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Kunashir (Kuriles) Oak 400-year reconstruction of temperature and relation to the Pacific Decadal Oscillation

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Abstract

Paleoclimatic records of northwest Pacific variations are scarce but can be extended by proxy records from old-aged trees around the North Pacific Rim. In July of 2001 on Kunashir Island at the southern extent of the Kuriles, tree cores were extracted from century-old oaks (*Quercus crispula*) and developed into a 400-year tree-ring width index series. Analyses showed the ring-width indices to correlate strongly with summer (June–September) temperatures as recorded at Ugno-Kurilsky on the Island. The summer temperatures were reconstructed using the tree-ring data and 52% of the variance was explained by the tree-ring indices. The recorded temperature data and the tree-ring data show similar correlation patterns with sea-surface temperatures (SSTs) of the North Pacific. Studies of North Pacific variations, as quantified by the Pacific Decadal Oscillation (PDO), show the PDO to be an important index of large-scale climate variation. The tree-ring series explains more than 33% of the variance of the July–September Pacific Decadal Oscillation and has similar spectral properties, further supporting the concept of multidecadal variation or shifts in North Pacific climate, for four centuries.

Keywords: Paleoclimate; Tree rings; North Pacific; PDO

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1. Introduction

Paleoclimatic data are sparse along the coastal northwest Pacific. There are old-aged trees on Hokkaido, some of the Kurile Islands and Kamchatka Peninsula. The annual growth variations of these trees as recorded by the annual rings may record climatic variations that relate to coastal and oceanic conditions. Kunashir, the southernmost large island in the Kurile Island chain, (Fig. 1) has an extremely maritime climate. The island is small enough that the local climate is dominated by the effects of the Pacific Ocean and the Sea of Okhotsk. Temperatures on the island are strongly influenced by the surrounding sea-surface temperatures (SSTs). The Anadyr-Oyashio current runs southward along the east side of the island, bringing cold waters from the Bering Sea. The Island is just to the north of the conjunction of the northern current, Oyashio, with the Kuroshio from the south. In winter, the Sakhalin current in the Sea of

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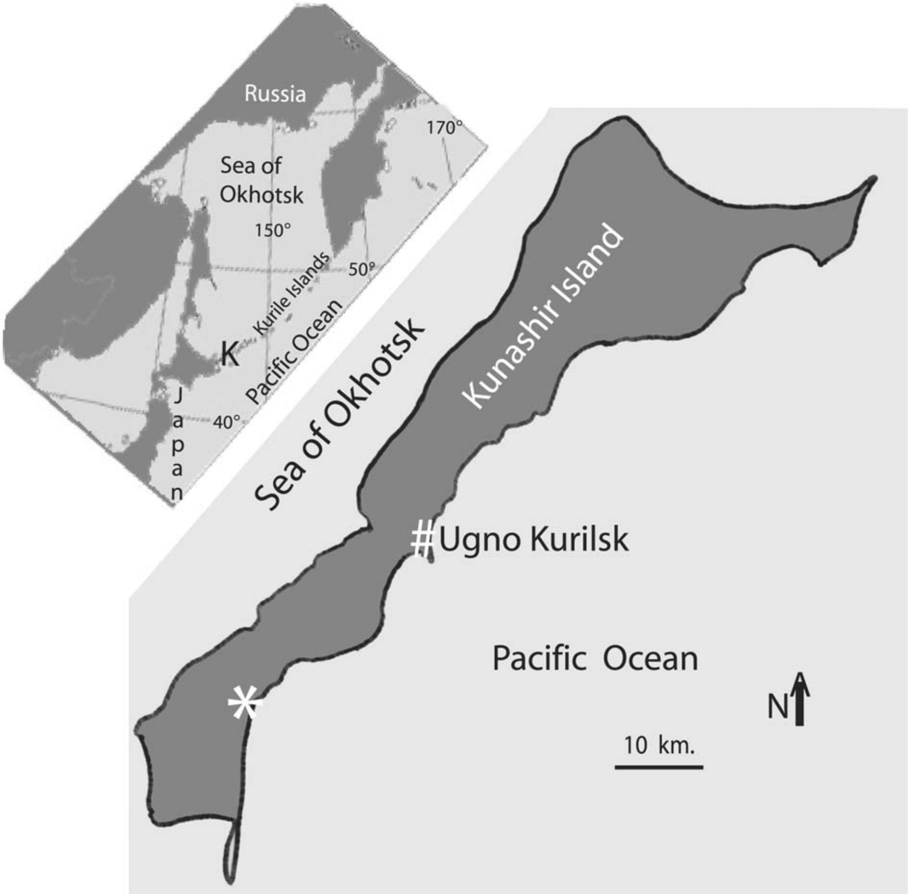

Fig. 1. Map of Kunashir Island at the southern extent of the Kurile Islands, Russia. The location of the island, meteorological station, and the sampling site are indicated by K, #, and ∗, respectively.

Okhotsk brings sea ice and cold water to Kunashir (Tabata, 1972a,b). Northerly to northwesterly winds come from the northeastern Asian region, influenced by the Asian High (Fukui, 1977). In summer, southerly to southeasterly winds from the central Pacific bring warmer temperatures to Kunashir (Martyn, 1988). There is a climatic gradient across the island from the Pacific side to the Okhotsk Sea side. Eastern side temperature fluctuations are slightly attenuated by the Pacific Ocean.

To develop paleoclimatic information about the area, a stand of oak trees was located and sampled within 1 km of the Pacific Ocean. The location is called Bryansky Forest (BRL, Bryanski Les) after a forest of the same name about 300 km from Moscow. The area is part of the Zapovednik Kurilsky (Kurile Preserve), a protected natural area. The tree-ring data were compared to local meteorological data and North Pacific climatic variations.

2. Tree-ring data

The Bryansky Forest (BRL) site is located near the east coast of the southern end of Kunashir Island about 37 km south of Ugno-Kurilsky by road, 43°52′ 47.0″N, 145°36′ 24.2″E. The road is along the east side of the stand of trees, and there is evidence of a previous road through the eastern margin of the site that is now grown over. All the trees sampled were at least one or more crown diameters away from the roads. Therefore, sun exposure and soil disturbance due to the roads would not have much effect on the trees. The terrain is flat. It is a closed canopy forest and the oaks are the dominant canopy trees. There are smaller birch (*Betula ermanii*) trees among them along with a dense bamboo understory.

Core samples were taken from 34 trees, but cores from several trees were not processed due to decay or cores being in multiple pieces. The final chronology was developed from 30 cores from 20 trees. The borers were sterilized with alcohol between each tree and the holes were sealed using a procedure developed by Savchenko (1994). The cores were mounted, surfaced, dated and measured using standard dendrochronological procedures. The resulting data were tested for dating accuracy using the COFECHA program (Holmes, 1983) and the ARSTAN procedure was used to develop the ring-width data into chronologies (i.e., time series of calendar-dated, ring-width indices—Cook, 1985; Cook and Kairiukstis, 1990). The ARSTAN program produces four chronologies. The RAW chronology is averaged raw ring-width measurements with no removal of age trends. The Standard (STD) and Arstan (ARS) chronologies can retain all frequencies, the former using averaged indices and the latter by modeling the communal low frequency and adding it back to the residual (RES) chronology. The RES chronology comprises residual indices after prewhitening the STD chronology to remove low-frequency variation. The STD and ARS are usually very similar, but the ARS chronology can reduce the effects of competition in closed canopy forests (Cook, 1985). Both the STD and the ARS chronologies were tested by comparison to the meteorological data and there was no significant difference between the results. The ARS and STD chronologies or ring-width indices correlate at 0.98 for the full 416-year length of the series. The chronology was terminated in 1600 due to small sample size and convenience in plotting.

The ARS chronology was used in these analyses because the site is a closed canopy stand. RBAR is

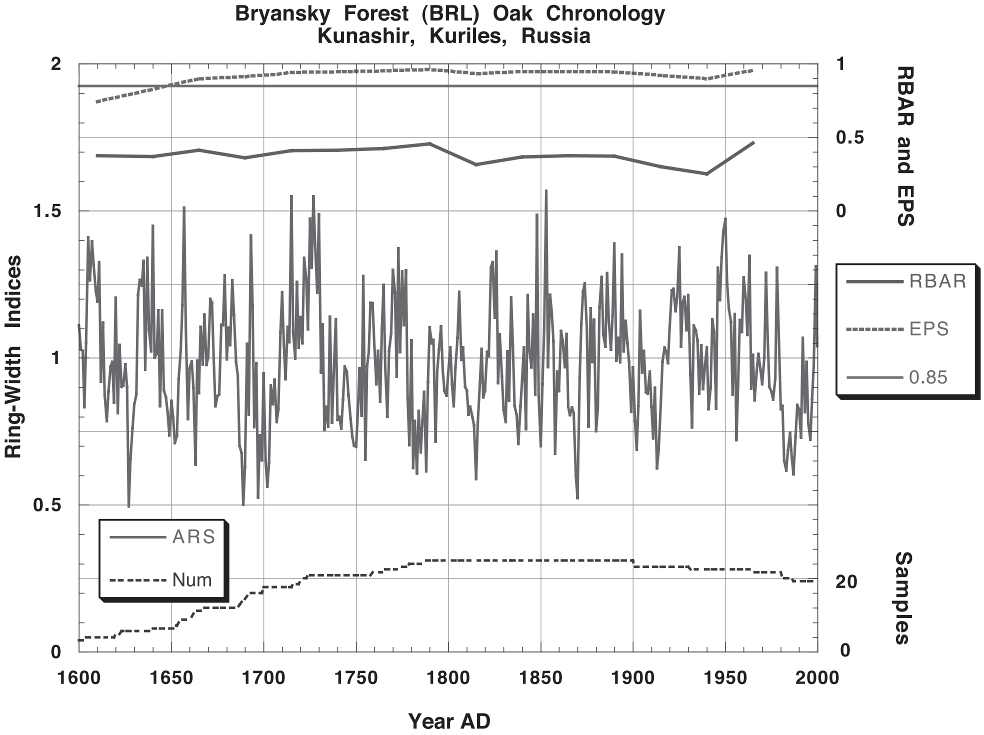

Fig. 2. The ARS chronology of ring-width indices for the Bryansky Forest (BRL) site on Kunashir Island. The chronology is displayed in the middle of the plot. The number of samples is the lowest curve. The upper two curves are RBAR (lower) and the EPS (upper). Note that the EPS is above 0.85 back until 1650.

the average correlation between indices for each year over sequential time periods, in this case 50 years in length. Expressed Population Signal (EPS) is a similar parameter for the agreement between trees or common variance in relation to total variance. An EPS over 0.85 is considered a generally acceptable threshold for reliable chronologies (Briffa and Jones, 1990). Fig. 2 shows the ARS chronology, RBAR, and EPS parameters.

3. Meteorological data

The meteorological record in the Global Historical Climate Network (GHCNv2) (Peterson and Vose, 1997) for Ugno-Kurilsky comprises temperature data from 1947 to 1989. The station is about 25 km northeast of the tree-ring sampling site. Monthly data of maximum, mean, and minimum temperatures are available. Precipitation data was taken from GHCNv1 (Vose et al., 1992). There are no other stations on the island with which to develop a multistation series of meteorological data. Due to the shortness of the Ugno-Kurilsky record, we also compared the tree-ring data to the nearest long record from Nemuro, Japan that extends from 1881 to 1990 to test for the climatic response. The Nemuro station is on a narrow peninsula extending eastward from the island of Hokkaido, Japan and is about 55 km south of the tree-ring site across the Nemuro Strait.

The Pacific Decadal Oscillation (PDO) is a key index of major variations in the North Pacific climate and ocean productivity (Mantua et al., 1997). First defined as "the leading principal component of North Pacific monthly sea surface temperature variability ("poleward of 20°N for the 1900–1993 period"), the PDO was recognized as an important parameter of North Pacific variation. Initial efforts of extending the record using proxy data showed some promise (Gedalof and Smith, 2001; Biondi et al., 2001), and a later reconstruction by D'Arrigo et al., (2001) using a more comprehensive data base explained 53% of the variation. The sources of proxy data were on the eastern side of the Pacific and only the cold season PDO was reconstructed. Cook (2002) made a reconstruction of spring–summer PDO. Because of the strong influence of sea-surface temperatures (SSTs) and the PDO on island temperatures, we related the tree-ring data to both data sets. Both cold season and warm season PDO relate to SSTs in the northwest Pacific. Positive values indicate colder temperatures in the northwest Pacific.

4. Analyses and results

The meteorological data were compared to the tree-ring data in correlation and principal component regression analyses (Cook and Kairiukstis, 1990). Each meteorological data set was tested using 24 months from January of the year preceding ring formation through December of the year of ring formation. The highest correlations were between the mean monthly maximum temperatures and the ring-width indices. The mean monthly maximum temperature values from Ugno-Kurilsky explained 57% of the variance in ARS ring-width indices with significant (0.05) correlation occurring mainly for the warm season months (Fig. 3). The variance explained by the mean monthly temperatures was 43% and by the mean monthly minimum temperatures was 27%. There were far fewer significant correlations between monthly precipitation and the tree-ring data. In the moist climate of Kunashir, the negative correlations for July and August are likely due to the inverse correlations between July and August temperatures and precipitation (– 0.375 and – 0.424, respectively) or the beneficial effects of less cloudiness during the growing season.

The season of June–September of the growth year was best for reconstruction because the inclusion of October slightly lowered the explained variance. The possibility of a 1-year lead of the tree-ring data was tested as there were significant correlations with prior year temperatures but there was no improvement in the regression and reconstruction. The explained variance after adjustment for loss of degrees of freedom due to the regression was 52% for the reconstruction (Fig. 4).

The Nemuro, Japan temperature data (1880–1990) was also tested to see the effects of the longer record. The pattern of the results was similar to the Ugno-Kurilsky results. There were significant correlations with June, July, August, and September temperatures, and the mean monthly maximum temperature also had the highest correlations. The 2-year temperature data

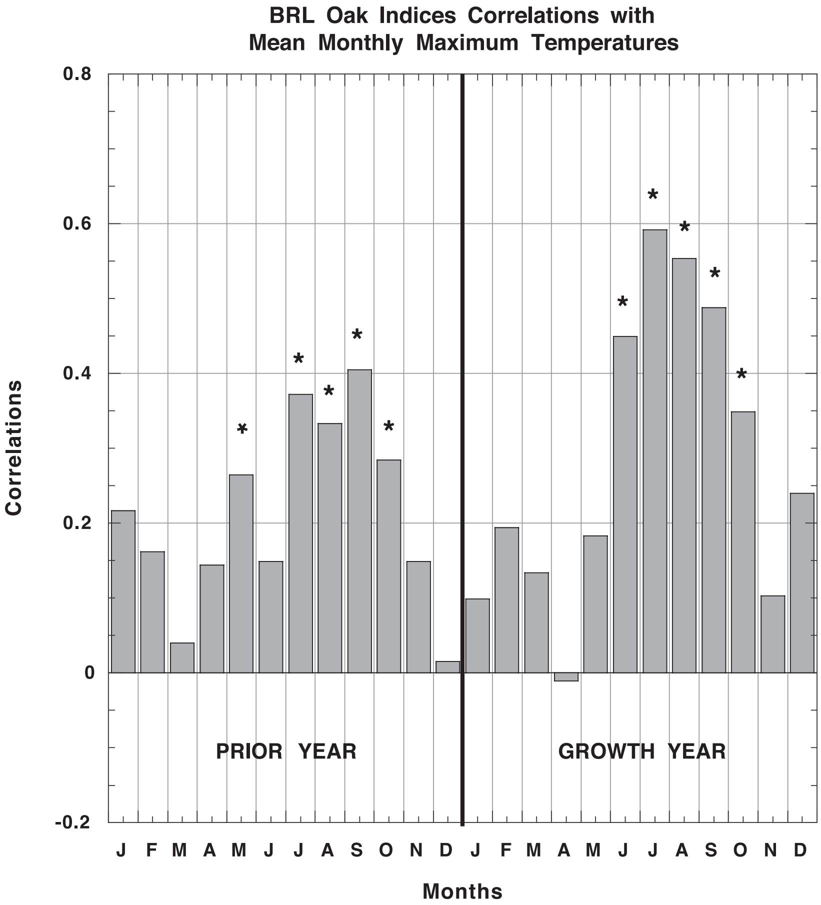

Fig. 3. The correlations between mean monthly maximum temperature and the ring-width indices. Because the reconstruction was a simple linear rescaling of the time series of ring-width indices, correlations between the mean monthly maximum temperatures and the reconstruction would be the same. The * marks correlations that are significant at the 0.05 level.

explained 38% of the variance in ring-width indices. Unlike previous results (e.g., Jacoby et al., 2000), combining two stations in this particular situation did not improve the results over using Ugno-Kurilsky alone. Using the combined two-station mean monthly maximum temperatures, the variance explained was only 44%.

5. Sea-surface temperatures and the Pacific Decadal Oscillation

We tested the tree-ring time series against sea-surface temperatures (SSTs) (Kaplan et al., 1998) and the PDO (Mantua et al., 1997). The spatial correlation between sea-surface temperatures (SSTs) and (1) the recorded temperature and (2) tree-ring indices are very similar. Both spatial patterns indicate correlation with SSTs across the North Pacific at about the same latitude as Kunashir.

We previously examined tree-ring series from Hokkaido (D'Arrigo et al., 1997; Davi et al., 2000) and Kamchatka (Gostov et al., 1996) and found less relation to the North Pacific SSTs although their interrelations appeared to indicate some oceanic effects. Both the Kamchatka larch and Hokkaido spruce are inland and not as exposed to maritime climate as the Kunashir trees. An oak (*Quercus dentata*) chronology from the Saroma site on Hokkaido (D'Arrigo et al., 1997) is about 140 km due

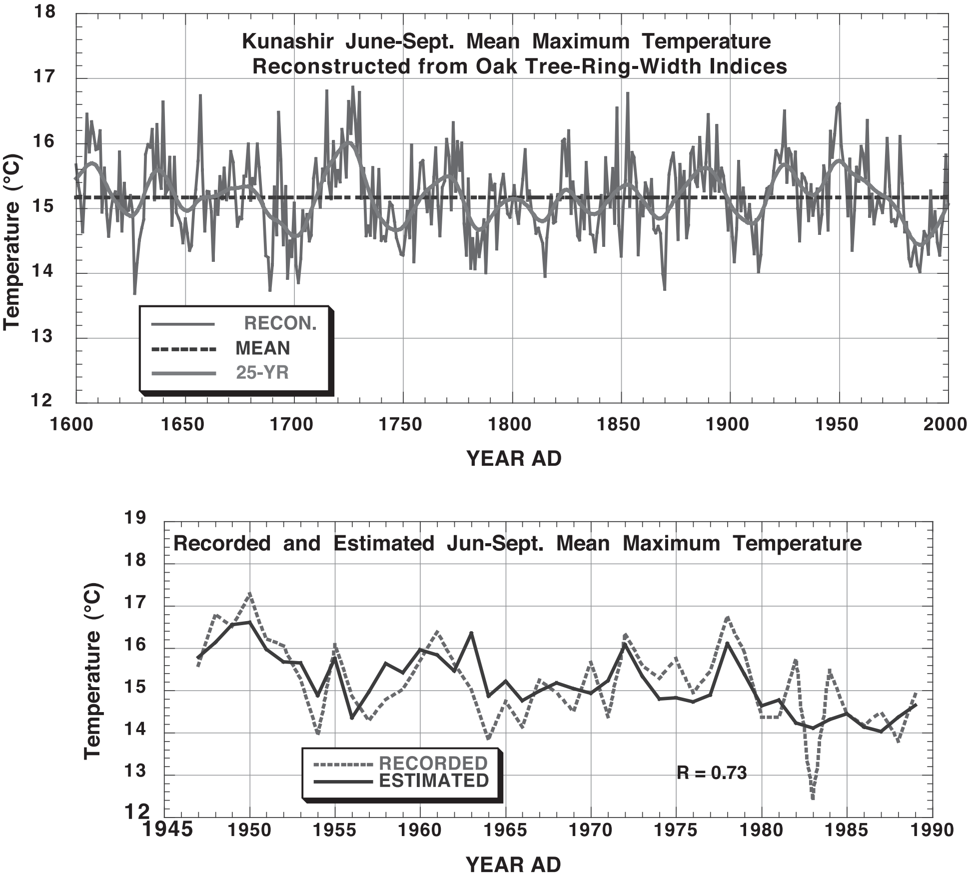

Fig. 4. The reconstruction of summer (June–September) mean maximum temperature. The final regression for the reconstruction was a simple linear equation to estimate °C. The lower curves are the recorded and estimated temperatures.

west of the BRL site. These oaks grow on a nutrient-poor, sandy soil spit whereas the BRL oaks grow on a much richer volcanic soil. The Saroma oaks have higher correlations with cold season temperatures, which is quite different from the BRL oaks. The correlation between these two series is 0.32 and they show similar variation in certain periods but also significant differences.

We screened the monthly PDO values correlations with the BRL time series for 1900–2000, and all the correlations were negative with July, August, and September being the strongest at −0.52, −0.44, and −0.44, respectively; and variance explained 25%. The negative correlation with the PDO was expected because a positive PDO indicates cooler temperatures in the northwest Pacific as previously stated. Using the years 1947–1989 (timespan covered by the temperature data), the temperature data explains 30% of the variance in the July–September PDO and the BRL oak chronology explains 33% of the variance. Thus for this time period, the trees are at least equal to the temperature record as predictors of PDO and possibly better. Because the temperature reconstruction is a linear transform of the oak indices, the oak series represents the June–September temperature and the July–September PDO with the same single series rescaled.

6. Spectral analyses

Both the tree-ring indices and the July–September PDO were analyzed using multitaper spectral analysis (Mann and Lees, 1996). The results (Fig. 5) show

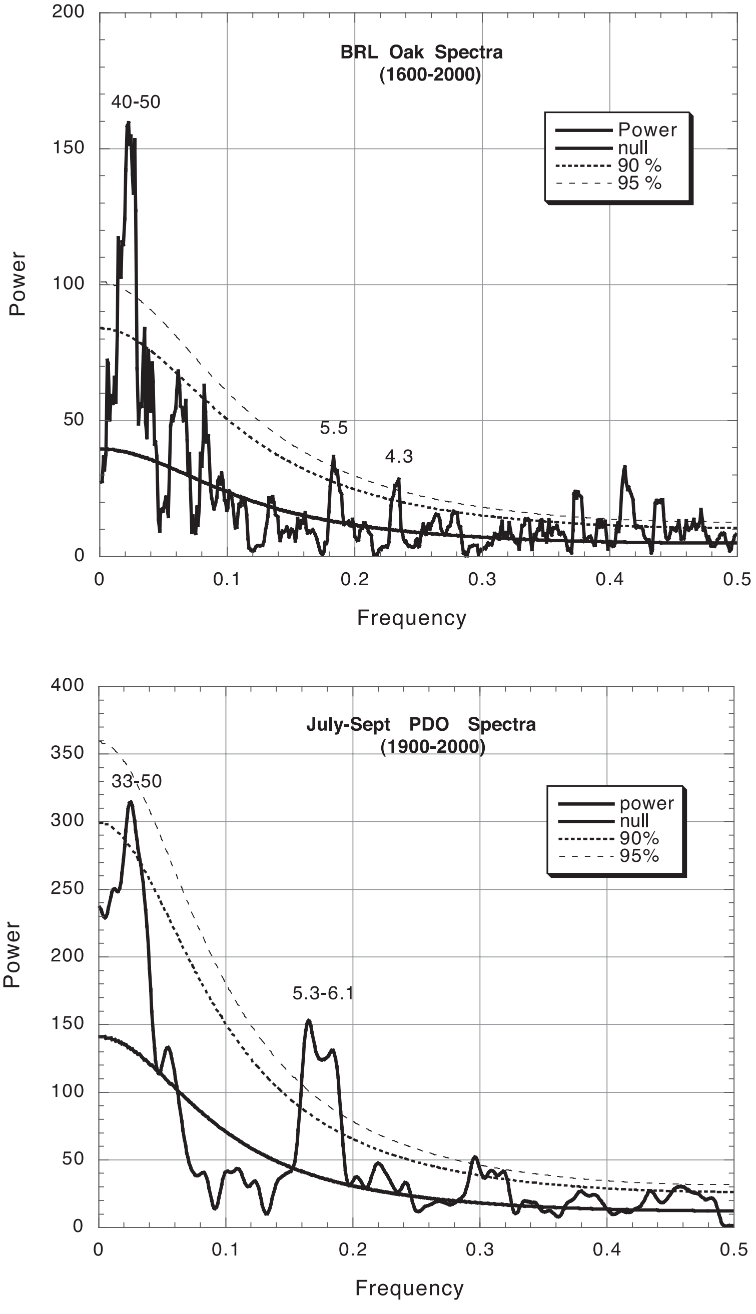

Fig. 5. Spectral patterns of the BRL oak series (1600–2000) (upper plot) and the July–September PDO (1900–2000) (lower plot). The spectral power and the null, 90%, and 95% confidence limits are shown. The numbers on the plots are periodicities in years.

similar spectral properties. The multidecadal peaks of 30–50 and 28 years in the oaks correspond to the broader 33–50-year peak in the PDO. The recorded PDO are based on a shorter record comprising fewer cycles. The oaks support the concept of long-term, multidecadal variations in the Pacific (e.g., D'Arrigo et al., 2001; Cook, 2002) and that such variation or shifts have been present in the Pacific for several centuries. There are also variations in the ENSO range of 4–6 years in both series.

7. Conclusion

The BRL chronology and analyses provide an extended temperature record for Kunashir and new information about North Pacific variations. The 1900–2000 portion of the oak chronology and reconstruction of mean monthly maximum temperature of June–September show correspondence to the summer PDO. The phase shifts of the 1940s, late 1970s, and, possibly, late 1990s are clearly captured along with other fluctuations. The plots (Fig. 4) suggest that similar phase shifts have occurred over the past 400 years. This record helps broaden the climatic information resource to the northwestern region of the Pacific where heretofore there was little long-term data.

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