreased by 36% while overall total precipitation

335   increased by 7% with an approximately 7% increase in rain during the late summer to early fall

336   months (JAS) (Hartmann and Wendler 2005). This higher percentage of precipitation falling as

337   rain after the mid-1970s shift, forced by the increased warming, may also have influenced the

338   simultaneous marked shift in YCLBi.

339   Sullivan et al. (2017) noted a summer temperature driven response to a more moisture-

340   limited signal in Alaskan white spruce (*Picea glauca*) and, similar to our work, did not detect a

341   widespread decrease in radial growth (RW). These results from interior Alaska are in contrast to

342   earlier work at some interior sites, (ie., Barber et al., 2000; Juday et al., 2003; Juday and Alix,

343   2012; D'Arrigo et al., 2008) which identified a recent reduction in radial growth likely due to

344   moisture stress. Additionally, for white spruce in the interior of Alaska, Ohse et al. (2012) point

345   out that growth is further complicated by regional gradients in climate and site-specific

346   attributes, as well as Pacific decadal climate shifts, which also have been implicated for these

347   transitions. Finally, Wright et al. (2018) identified the role of stand dynamics in southwestern

348   Alaska can drive varying degrees of temperature stress responses.

349　　　　Blue-intensity parameters measured in yellow-cedar could complement such studies of

350　　divergent tree growth and warming temperatures in northern forests, which have been primarily

351　　based on ring-widths (D'Arrigo et al., 2008). Here the YCLBi measurements show a change,

352　　whereas the RW do not, suggesting that blue intensity, at least for yellow cedar, may experience

353　　divergent phenomena. Thus, when the limiting factors on growth at a location change, it may

354　　result in distinct challenges for using blue intensity from yellow-cedar in dendroclimatology. It is

355　　possible that a band-pass approach could be performed with RW providing the low frequency

356　　signal with the BI record providing the higher frequency signal (Wilson et al., 2014). However,

357　　the challenge remains that the climate sensitivity of the RW is not as strong as the YCLBi record,

358　　although the multi-decadal to century scale variability appears to be relatively coherent (Fig. 2).

359　　　　　Requiring further investigation is the divergence in the BI record that may be influenced

360　　by heartwood-sapwood color differences even though we did not observe a strong visual color

361　　change in many of the cores. Such factors warrant more detailed evaluation to ensure that BI data

362　　are able to adequately capture climatic variability through the last several decades. Whereas this

363　　needs to be investigated more fully for yellow-cedar, the coincidence of loss of signal (non-

364　　significant correlations) at times of known shifts in climate (1976/77 and 1999) supports a

365　　climate-driven response of the tree growth. Further work could include investigating other

366　　chemical treatments of the wood prior to analysis (Rydval et al., 2014).　Delta BI (dBi) proposed

367　　to ameliorate the heartwood/sapwood transition also shows a strong divergence (not shown) but

368　　dBi is much less sensitive to temperature variability in this study perhaps because of the strong

369　　intercorrelation between the LWBi and EWBi series, and so is not helpful here. In contrast, for

370　　the GOA mountain hemlock dBi seems to be a more climatically sensitive parameter than LWBi

371　　(Wilson et al., 2017).

372   Our YCLBi series is climatically sensitive to January through August maximum average

373   temperatures a broader climate window than the June-September sensitive GOAdBi study by

374   Wilson et al. (2019). We hypothesize that the broader climate window for the YCLBi record

375   compared with the more restricted summer signal found in Wilson et al (2017) may be due to the

376   ecophysiological tendency of yellow-cedar to deharden earlier in the spring, thus responding

377   favorably to winter/spring temperatures. This early dehardening may allow yellow cedar to gain

378   a competitive advantage with respect to nutrient uptake (D'Amore et al., 2009) relative to other

379   conifer species and thus yellow-cedar respond to late winter/spring temperatures as well as

380   summer.

381   Finally, although the three sites in this investigation have not shown indications of

382   decline at the stand level or a marked decrease in radial growth (RW), they appear to have been

383   impacted by changes in climate in the mid to late 1970s, behaving similarly to stands that have

384   experienced extensive mortality (Beier et al., 2008). Since about 1999, these populations

385   recovered their climate sensitivity suggesting some level of resilience. This is consistent with the

386   concept that this population is "on the edge" of climatic vulnerability (Buma, 2018). Thus, it may

387   be that at some of the locations in the Juneau area, yellow-cedar sites remain healthy forests.

388   However, since they are near the leading edge of the decline and outside of the "historical

389   decline," a slight warming in the region could push these trees closer toward conditions of

390   potential mortality as recognized farther south in coastal Alaska.

391   As Buma (2018) points out, across the range of yellow-cedar, if the rate of warming is

392   great enough to ameliorate the occurrence of frost, then the warming and loss of snowpack may

393   not influence cedar growth. Although the roots are vulnerable, frosts are less likely to occur in a

394   rapidly warming climate. A drop toward nonsignificant correlations in both the non-transformed

395   and first differenced series between 1976 and 1999 is consistent with stress-related changes,

396   perhaps related to warming temperatures and its interactions with snowpack and frost.

397   Furthermore, the secular increase as well as the decadal changes in the North Pacific emphasized

398   here will drive and modulate the tree response to climate.

399   Clearly, decadal-scale variability needs to be considered in the context of forest health. It

400   is difficult to separate the effect of secular warming and the decadal shifts from one another and

401   it is likely that they have worked synergistically to cause the decoupling of tree growth and

402   maximum temperature. Hennon et al. (2016) point out that although the yellow-cedar competes

403   well on saturated soils relative to other species, trees rooted in saturated soils tend to have more

404   shallow rootlets making them more vulnerable to freezing damage. The species' preference and

405   its ability to out-compete other tree species on wetter soils can increase their vulnerability to

406   freezing if the insulating layer of snow disappears so that shallow roots can freeze. Even though

407   the primary driver in the decline remains temperature, increased precipitation may also

408   exacerbate the tree stress related to warmer temperatures, loss of snow pack, and the detrimental

409   impact of frosts on root systems. These factors need to be explored more fully.

410   Our results suggest that with further work YCLBi records could be used to reconstruct

411   past climate. Melting glaciers across the GOA continue to reveal ancient forests, and in at least

412   one case, have exposed sub-fossil wood that includes yellow-cedar (Gaglioti et al., unpublished

413   data). This presents the emerging possibility of extending these cedar series further back in time.

414   As in the case for mountain hemlock (Wilson et al., 2017), blue intensity tree-ring series in

415   yellow-cedar show promise to improve temperature reconstructions for the GOA and perhaps in

416   the future entering into multi-species climate reconstructions.

417

418   **5. Conclusions**

419   This analysis of yellow-cedar response to climate is the first to examine the latewood

420   blue intensity parameter. Previous work with ring-widths from yellow cedar of southeast Alaska,

421   although valuable in examining changing climate response, have been limited with respect to

422   reconstructing past climate. Our well-replicated YCLBi series has a strong temperature response

423   until the mid-1970s equal to or greater than many published ring-width series from the

424   traditionally used mountain hemlock from the region.

425   The trends in the observational climate records and in the YCLBi data suggest changes in

426   tree physiology around the mid-1970s shift in the PDO that may have been detrimental to tree

427   growth but do not necessarily appear to be affecting bioproductivity as inferred from ring-widths.

428   The presumed recovery in temperature sensitivity in YCLBi after a shift to a cooler regime in

429   1998/99 (Wills et al., 2018) is further evidence of a response to decadal climate change, although

430   additional years for comparison in the coming decades may strengthen or refute this observation.

431   The climate sensitivity of this economically, ecologically and culturally important species should

432   be coupled with the existing knowledge of past migrations and the mechanisms of decline when

433   anticipating its future range (Krapek et al., 2017), especially in the face of unprecedented

434   warming.

435   Further study of the impact of decadal shifts and secular warming in yellow-cedar across

436   its range, together with monitoring could help anticipate the risks that these sites may experience

437   in the future. This work emphasizes the findings of previous studies on the ecology of yellow-

438   cedar (Krapek and Buma, 2017), supporting the observation that this species has not responded

439   linearly to secular warming.

440

447

448 **References**

449 Barber, V.A., Juday, G.P., and, Finney, B.P. 2000. Reduced growth of Alaskan white spruce in

450 the twentieth century from temperature-induced drought stress. Nature **405**: 668-673.

451

452 Barclay, D.J., Wiles, G.C., and, Calkin, P.E. 1999. A 1119-year tree-ring width chronology from

453 western Prince William Sound, southern Alaska. The Holocene **9**: 79-84.

454

455 Barrett, T.M., and Pattison, R.R. 2017. No evidence of recent (1995–2013) decrease of yellow-

456 cedar in Alaska. Can. Jour. of For. Res. **47**: 97–105.

457

458 Beier, C.M., Sink, S.E., Hennon, P.E., D'Amore, D.V., and, Juday, G.P. 2008. Twentieth-

459 century warming and the dendroclimatology of declining yellow-cedar forests in southeastern

460 Alaska Can. Jour. of For. Res. **38**: 1319-1334.

461

462 Bidlack, A., Bisbing, S., Buma, B., D'Amore, D., Hennon, P., Heutte, T., Krapek, J., Mulvey, R.,

463 and, Oakes, L. 2017. Alternative interpretation and scale-based context for "No evidence of

464   recent (1995–2013) decrease of yellow-cedar in Alaska" (Barrett and Pattison 2017). Can. Jour.

465   of For. Res. **47**: 1145–1151.

466

467   Björklund, J., Gunnarson, B.E., Seftigen, K., Esper, J., and, Linderholm, H.W. 2014. Blue

468   intensity and density from northern Fennoscandian tree rings, exploring the potential to improve

469   summer temperature reconstructions with earlywood information. Clim. of the Past **10**: 877-885.

470

471   Björklund, J., Gunnarson, B.E., Seftigen, K., Zhang, P., and, Linderholm, H.W. 2015. Using

472   adjusted blue intensity data to attain high-quality summer temperature information: A case study

473   from Central Scandinavia. The Holocene **25**: 547–556.

474

475   Boulton, C.A., and, Lenton, T.M. 2015. Slowing down of North Pacific climate variability and

476   its implications for abrupt ecosystem change. Proc. Nat. Acad. of Sci. **112**: 11496–11501.

477   Buckley, B., Hansen, K.G., Griffin, K.L., Schmiege, S., Oelkers, R., D'Arrigo, R.D., Stahle,

478   D.K., Davi, N., Nguyen, T., Le, C.N., and, Wilson, R.J.S. 2018. Blue intensity from a tropical

479   conifer's annual rings for climate reconstruction: An ecophysiological perspective.

480   Dendrochronologia **50**: 10-22.

481

482   Buma, B. 2018. Transitional climate mortality: slower warming may result in increased climate-

483   induced mortality in some systems. Ecosphere **9**: e02170.

484

485   Buma, B., Hennon, P.E., Harrington, C.A. Popkin, J.R., Lamb, M.S., Oakes, L.E., Saunders, S.,

486   and, Zeglen, S. 2017. Emerging climate-driven disturbance processes: widespread mortality

487   associated with snow-to-rain transitions across 10° of latitude and half the range of a climate-

488   threatened conifer. Global Change Biology **23**: 2903–2914.

489

490   Campbell, R., McCarroll, D., Loader, N.J., Grudd, Häkan, Robertson, I., and, Jalkanen, R. 2007.

491   Blue intensity in Pinus sylvestris tree-rings: developing a new palaeoclimate proxy. The

492   Holocene **17**: 821-828.

493

494   Charlton, J., Cruz, A., Lummus, M., Loadholt, K., Messerich, C., Wiles, G., Buma, B., and,

495   Krapek, J. 2017. Yellow cedar growth response to decadal climatic shifts at Cedar Lake, Juneau,

496   Alaska. Geol. Soc. Am. Abst. Progr. **49**, Seattle, Washington, USA, 22-25 October 2017.

497

498   Cohen, W.B., Yang, Z., Stehman, S.V., Schroeder, T.A., Bell, D.B., Masek, J.G., Huang, C.,

499   and, Meigs, G.W. 2016. Forest disturbance across the conterminous United States from 1985–

500   2012: The emerging dominance of forest decline. For. Ecol. and Management **360**: 242-252.

501

502   Cook, E.R. 1985. A Time Series Analysis Approach to Tree-Ring Standardization. PhD Thesis,

503   University of Arizona, Tucson, USA.

504

505   D'Amore, D.V., and, Hennon, P.E. 2006. Evaluation of soil saturation, soil chemistry, and early

506   spring soil and air temperatures as risk factors in yellow-cedar decline. Glob. Chan. Biol. **12**:

507   524-545.

508

509   D'Amore, D.V., Hennon, P.E., Schaberg, P.G. and, Hawley, G. J. 2009. The adaptation to

510   exploit nitrate in surface soils predisposes yellow-cedar to climate change-induced decline and

511   enhances the survival of red cedar. For. Ecol. and Management **258**: 2261–68.

512

513   D'Arrigo, R., Kaufmann, R.K., Davi, N., Jacoby, G.C., Laskowski, C., Myneni, R.B., and,

514   Cherubini, P. 2004. Thresholds for warming-induced growth decline at elevational tree line in

515   the Yukon Territory, Canada. Glob. Biogeochem. Cycles **18**: GB3021.

516

517   D'Arrigo, R., Villalba, R., and, Wiles, G. 2001. Tree-ring estimates of Pacific decadal climate

518   variability. Clim. Dyn. **18**: 219-224.

519

520   D'Arrigo, R., Wilson, R., Liepert, B., and, Charubini, P. 2008. On the 'Divergence Problem' in

521   Northern Forests: A review of the tree-ring evidence and possible causes. Glob. Planet. Chan.

522   **60**: 289-305.

523

524   Ding, H., Greatbatch, R. J., Latrif, M., Park, W., and Gerdes, R., 2013, Hindcast of the 1976/77

525   and 1998/99 climate shifts in the Pacific: J. Climate. Doi 10.1175/JCLI-12-00626.1.

526

527   Dolgova, E. 2016. June–September temperature reconstruction in the Northern Caucasus based

528   on blue intensity data. Dendrochronologia **39**: 17-23.

529

530   Ebbesmeyer, C.C., Cayan, D.R., Mclain, D.R., Nichols, F.H., Peterson, D.H., and, Redmond,

531   K.T. 1991. 1976 step in the Pacific climate: forty environmental changes between 1968–1975

532   and 1977–1984. In: Proceedings of the 7th Annual Climate (PACLIM) Workshop (ed by

533   Betancourt JL and Tharp VL), April 1990, pp. 115-126. California Department of Water

534   Resources, Interagency Ecological Studies Program Technical Report **26**.

535

536   Fuentes, M., R. Salo, J. Björklund, K. Seftigen, P. Zhang, B. Gunnarson, J. Aravena and H.

537   Linderholm. 2018. A 970-year-long summer temperature reconstruction from Rogen, west-

538   central Sweden, based on blue intensity from tree rings. The Holocene **28**: 254-266.

539

540   Gaglioti, B.V., Mann, D.H., Williams, A.P., Wiles, G.C., and, Jones, B. accepted 2019, Sudden

541   shifts in wintertime Aleutian Low variability revealed in a 550-year record of storm-damaged

542   trees from Southeast Alaska. Journal of Geophysical Research - Biosciences.

543

544   Grissino-Mayer, H.D. 2001. Evaluating crossdating accuracy: A manual and tutorial for the

545   computer program COFECHA. Tree-Ring Research **57**: 205–221.

546

547   Harris, I., Jones, P.D., Osborn, T.J., and, Lister, D. 2014. Updated high-resolution grids of

548   monthly climatic observations – the CRU TS3. 10 Dataset. Intern. Jour. of Clim. **34**: 623–642.

549

550   Hartmann, B. and, Wendler, G. 2005. The significance of the 1976 Pacific climate shift in the

551   climatology of Alaska. Jour. of Clim. **18**: 4824-4839.

552

553   Hennon, P.E., and, Shaw, C.G. III 1994. Did climatic warming trigger the onset and

554   development of yellow-cedar decline in southeast Alaska? For. Path. **24**: 399–418.

555

556   Hennon, P.E., D'Amore, D.V., Schaberg, P.G., Wittwer, D.T., and, Shanley, C.S. 2012. Shifting

557   climate, altered niche, and a dynamic conservation strategy for yellow-cedar in the North Pacific

558   coastal rainforest. BioScience **62**: 147–158.

559

560   Hennon, P.E., D'Amore, D., Wittwer, D., Johnson, A., Schaberg, P., Hawley, G., Beier, C., and,

561   Sink, G. 2006. Climate warming, reduced snow, and freezing injury could explain the demise of

562   yellow-cedar in southeast Alaska, USA. World Res. Rev. **18**: 227–250.

563

564   Hennon, P.E., McKenzie, C.M., D'Amore, D., Wittwer, D.T., Mulvey, R.L., Lamb, M.S., Bile,

565   F.E. and Cronn, R.C., and, Juday, G. 2016. A climate adaptation strategy for conservation and

566   management of yellow-cedar in Alaska. Pacific Northwest Research Station General Technical

567   Report no. **917**. Portland, Oregon, USA: US Department of Agriculture, Forest Service.

568

569   Hennon, P.E., Shaw, C.G., and, Hansen, E.M. 1990. Dating decline and mortality of

570   Chamaecyparis nootkatensis in southeast Alaska. For. Sci. **36**: 502–515.

571

572   Holmes, R. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-

573   Ring Bull. **44**: 69–74.

574

575   Jarvis, S. K., Wiles, G.C., Appleton, S.N., D'Arrigo, R.D., and, Lawson, D.E. 2013. A warming-

576   induced biome shift detected in tree growth of Mountain Hemlock (Tsuga mertensiana (Bong.)

577   Carrière) along the Gulf of Alaska. Arct., Ant. and Alp. Res. **45**, DOI 10.1657/1938-4246-45.2.

578

579   Juday G. P., Barber V., Rupp S., Zasada, J. and Wilmking, M. 2003. Climate Variability and

580   Ecosystem Response at Long-Term Ecological Research Sites ed. D Greenland et al (New York:

581   Oxford University Press) pp 226–50

582   Juday, G.P., and Alix, C. 2012. Consistent negative temperature sensitivity and positive

583   influence of precipitation on growth of floodplain Picea glauca in interior Alaska. Can. J. For.

584   Res. **42**: 561–573. doi:10.1139/x2012-008.

585   Kaczka, R., J., Spyt, B., Janecka, K., Beil, I., Büntgen,U., Scharnweberb, T., Nievergeltd, D.,

586   and, Wilmking, M. 2018. Different maximum latewood density and blue intensity measurements

587   techniques reveal similar results. Dendrochronologia, **49**: 94-101,

588   https://doi.org/10.1016/j.dendro.2018.03.005.

589

590   Krapek, J., and Buma, B. 2015. Yellow-cedar: climate change and natural history at odds. Front.

591   in Ecol. and Envir. **13**: 280-281.

592

593   Krapek, J., and, Buma, B. 2017. Persistence following punctuated range extension: limited

594   dispersal of migrating tree despite habitat ahead of its range. Jour. of Ecol. **106**: 911-924.

595

596   Krapek, J., Hennon, P.E., D'Amore, D.V., and, Buma, B. 2017. Despite available habitat at

597   range edge, yellow-cedar migration is punctuated with a past pulse tied to colder conditions.

598   Diversity and Distributions **23**: 1381–1392.

599

600   Larsson, L-Å. 2016. CDendro & CooRecorder program package for tree ring measurements and

601   crossdating of the data, version 8.1.1. Available at: http://www.cybis.se/forfun/dendro.

602

603   Manion, P.D., and, Lachance, D., 1992. Forest decline concepts. St. Paul: American Phyto-

604   pathological Society Press.

605

606   Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., and, Francis, R.C. 1997. A Pacific

607   Interdecadal climate oscillation with impacts on salmon production. Bull. of the Am. Met. Soc.

608   **78**: 1069-1079.

609

610   Marcinkowski, K., Peterson, D.L. and Ettl, G.J. 2014. Nonstationary temporal response of

611   mountain hemlock growth to climatic variability in the North Cascade Range, Washington, USA.

612   Can. J. For. Res. **45:** 676-688.

613

614   McAfee, S.A. 2014. Consistency and the lack thereof in Pacific Decadal impacts on North

615   American winter climate. J. Clim. **27**: 7410– 7431.

616

617   McAfee, S.A. 2016. Uncertainty in Pacific decadal oscillation indices does not contribute to

618   teleconnection instability. Int. J. Climatology **37**: https://doi.org/10.1002/joc.4918.

619

620 McCarroll, D., Pettigrew, E., Luckman, A., Guibal., F., and, Edouard, J.L. 2002. Blue reflectance

621 provides a surrogate for latewood density of high-latitude pine tree rings. Arct., Ant., and Alp.

622 Res. **34**: 450–453.

623

624 Melvin, T.M., and, Briffa, K.R. 2008. "Signal-free" approach to dendroclimatic standardisation.

625 Dendrochronologia **26**: 71–86.

626

627 Melvin, T.M., and, Briffa, K.R. 2014. CRUST: Software for the implementation of Regional

628 Chronology Standardisation: Part 2. Further RCS options and recommendations.

629 Dendrochronologia **32**: 343–356.

630

631 Melvin, T.M., Briffa K.R., Nicolussi, K., and, Grabner, M. 2007. Time-varying-response

632 smoothing. Dendrochronologia **25**: 65– 69.

633

634 Newman, M., Alexander, M.A., Ault, T.R., Cobb, K.M., Deser, C., Di Lorenzo, E., Mantua,

635 N., Miller, A.J., Minober, S., Nakamurai,H., Schneider, N., Vimont, D.J., Phillips, A.S., Scott,

636 J.D., and, Smith, C.A. 2016. The Pacific decadal oscillation, revisited. Jour. of Clim. **29**: 4399-

637 4427.

638

639 Oakes, L.E., 2018, In search of the canary tree. Hachette Book Group. 272 p.

640

641   Oakes, L.E., Hennon, P.E., Ardoin, N.M., D'Amore, D., Feruson, A.J., Steel, E.A., Wittwer,

642   D.T., and Lambin, E.F. 2015. Conservation in a social–ecological system experiencing climate-

643   induced tree mortality. Biol. Cons. **192**: 276– 285.

644

645   Oakes, L.E., Hennon, P.E., O'Hara, K.L., O'Hara, K.L., and, Dirzo, R. 2014. Long-term

646   vegetation changes in a temperate forest impacted by climate change. Ecosphere **5**:1-28.

647

648   Ohse, B., Jansen, F., and, Wilmking, M. 2012. Do limiting factors at Alaskan treelines shift with

649   climatic regimes? Envir. Res. Lett. **7**: 1-12.

650

651   Overland, J., Rodionov, S., Minobe. S., and Bond, N., 2008. North Pacific regime shifts:

652   Definitions, issues and recent transitions: Progress in Oeanography, **77**: 92-102.

653

654   Peterson, T.C., and, Vose, R.S. 1997. An overview of the Global Historical Climatology

655   Network temperature database. Bull. of the Am. Met. Soc. **78**: 2837-2849.

656   Rydval, M., Larsson, L-Å., McGlynn, L., Gunnarson, B.E., Loader, N.J., Young, G.H.F., and,

657   Wilson. R. 2014. Blue intensity for dendroclimatology: Should we have the blues? Experiments

658   from Scotland. Dendrochronologia **32**: 191-204.

659

660   Rydval, M., Loader, N.J., Gunnarson, B.E. Druckenbroad, D.L., Linderholm, H.W., Moreton,

661   S.G., Wood, C.V., and Wilson, R. 2017. Reconstructing 800 years of summer temperatures in

662   Scotland from tree rings. Clim. Dyn. **49**: 29-51.

663

664   Schaberg, P.G., D'Amore, D.V., Hennon, P.E., Halman, J.M., Hawley, G.J.,. 2011. Do limited

665   cold tolerance and shallow depth of roots contribute to yellow-cedar decline? For. Ecol. and

666   Manage. **262**: 2142–2150.

667

668   Schaberg, P.G., Hennon, P.E., D'Amore, D., Hennon, P.E., Halman, J.M., and, Hawley, G.J.

669   2008. Influence of simulated snow cover on the cold tolerance and freezing injury of yellow-

670   cedar seedlings. Glob. Chan. Biol. **14**: 1-12.

671

672   Sullivan, P.F., Pattison, R.R., Brownlee, A.H., Cahoon, S.M.P., and, Hollingsworth, T.N. 2017.

673   Limited evidence of declining growth among moisture-limited black and white spruce in interior

674   Alaska. Scientific Reports **7**: 15344.

675

676   Trenberth, K.E., and, Hurrell, J.W. 1994. Decadal atmosphere-ocean variations in the Pacific.

677   Clim. Dyn. **9**: 303–319.

678

679   Trouet, V., and, Van Oldenborgh, G.J. 2013. KNMI Climate Explorer: A web-based research

680   tool for high-resolution paleoclimatology. Tree-Ring Res. **69**: 3-13.

681

682   Wang. X., Li, Z., and, Ma, K. 2014. Decreased sensitivity of tree growth to temperature in

683   southeast China after the 1976/'77 regime shift in Pacific climate. Sains Malaysiana **43**: 9-19.

684

685   Wendler, G., Gordon, T., and, Stuefer, M. 2017. On the precipitation and precipitation change in

686   Alaska. Atmosphere **8**: 253.

687

688   Wigley, T.M., Briffa, K.R., and, Jones, P.D. 1984. On the average value of correlated time

689   series, with applications in dendroclimatology and hydrometeorology. Jour. of Clim. and Appl.

690   Meteor. **23**: 201–213.

691

692   Wiles, G.C., D'Arrigo, R.D., Barclay, D, Javis, S., Appleton, S., Wiesenberg, N., and Lawson,

693   D. 2014. Surface air temperature variability reconstructed with tree rings for the Gulf of Alaska

694   over the past 1200 years. The Holocene **24**: 198-208.

695

696   Wiles, G.C., Mennett, C.R., Jarvis, S.K., D'Arrigo, R.D., Wiesenberg, N., and, Lawson, D. 2012.

697   Tree-ring investigations into changing climatic responses of Yellow-Cedar, Glacier Bay, Alaska.

698   Can. J. For. Res. **42**: 814-819.

699

700   Wills, R.C., Schneider, T., Wallace, J.M., Battisti, D.S., and Hartman, D. L. 2018. Disentangling

701   global warming, multidecadal variability, and el Nino in Pacific temperatures. Geophys. Res.

702   Lett. **45**: https://doi.org/10.1002/2017GL076327.

703

704   Wilson, R., Anchukaitis, K., Andreu Hayles, L., Cook, E., D'Arrigo, R., Davi, N., Haberbauer,

705   L., Krusic, P., Luckman, B., Morimoto, D., Oelkers, R., Wiles, G., and Wood, C., in press,

706   Improved dendroclimatic calibration using Blue Intensity for white spruce in the southern

707   Yukon. The Holocene.

708

709 Wilson, R., Rao, R., Rydval, M., Wood, Larsson, L.A., and, Luckman, B.H. 2014. Blue intensity

710 for dendroclimatology: the BC blues: a case study from British Columbia Canada. The Holocene

711 **24**:1428–1438.

712

713 Wilson, R., D'Arrigo, R., Andrew-Hayles. L., Oelkers, R., Wiles, G., Anchukaitis, K., and, Davi,

714 N. 2017. High-sensitivity warm-season climate signatures in a Gulf of Alaska Blue Light

715 Intensity tree-ring composite record. Clim. of the Past **13**: 1851-1900, doi:10.5194/cp-2017-26.

716

717 Wilson, R., Wiles, G., D'Arrigo, R., and, Zweck, C. 2007. Cycles and shifts: 1300-years of

718 multidecadal temperature variability in the Gulf of Alaska. Clim. Dyn. **28**: 425-440.

719

720 Wilmking, M., G. P. Juday, V. A. Barber, and H. S. Zald. 2004. Recent climate warming forces

721 contrasting growth responses of white spruce at treeline in Alaska through temperature

722 thresholds. Global Change Biology **10**:1724–1736.

723

724 Wright, M., Sherriff, R.L., Miller, A.E., and Wilson, T., 2018, Stand basal area and temperature

725 interact to influence growth in white spruce in southwest Alaska. Ecosphere **9**:

726 https://doi.org/10.1002/ecs2.2462.

727

728

729

Table 1. Parameters of tree-ring sites shown in Figure 1.

Site*	Lat./Long.	Elev. (m)	# series/trees	Interval (CE)	RBAR LBi/RW
BC	58.6301, -134.9304	140	49/29	1644-2014	0.41/0.50
CL	58.6655, -134.9688	110	70/41	1611-2014	0.41/0.46
EG	58.4077, -134.5243	480	60/43	1114-2014	0.42/0.56

*BC – Bridget Cove; CL – Cedar Lake; EG – East Glacier (see Figure 1 for locations). RBAR is the mean correlation coefficient among tree-ring series.

Table 2. Correlations among ring-width (*RW*) and latewood blue intensity (LBi) chronologies for the interval CE1750-1975 at individual tree-ring sites for non-transformed and first difference series (parens.).

Chron	CL (RW)	CL (LBi)	BC (RW)	BC (LBi)	EG (RW)	EG (LBi)
CL (RW)	----	0.43(-0.03)	**0.81 (0.78)**	0.36(-0.04)	*0.65 (0.63)*	0.57 (0.32)
CL (LBi)		----	0.37 (0.05)	<u>0.53 (0.47)</u>	0.34(-0.02)	<u>0.39 (0.28)</u>
BC (RW)			----	0.44(-0.02)	*0.76 (0.53)*	0.54 (0.31)
BC (LBi)				----	0.42(-0.05)	<u>0.41 (0.57)</u>
EG (RW)					----	0.51 (0.19)

* BC – Bridget Cove; CL – Cedar Lake; EG – East Glacier (see Figure 1 for locations). **Bold** are comparisons between RW series and <u>underlined</u> are comparisons between LBi.

Table 3. Correlations among key tree-ring series relative to YCLBi and those used in climate reconstruction along the GOA. The first value is the non-transformed correlation and those in parentheses are 1st differenced.

| *YCLBi_Cedar*	1600-1975	1976/99	2000/14
RW_Cedar	**0.53 (0.34)**	0.07 (-0.41)	0.42 (0.15)
GOAdBi	**0.50** (0.04)	0.18 (0.56)	**0.80 (0.82)**
GOARW	**0.48 (0.29)**	-0.19 (0.16)	**0.70 (0.72)**

***Bold** correlations are significant <0.01 level.

Fig. 1. Location of the three yellow-cedar sites used in the composite ring-width and latewood blue intensity (YCLBi) chronology (CL = Cedar Lake, BC = Bridget Cove, EG = East Glacier). The inset map shows the location of the Juneau area and the box includes the region over which the maximum temperature (Tmax) series were averaged.
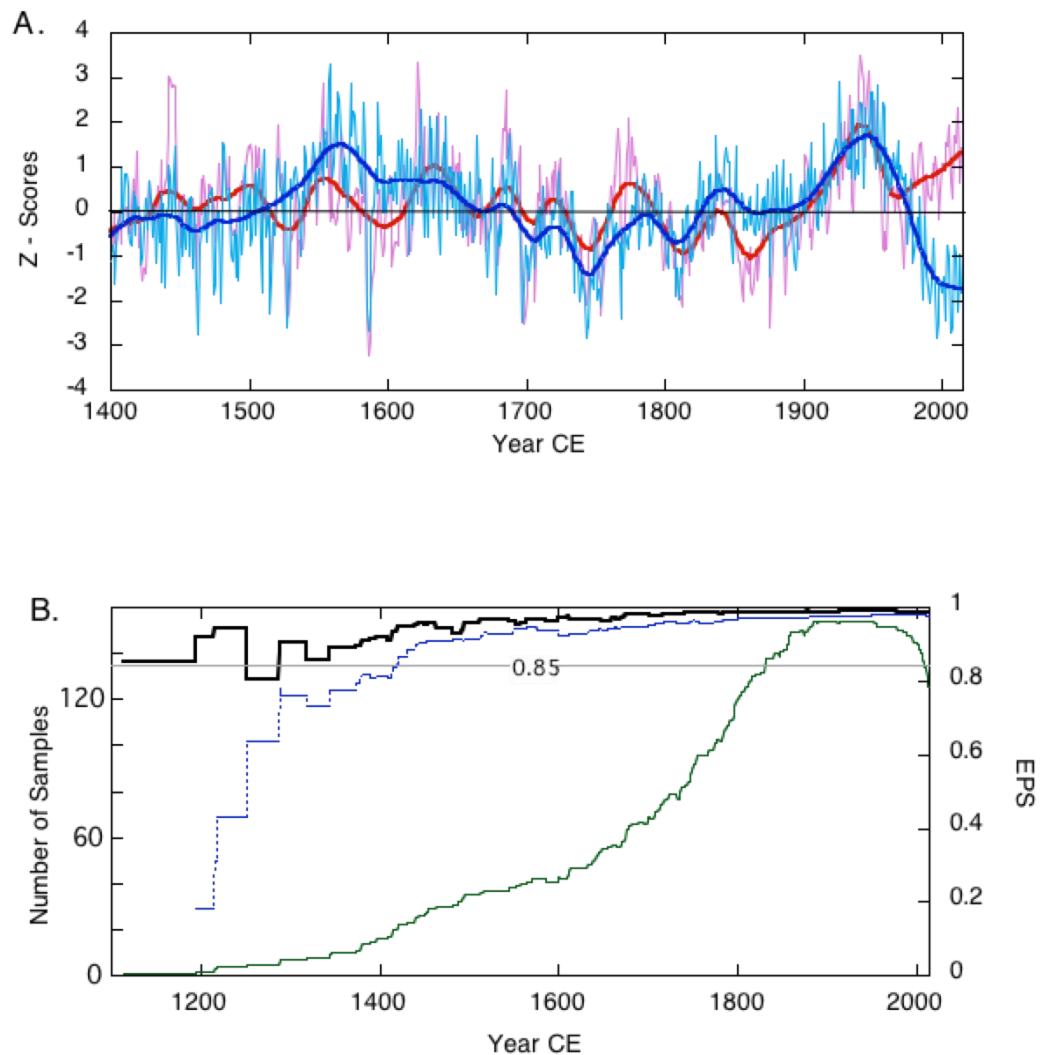
Fig. 2. (a) Z-scores (relative to the 1400-1900 interval) of the ring—width (red) and latewood blue intensity (YCLBi, blue) both chronologies are built from the composite of the three cedar sites (Figure 1). (b) Shows the sample size (green) and the EPS for each of the chronologies (black (RW) and blue (YCLBi). Note that the EPS statistic for both sites exceeds the critical 0.85 value about CE 1400.
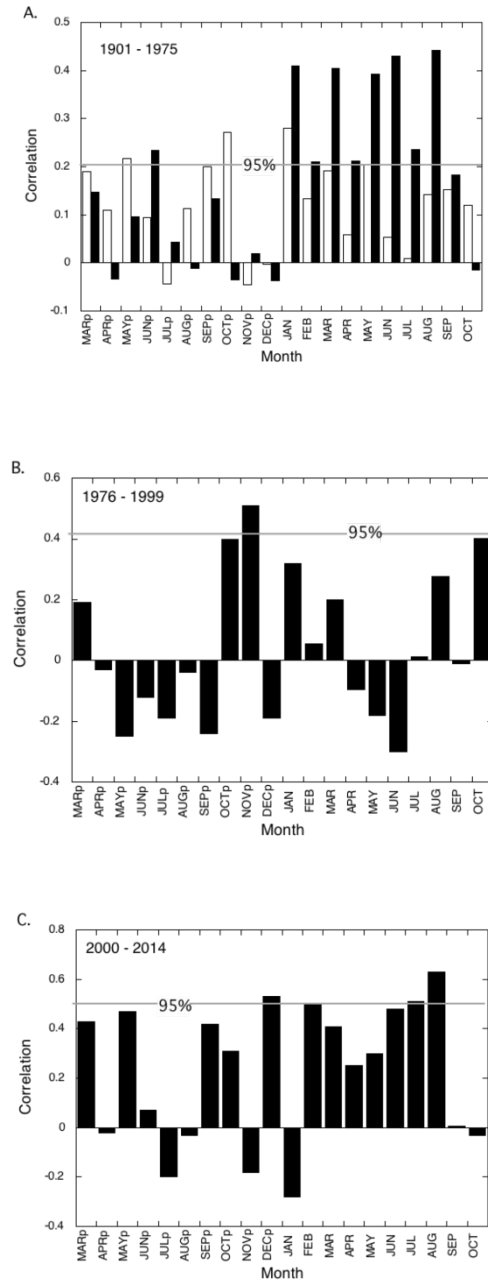
Fig. 3. (a) The temperature response (monthly correlations) for the ring-width (white) and blue intensity(black) cedar records for the dendroclimatic year. Note that for the 1901-1975 interval the YCLBi record correlates much more strongly with monthly temperatures than the RW. For the 1976-1999 interval, there is a significant loss of temperature sensitivity for YCLBi (b) and for the 2000-2014 interval correlations recover. The 95% confidence level is shown for each data set.
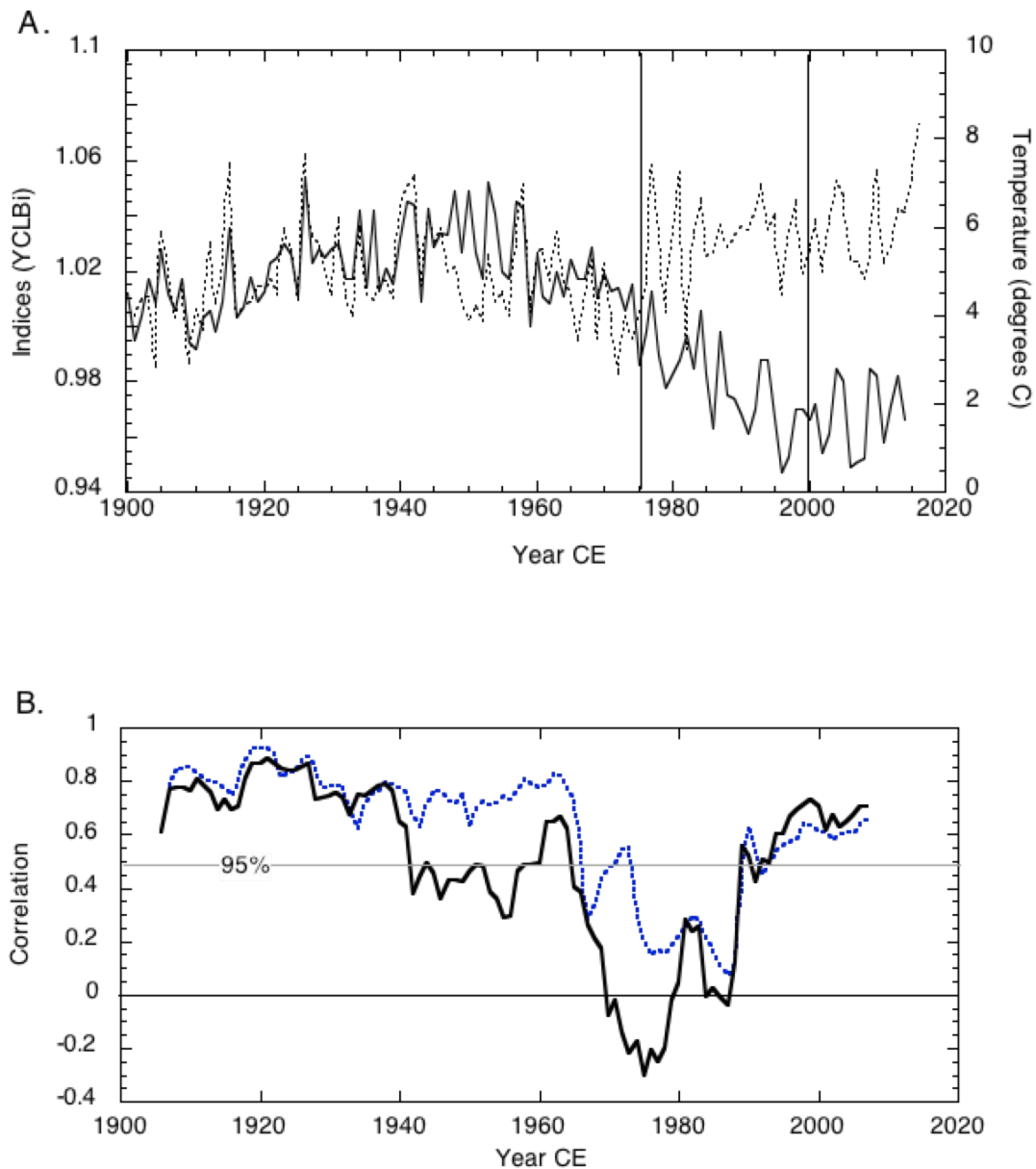
Fig. 4. Plots of (a) January through August average maximum temperatures (broken line) compared with YCLBI. Note how after 1975 the relationship diverges. (b) 15-year running correlations of the YCLBi series with maximum temperature (January-August average), with the non-transformed series (solid line) and with the first differenced data (broken line) showing the decadal loss of climate signal and then recovery.

A.

B.
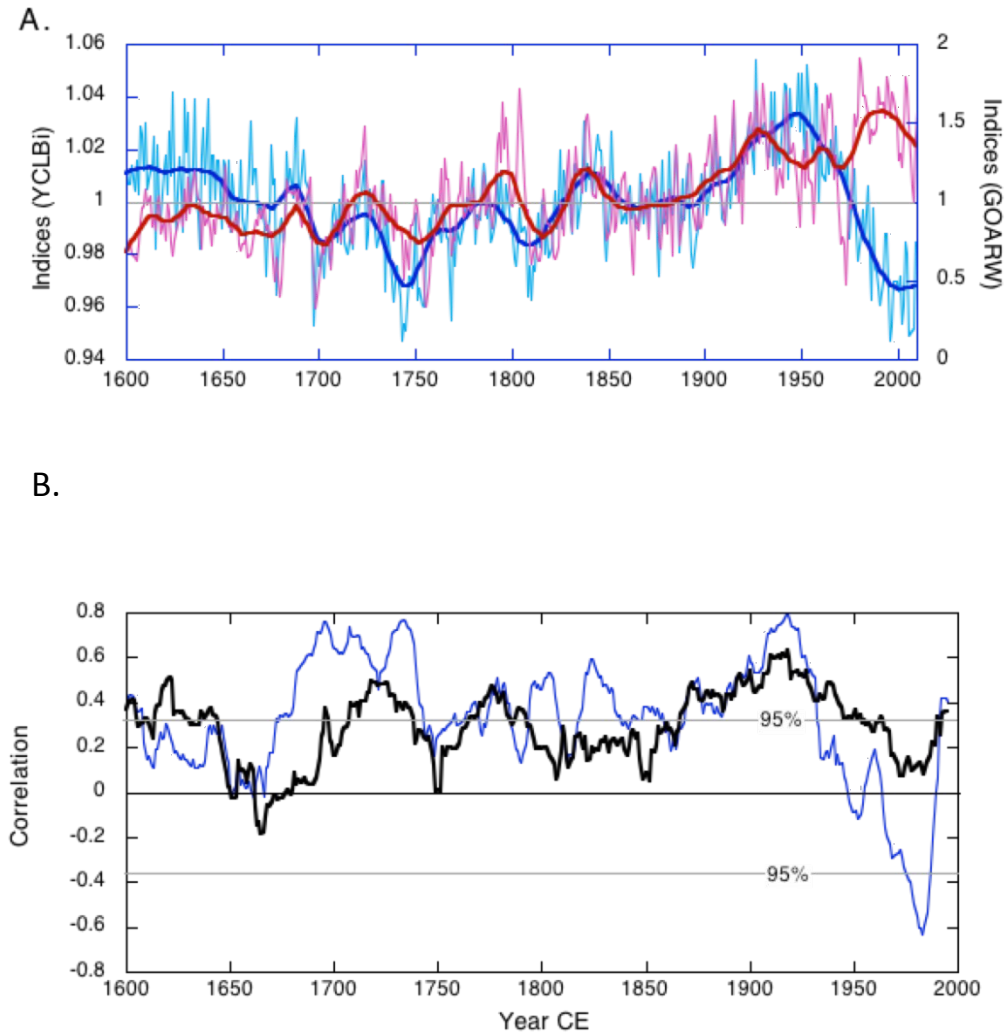
Fig. 5. YCLBi (blue) and GOARW (red) records compared. (a) Note the divergence of the two series in the last few decades. (b) 31-year running correlations between the two series (not transformed (blue) and the first differences (black). These running correlations show the dramatic drop in correlation after the 1976/77 regime shift in the North Pacific and a recovery in correlation after ~1999.