Sample Collection

Living plants of *Clathromorphum nereostratum* were collected from hard substrate via SCUBA at 11 localities along the Aleutian Islands, Alaska (Figs. 1 and DR1). Specimens were a) obtained from museum collections established in 1969 (all live collected) (Herbarium of University of British Columbia and Smithsonian Institution, Washington D.C) and b) live collected in the field in August 2004 and June 2008. Percent macroalgal (e.g. kelp) cover was visually estimated by divers (estimates from two divers were averaged) during the 2008 collection at 7 localities ranging from macroalgal free to 100% macroalgal cover. Sampling depth was at 10m for the 2004 and 2008 collections, whereas the 1969 samples were collected between 10-33 m water depth.

Sample Preparation and Analysis

The air-dried *C. nereostratum* specimens were sectioned vertically parallel to the direction of growth using a rock saw. Slabs of up to 12x8x2cm were polished to 1µm. High-resolution digital images of the polished surface were produced using an automated reflected-light microscope system (Hetzinger et al., 2009). The resulting high-resolution photomosaics enabled the identification and lateral mapping of growth patterns over the entire sample (Fig. DR1). The formation of easily identifiable growth lines separating annual growth increments is due to large and poorly calcified cells forming in the spring, which overlay short and heavily calcified cells having developed in the previous year (Moberly, 1968). Furthermore, in *C. nereostratum* calcified conceptacles (spheroidal cavities accommodating reproductive sporangia of coralline alga –Fig. DR1c) form annually and assist in the detection of annual growth increments (Hetzinger et al., 2009).

Growth – kelp relationship

Vertical growth was digitally measured to 5µm precision on 70 short-lived coralline algal specimens (10 years of growth from 1997-2007) from 7 field sampling sites (e.g. 700 individual measurements) where macroalgal cover information was recorded by divers in 2008 (2008 collection only – see above). It is assumed that kelp cover recorded in 2008 remained unchanged during the previous 10 years. This assumption is based on persistently low numbers of sea otters in the Aleutians since the 1990s (Laidre et al., 2006). Sea otters control kelp abundance through consumption of sea urchins, which in turn use kelp as their primary food source (Estes et al., 1998).

Composite growth-increment width chronology

In addition, vertical growth was measured on 29 long-lived specimens ranging from 15 to 185 years in ontogenetic age (Table DR2). A 225-year growth-increment width composite

chronology (1782-2007) was compiled by calculating the arithmetic mean of all 29 normalized growth-increment width time series (age uncertainties 1-3 years per time series; normalization to unit variance was conducted by subtracting the mean and dividing by the standard deviation; normalized time series available in DR6). The robustness of the early portion of the chronology of the composite time series is confirmed by 2 records (AM-KR-80 and AM-KR-70) extending to 1783 and 1785, respectively. Both records show similar growth anomalies throughout and are significantly correlated (r_{annual}=0.43, p< 0001; 1785-1968; Figure DR5). All samples containing a growth record prior to 1877 were collected at or below 20 m water depth (see Table DR2), with 20 m water depth being the limit of kelp growth in the Aleutian Islands (Estes, 2008). Hence, all samples from the early part of the chronology are from locations that were kelp free throughout the lifespan of the samples, and unaffected by local variability related for example to local changes in sea otter abundance.

Similarities were evaluated between the growth-increment width composite chronology, instrumental and historical observations between 1924 and 2007 - the period of most reliable instrumental observations (Fig. 3). All p-values of smoothed data have been adjusted for loss of degrees of freedom in order to account for the correlation of means. Instrumental temperature observations were obtained from gridded SST data available from the National Oceanic and Atmospheric Administration Extended Reconstructed Sea Surface Temperature version 3 data set (NOAA ERSST.v3 — Smith et al., 2008) for the 50-55°N; 165°E-170°W grid spanning all algal collection sites (Fig. 3). The instrumentally derived PDO index was obtained from http://jisao.washington.edu/pdo/PDO.latest (Mantua et al., 1997). The Aleutian Low Pressure index is available at http://www.pac.dfo-mpo.gc.ca/science/species-especes/climatology-ie/cori-irco/indices/alpi.txt (Beamish et al., 1997). A Bering Sea cloud cover time series (1924-2007) was developed from the ICOADS (International Comprehensive Ocean-Atmosphere Data Set) 2-degree enhanced cloud cover data (Worley et al., 2005). Total cloud cover is coded as a number (N) from 0 to 8, indicating eighths (octas) of sky cover. A measurement of 9 octas indicates sky obscured due to fog, rain or snow; the latter number is not integrated into ICOADS cloud cover data set (Hahn et al., 1992). In the Bering Sea the cloud cover dataset is spatially and temporally incomplete, as this region is characterized by low cloud cover sampling density (Norris, 2000) and measurements are hampered by persistent fog, which accounts for more than 20% of sky-obscured-due-to-fog observations in the North Pacific above 40°N (Hahn et al., 1992). Sockeye salmon landing data for western and central Alaska (Figures 3 and 4) were obtained from Eggers et al. (2005). A distinct increase in the Aleutian Low Pressure Index (ALPI) since the 1990s is not recorded by the algae. A likely explanation is that industrial whale hunting has changed the prey of killer whales from whales to sea otters (Springer et al., 2003). Sea otter populations in the Aleutian Islands began to collapse in the 1990s causing sea urchins (an important food source of sea otters) to overgraze the kelp forest ecosystem (Springer et al., 2003). Kelp forests have been in sharp decline throughout the Aleutians, which enhanced light on the seafloor causing algal growth rates to increase with respect to the increasing strength of the ALPI since the 1990s.

Figure DR1—*Clathromorphum nereostratum* from the Aleutian Islands. Direction of growth upwards in all images. A) Large live-collected coralline plant (weight ~60 kg, vertical thickness 30 cm); B) Annual growth increments in cross section, fragment had life span of 136 years; C) Detail of cross section showing annual growth increments and circular conceptacle (=reproductive) structures. D) Large, poorly calcified spring cells overlay heavily calcified cells formed in previous year, conceptacle shown in center of image. Dashed lines delimit annual growth breaks.

Table DR1—Description of samples used for coralline algal growth-increment width composite chronology

Figure DR2—Spatial correlations of algal growth time series with global sea-level pressure anomalies for the period 1924-2007 (Trenberth and Paolino, 1980) conducted using Climate Explorer (Oldenborgh et al., 2009); only regions with significant correlations ($p<10\%$) are shaded. Note significant correlations with eastern Bering Sea and eastern North Pacific, the center of SLP anomalies associated with AL. Location of AL in January (as defined by <= 100.5 kPa sea level pressure contour) shown by dashed lines, intense AL encompassing much of Bering Sea and North Pacific (long dashed line), weak AL confined to southeastern Bering Sea, Aleutian Islands, and western Gulf of Alaska (short dashed line) (Beamish and Bouillon, 1993).

Figure DR3—Wavelet power spectrum of algal growth-increment width time series indicating multidecadal scale variability centered at 20-30 and 50-70 years (Morlet wavelet, wave-number = 6). A red noise background spectrum (increasing power with decreasing frequency) was chosen to determine significance levels for the wavelet power spectrum (Torrence and Compo, 1998). Hatched area identifies cone of influence where edge effects become significant. Note that ~30 year variability becomes insignificant between ~1830 and ~1920, whereas 50-70 year variability is significant throughout time span outside the cone of influence. Wavelet decomposition can detect local features of a signal and allows for multi-level resolution of a signal. Black contours denote regions of significance $p \leq 0.1$. Calculated at http://paos.colorado.edu.research/wavelets/ (Torrence and Compo, 1998).

Figure DR4—Comparison of coralline algal time series AM-KR-80 and AM-KR-70 extending to 1783 and 1785, respectively. Both records show similar growth anomalies throughout and are significantly correlated ($r_{annual}=0.43$, $p< 0001$; 1785-1968).

Table DR2—225-year growth-increment width composite chronology (1782-2007) compiled by calculating the arithmetic mean of 29 normalized growth-increment width time series.

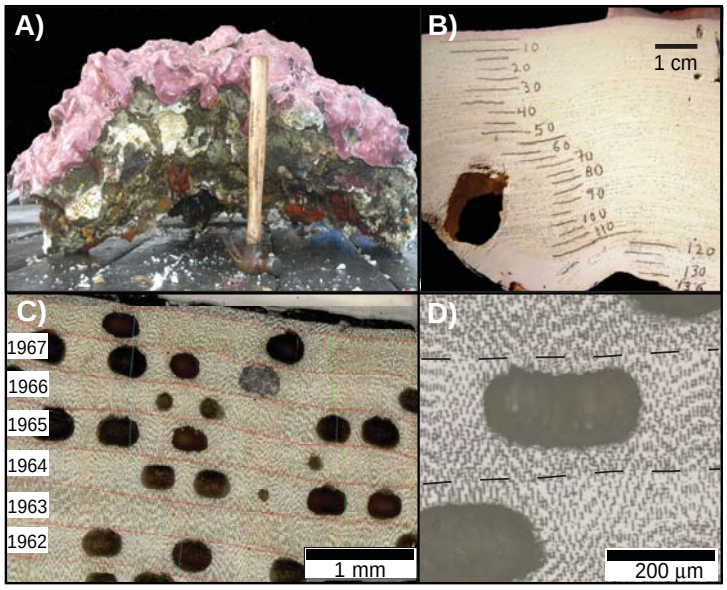

Fig DR1

Table DR1 – Description of samples used for coralline algal growth-increment width composite chronology

Location	Sample #	End of Record	Start of Record	Length of Record (years)	Water Depth	Latitude	Longitude	Average Annual Growth
Akun	08-10-27	2007	1947	60	10	N 54° 12.945	W 165° 30.850	450
	08-10-24	2007	1958	49	10	N 54° 12.945	W 165° 30.850	406
	08-10-13	2007	1966	41	10	N 54° 12.945	W 165° 30.850	425
	08-10-42	2007	1963	44	10	N 54° 12.945	W 165° 30.850	362
Amchitka	AM-KR-70-A	1968	1783	185	20	N 53° 38.560	E 178° 44.928	287
	AM-KR-70-B	1968	1925	43	20	N 53° 38.560	E 178° 44.928	300
	AM-KR-80	1968	1785	183	25	N 53° 38.560	E 178° 44.928	295
	AM-OC-70	1968	1936	32	20	N 53° 38.560	E 178° 44.928	350
	AM-KP-80	1968	1901	67	25	N 53° 38.560	E 178° 44.928	300
	AM-SM-30	1968	1940	28	10	N 53° 38.560	E 178° 44.928	357
	AM-BI-100	1968	1927	41	30	N 51° 25.566	E 179° 14.275	304
	AM-BI-110-U	1968	1890	78	33	N 51° 25.566	E 179° 14.275	288
	AM-BI-110-A	1968	1883	85	33	N 51° 25.566	E 179° 14.275	284
	7-6	2003	1934	69	10	N 51° 24.541	E 179° 23.008	465
	4-1	2003	1960	43	10	N 51° 25.568	E 179° 14.277	342
	4-7	2003	1963	40	10	N 51° 25.566	E 179° 14.275	296
	4-16	2003	1965	38	10	N 51° 25.566	E 179° 14.275	337
Ogliuga	08-06-18	2007	1988	19	10	N 51° 49.750	E 178° 15.100	418
	08-06-14	2007	1961	46	10	N 51° 49.750	E 178° 15.100	453
	08-06-12	2007	1968	39	10	N 51° 49.750	E 178° 15.100	467
	08-06-11	2007	1981	26	10	N 51° 49.750	E 178° 15.100	459
Rat	08-04-16	2007	1973	34	10	N 51° 49.750	E 178° 15.100	321
	08-04-22	2007	1969	38	10	N 51° 49.750	E 178° 15.100	322
	08-04-29	2007	1981	26	10	N 51° 49.750	E 178° 15.100	363
	08-04-39	2007	1992	15	10	N 51° 49.750	E 178° 15.100	468
Attu	11-4	2003	1877	126	10	N 52° 47.787	E 173° 10.796	394
	08-1-38-1	2007	1985	22	10	N 52° 56.016	E 173° 15.970	422
	08-1-26	2007	1989	18	10	N 52° 56.016	E 173° 15.970	481
	08-1-25	2007	1984	23	10	N 52° 56.016	E 173° 15.970	499
	08-1-18	2007	1984	23	10	N 52° 56.016	E 173° 15.970	456

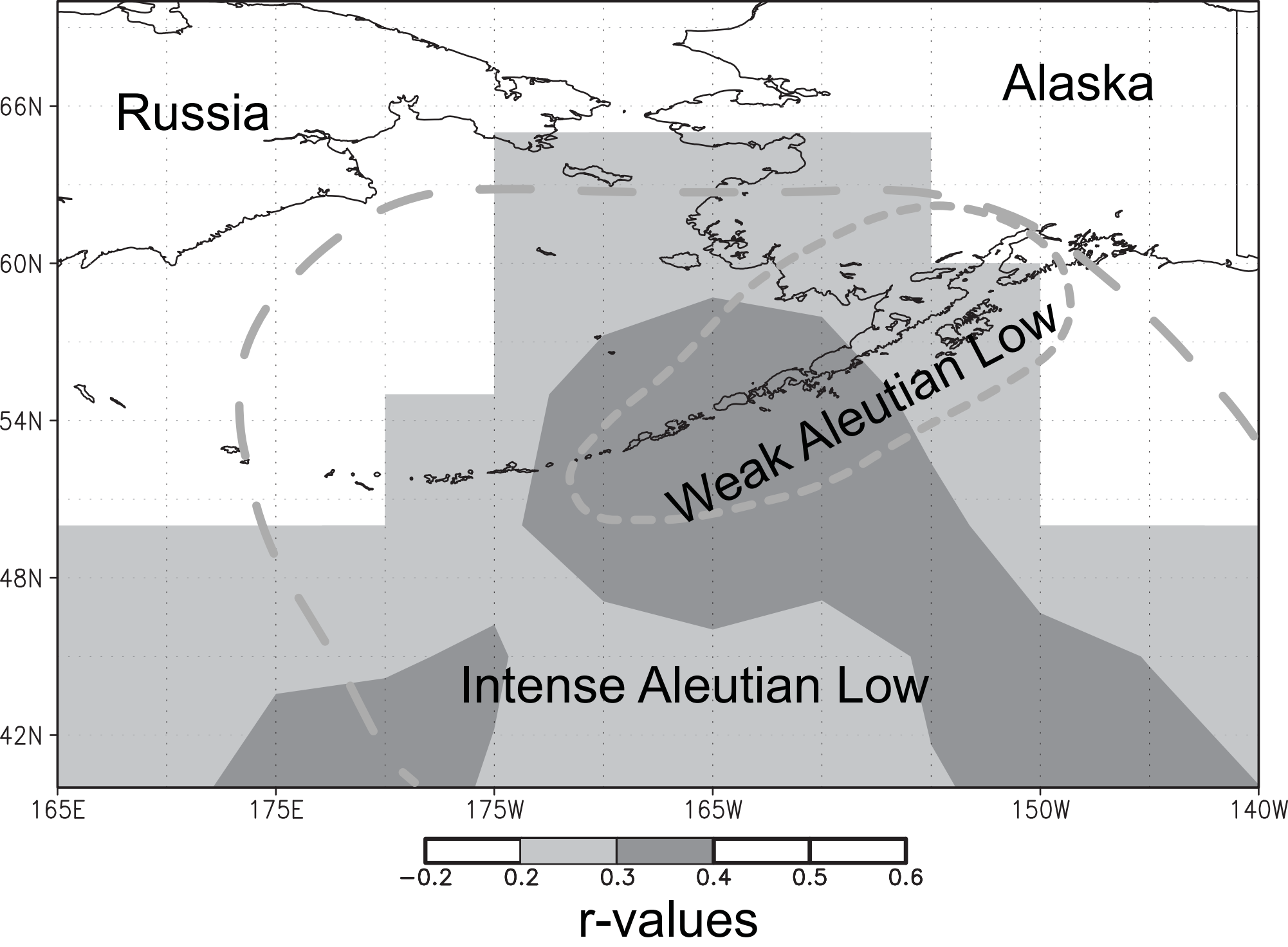
Russia
Alaska
Weak Aleutian Low
Intense Aleutian Low
66N
60N
54N
48N
42N
165E
175E
175W
165W
150W
140W
−0.2
0.2
0.3
0.4
0.5
0.6
r-values

Figure DR2

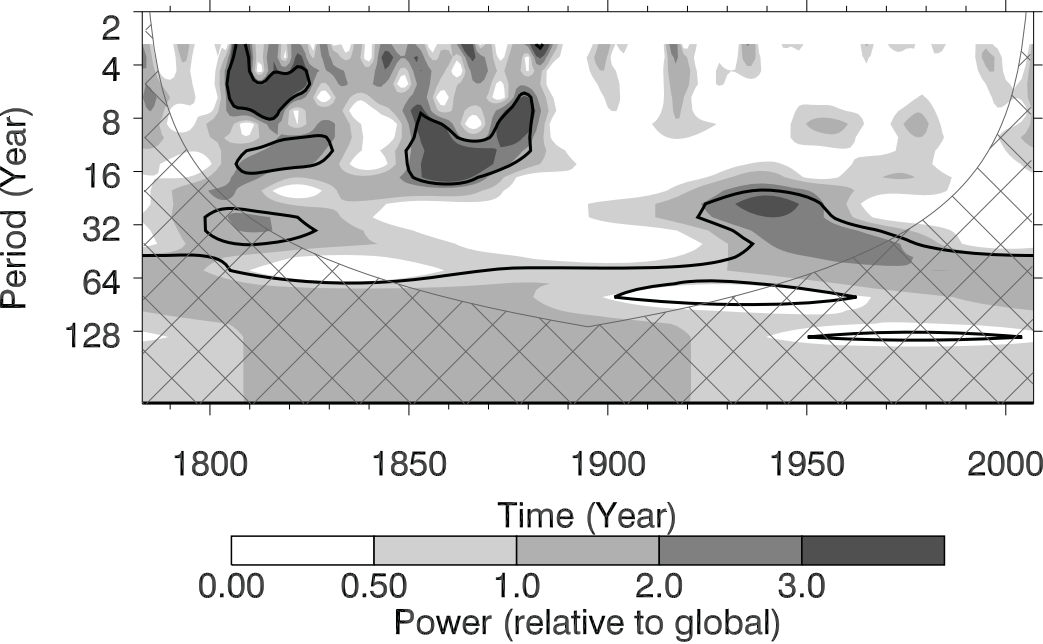
Period (Year)
2
4
8
16
32
64
128
1800
1850
1900
1950
2000
Time (Year)
0.00
0.50
1.0
2.0
3.0
Power (relative to global)

Figure DR3

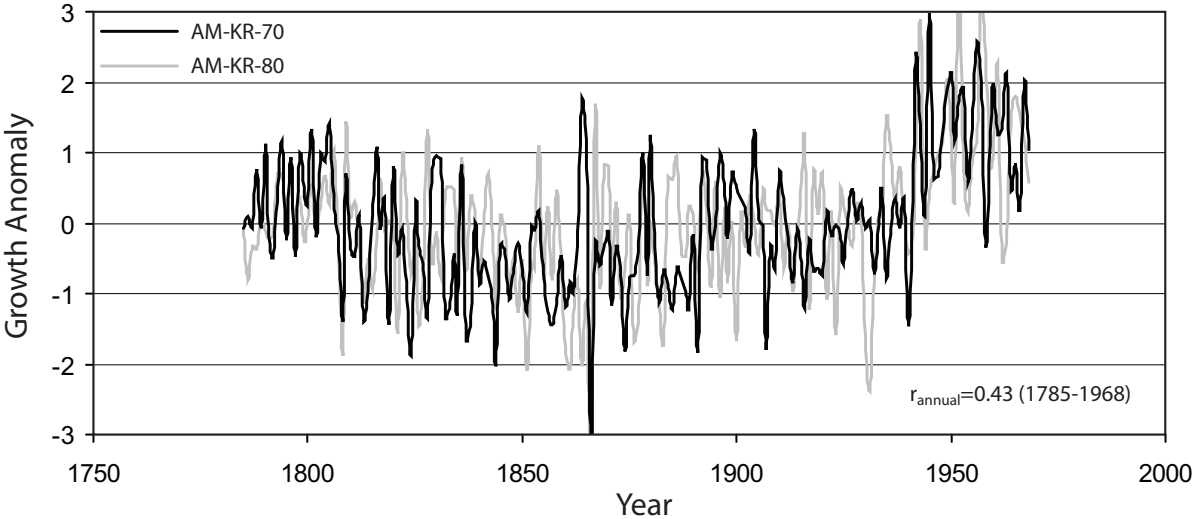
AM-KR-70
AM-KR-80
Growth Anomaly
3
2
1
0
-1
-2
-3
1750
1800
1850
1900
1950
2000
Year
r annual=0.43 (1785-1968)

Figure DR4

Table DR2.

Year	Algal Growth Normalized	Year	Algal Growth Normalized	Year	Algal Growth Normalized	Year	Algal Growth Normalized
2007	-0.03	1949	0.55	1891	-0.05	1833	-0.41
2006	0.16	1948	0.82	1890	-0.20	1832	0.69
2005	-0.04	1947	0.05	1889	-0.39	1831	0.09
2004	0.17	1946	0.45	1888	-0.45	1830	0.32
2003	0.11	1945	-0.15	1887	-0.09	1829	-0.92
2002	-0.10	1944	-0.08	1886	-0.32	1828	0.38
2001	-0.12	1943	0.14	1885	-0.59	1827	-0.57
2000	-0.27	1942	-0.27	1884	0.25	1826	-0.58
1999	-0.29	1941	-0.08	1883	-0.86	1825	-1.02
1998	0.14	1940	-0.54	1882	-0.82	1824	-0.85
1997	0.34	1939	-0.12	1881	0.39	1823	0.07
1996	0.13	1938	-0.30	1880	-0.22	1822	0.25
1995	-0.31	1937	0.15	1879	0.31	1821	-0.37
1994	-0.07	1936	-0.52	1878	0.02	1820	-0.74
1993	0.23	1935	-0.40	1877	-0.84	1819	0.18
1992	-0.22	1934	0.31	1876	-1.22	1818	-0.08
1991	-0.07	1933	-0.14	1875	-0.86	1817	0.86
1990	-0.25	1932	0.13	1874	-0.64	1816	-0.04
1989	-0.01	1931	-0.01	1873	-0.67	1815	-0.95
1988	-0.21	1930	0.37	1872	-0.43	1814	-0.93
1987	-0.07	1929	0.45	1871	-0.54	1813	-0.52
1986	-0.17	1928	0.43	1870	0.23	1812	-0.34
1985	-0.20	1927	-0.02	1869	0.10	1811	-0.03
1984	0.15	1926	0.03	1868	-0.61	1810	0.40
1983	-0.56	1925	0.22	1867	-0.71	1809	0.01
1982	0.21	1924	0.28	1866	-0.87	1808	-1.06
1981	-0.43	1923	0.15	1865	0.33	1807	-0.01
1980	-0.38	1922	0.26	1864	-1.18	1806	1.23
1979	-0.63	1921	-0.27	1863	-0.89	1805	0.57
1978	-0.52	1920	0.66	1862	-1.10	1804	0.83
1977	-0.06	1919	0.14	1861	-1.63	1803	0.03
1976	0.10	1918	0.51	1860	-1.16	1802	0.60
1975	-0.04	1917	-0.81	1859	-0.85	1801	0.42
1974	0.30	1916	-0.27	1858	-0.48	1800	0.21
1973	0.30	1915	0.10	1857	-1.03	1799	0.35
1972	-0.05	1914	-0.13	1856	-0.23	1798	-0.06
1971	0.20	1913	0.11	1855	-0.31	1797	0.53
1970	0.15	1912	-0.06	1854	0.50	1796	0.10
1969	-0.16	1911	-0.03	1853	-0.34	1795	0.70
1968	0.28	1910	0.21	1852	-0.90	1794	0.55
1967	-0.10	1909	-0.03	1851	-1.38	1793	0.11
1966	0.46	1908	-0.09	1850	-0.41	1792	-0.17
1965	0.15	1907	0.09	1849	-0.96	1791	0.45
1964	-0.24	1906	-0.14	1848	-0.79	1790	-0.09
1963	0.13	1905	0.10	1847	-0.65	1789	0.39
1962	0.04	1904	-0.38	1846	-0.18	1788	-0.21
1961	0.32	1903	0.70	1845	-0.96	1787	-0.12
1960	0.34	1902	-0.20	1844	-1.18	1786	-0.44

1959	0.36	1901	0.52	1843	-0.52	1785	-0.10
1958	0.79	1900	-0.36	1842	0.08	1784	0.42
1957	0.63	1899	-0.21	1841	-0.43	1783	1.01
1956	0.70	1898	0.15	1840	-0.43		
1955	0.44	1897	0.42	1839	-0.64		
1954	0.14	1896	-0.07	1838	-0.64		
1953	0.57	1895	0.12	1837	0.06		
1952	0.10	1894	0.05	1836	-0.17		
1951	0.51	1893	0.30	1835	-0.61		
1950	0.40	1892	-0.17	1834	-0.39		