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Site Index of Sitka Spruce Along the Pacific Coast Related to Latitude and Temperatures

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ABSTRACT. Equations were developed which show that site index (100 years) of Sitka spruce along the North Pacific coast is highly correlated with latitude and mean annual growing degree days. Site decreases approximately 1 m per degree of latitude, averaging about 48 m in Lincoln County, Oregon, and 33 m in northern southeast Alaska. Farther north and west, Yakutat, Prince William Sound, and Kodiak average much lower in site than predicted by latitude or growing degree days. Sitka spruce will grow and reproduce in some areas of the naturally treeless Aleutian Islands but growth there is very slow. FOREST SCI. 25:145–153.

ADDITIONAL KEY WORDS. *Picea sitchensis*, growth.

SITKA SPRUCE (*Picea sitchensis* (Bong.) Carr.) occupys an extended north–south range along the North Pacific coast spanning about 22 degrees of latitude. It grows best near sea level with site index generally decreasing northward. Although this decrease in site index with latitude is evident from growth and yield studies (Taylor 1934, Meyer 1937), it has not been analyzed.

In southern British Columbia and the Pacific Northwest, Sitka spruce is restricted to a narrow band immediately adjacent to the coast and to valley bottoms of major coastal rivers. Its range in longitude and elevation widens in central coastal British Columbia and southeast Alaska to include a narrow mainland strip and numerous islands up to 200 km offshore where spruce grows from sea level to elevations of about 1,000 m. The most extensive stands occur in southeast Alaska where about 90 percent of the U.S. supply and about 60 percent of the world supply of Sitka spruce timber is located.

Abundant moisture and lack of a pronounced summer drought appear necessary for development of Sitka spruce. Summer dry spells are rare in areas of good spruce development (Table 1), and where most pronounced, their effects are often lessened by summer fog (Isaac 1946).

Many environmental factors doubtless contribute to site differences along the coast; these include heat available for tree growth and soil development, soil parent material, drainage, precipitation, cloudiness, and day length. The objective of this study was to determine if many of these factors could be integrated into simple, meaningful relationships between site index and growing degree days and/or latitude. Such relationships could help land managers compare potential productivity of forest land, and anomalies could point to areas of special interest to researchers.

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TABLE 1. Mean annual and selected monthly data for representative stations within the natural range of Sitka spruce, 1950–74.

Station	Latitude N	Longitude W	Degree days[a]	Precipitation	July precipitation	Days per month with trace or more of precipitation				Snowfall	Frost-free days
						June	July	Aug.	Sept.		
			number	*cm*	*cm*	*number*				*cm*	*number*
Oregon:											
Brookings	42°03′	124°17′	2,511	204.9	0.4	9	6	7	8	1	294
Otis	45°02′	123°56′	2,131	250.2	2.8	15	8	9	12	13	192
Washington:											
Forks	47°57′	124°22′	1,942	297.8	5.4	14	9	12	12	43	190
British Columbia:											
Quatsino	50°32′	127°37′	1,697	235.2	4.4	10	10	13	15	58	200
Langara	54°15′	133°03′	1,204	165.5	7.4	19	20	20	22	71	241
Alaska:											
Annette	55°02′	131°34′	1,408	298.0	13.1	20	19	20	21	142	210
Sitka	57°04′	135°21′	1,221	214.4	11.7	20	19	21	24	114	196
Juneau	58°22′	134°35′	1,014	134.5	10.7	21	21	22	23	279	129
Cordova	60°30′	145°30′	851	226.6	17.5	22	24	23	22	340	111
Seward	60°07′	149°27′	989	151.4	7.2	16	16	19	20	221	153

[a] Base: 5°C.

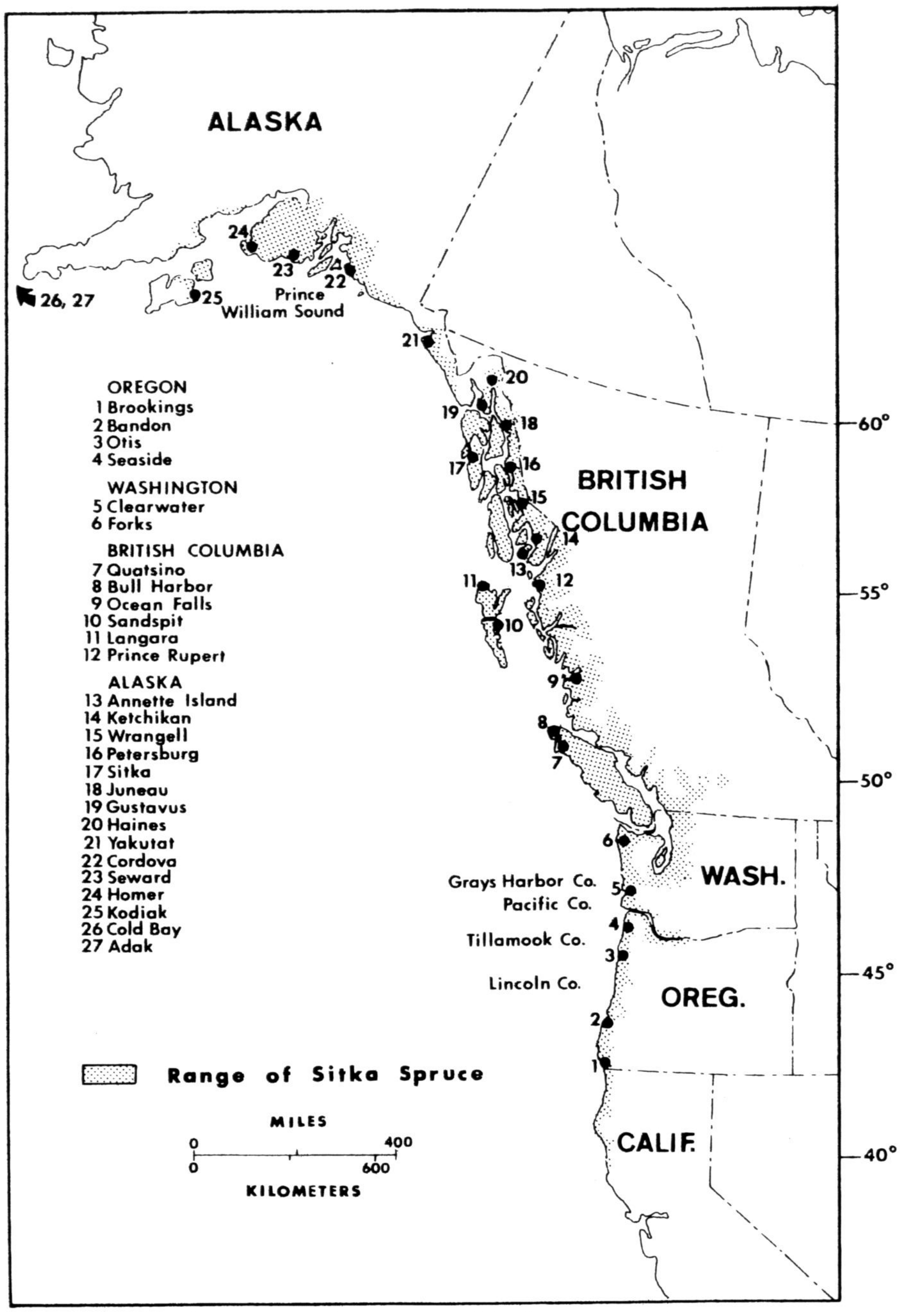

FIGURE 1. Location of selected weather stations within the range of Sitka spruce and geographical areas referred to in the analysis.

METHODS

Temperature data were summarized for 27 coastal stations within the range of Sitka spruce (Fig. 1) for the 25-year period 1950–74. All stations were located near sea level. Daily maximum and minimum temperatures were obtained from

TABLE 2. Mean number of growing degree days per year above various base temperatures, plus or minus one standard error (+SE), by stations, for the period 1950–74.

Station	Latitude	Mean number of degree days above—			
		0°C (32°F)	5°C (41°F)	15.6°C (60°F)	21.1°C (70°F)
Oregon:					
Brookings	42°03′	4,286 ± 34	2,511 ± 31	233 ± 8	41 ± 3
Bandon	43°07′	3,846 ± 64	2,155 ± 47	123 ± 13	7 ± 2
Otis	45°02′	3,785 ± 38	2,131 ± 33	231 ± 11	34 ± 3
Seaside	45°59′	3,966 ± 36	2,264 ± 32	193 ± 8	23 ± 2
Washington:					
Clearwater	47°35′	3,562 ± 37	1,963 ± 31	226 ± 10	38 ± 3
Forks	47°57′	3,517 ± 37	1,942 ± 30	257 ± 12	56 ± 5
British Columbia:					
Quatsino	50°32′	3,252 ± 44	1,697 ± 34	156 ± 12	20 ± 3
Bull Harbor	50°40′	3,029 ± 43	1,434 ± 32	26 ± 2	1 ± 0
Ocean Falls	52°50′	3,127 ± 51	1,676 ± 38	188 ± 14	28 ± 5
Sandspit	53°15′	2,943 ± 38	1,455 ± 29	20 ± 4	0
Langara	54°15′	2,750 ± 44	1,204 ± 29	11 ± 2	0
Prince Rupert	54°20′	2,728 ± 45	1,294 ± 31	43 ± 5	2 ± 1
Alaska:					
Annette Island	55°02′	2,837 ± 54	1,408 ± 39	98 ± 8	13 ± 2
Ketchikan	55°21′	2,911 ± 48	1,472 ± 33	121 ± 7	16 ± 2
Wrangell	56°28′	2,391 ± 48	1,143 ± 33	61 ± 7	3 ± 1
Petersburg	56°49′	2,281 ± 33	1,080 ± 21	54 ± 4	3 ± 1
Sitka	57°03′	2,611 ± 37	1,221 ± 24	38 ± 3	2 ± 1
Juneau	58°22′	2,135 ± 28	1,014 ± 19	71 ± 5	9 ± 1
Gustavus	58°25′	2,146 ± 42	994 ± 29	47 ± 4	4 ± 1
Haines	59°13′	2,263 ± 32	1,159 ± 22	91 ± 6	12 ± 1
Yakutat	59°31′	1,868 ± 41	819 ± 23	19 ± 2	2 ± 1
Cordova	60°30′	1,893 ± 37	851 ± 22	34 ± 3	3 ± 1
Seward	60°07′	2,062 ± 38	989 ± 25	74 ± 28	5 ± 1
Homer	59°38′	1,712 ± 27	754 ± 16	15 ± 2	1 ± 0
Kodiak	57°48′	2,002 ± 41	861 ± 24	33 ± 4	3 ± 1
Cold Bay	55°12′	1,593 ± 36	577 ± 21	4 ± 1	0
Adak	51°53′	1,837 ± 26	609 ± 17	4 ± 1	0

U.S. and Canadian monthly weather summaries (U.S. Weather Bureau 1950–74, Canada Atmospheric Environmental Service 1950–74).

The computer program described by Baskerville and Emin (1969) was used to compute total annual growing degree days[1] above 0.0°C (32°F), 5.0°C (41°F), 15.6°C (60°F), and 21.1°C (70°F) from maximum and minimum daily temperatures (Table 2). No maximum threshold temperature was imposed as temperatures during the growing season are rarely high enough to limit growth.

Mean annual degree days above each of the threshold temperatures was regressed against latitude to test the hypothesis that degree days is inversely related to latitude, and to evaluate the usefulness of the different threshold temperatures.

Information on site index was obtained from growth and yield data collected in the 1920's and 1930's for normal yield tables (Taylor 1934, Meyer 1937), from

[1] One degree day is accumulated for each 1°C rise in temperature above the daily mean when the daily mean temperature is above the minimum threshold.

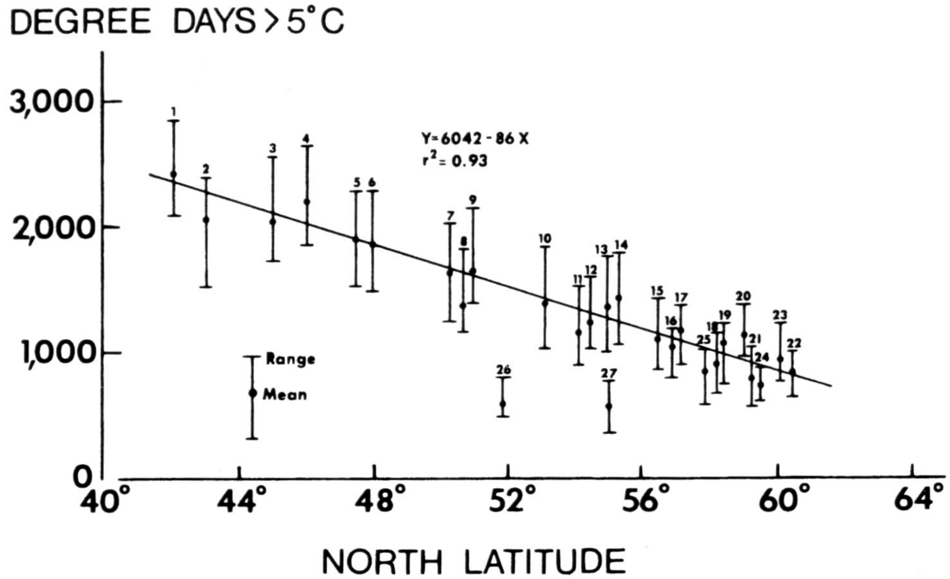

FIGURE 2. Relationship between degree days above 5°C and latitude for 25 stations along the North Pacific coast. Adak (27) and Cold Bay (26) were significant outliers and were not included in the regression. (See Figure 1 for station names.)

unpublished growth and yield studies in various areas within Alaska,[2] and from information provided for the Queen Charlotte Islands by McMillan Bloedel Limited.[3] All data were from even-aged stands located below 100 m in elevation. Provisional site index curves (index age 100 years) for Sitka spruce,[4] based on average height of dominant and codominant spruce and total age, were used to estimate site index of each of several hundred field plots. The coast was arbitrarily divided into several geographic areas where there were sufficient data to calculate an average site index. Data were available for the northern and southern portions of the range, but only for the Queen Charlotte Islands in Canada. Data were averaged by county in Oregon and Washington, and by broader areas within Alaska. A single average site index was used for each geographical area instead of individual plot values because a corresponding estimate of average growing degree days could not be calculated for each site index plot.

Mean site index for each area was regressed against latitude to test the hypothesis that mean site index is inversely related to latitude. Mean site index was also regressed against mean growing degree days to test the hypothesis that mean site index is inversely related to mean growing degree days. An estimate of mean growing degree days for each of the areas used in the regression was obtained from the relationship between degree days and latitude.

RESULTS

Relationships between mean number of annual degree days and latitude were linear and highly correlated ($P \leq 1$ percent). The best correlation was between degree days above 5°C and latitude (Fig. 2); however, we suspect that other

[2] Data on file, Forestry Sciences Laboratory, Juneau, Alaska.

[3] Personal correspondence with Don R. Reimer, MacMillan Bloedel Limited, Nanaimo, B.C., Canada.

[4] Data on file, Forestry Sciences Laboratory, Juneau, Alaska.

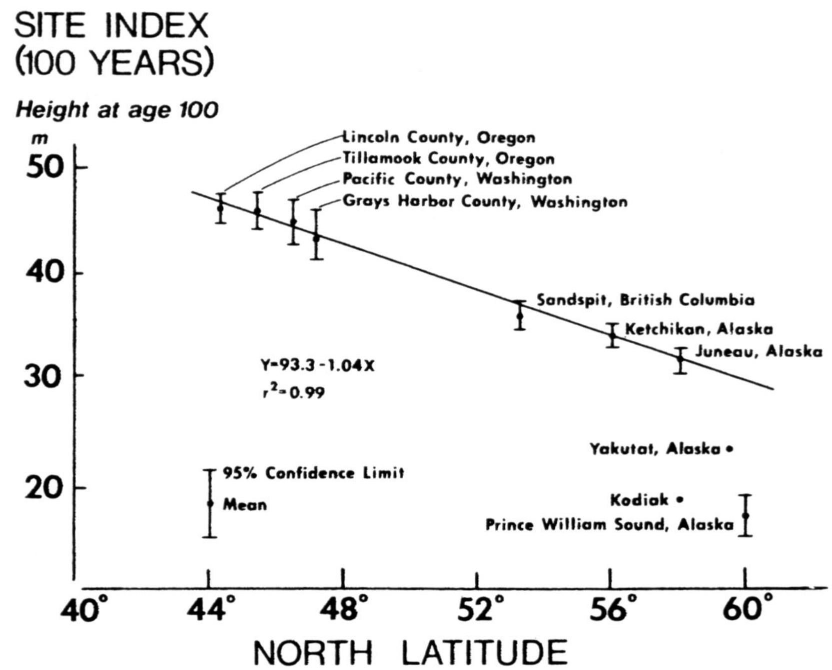

FIGURE 3. Relationship between site index of Sitka spruce and latitude along the North Pacific coast. Yakutat, Prince William Sound, and Kodiak were significant outliers and were not included in the regression.

threshold temperatures in the immediate range would serve as well for general analyses. Two significant outliers (Daniel and Wood 1971)—Adak and Cold Bay—were not used to calculate the coefficients of the regression line. Predicted number of degree days was within 200 for all other stations. Mean annual degree days above 5°C ranged from 2,511 at Brookings, Oregon, to 609 at Adak, Alaska.

Site index was also highly correlated with latitude for areas south of Yakutat (Fig. 3). Yakutat, Prince William Sound, and Kodiak were significant outliers. Site index data for these stations were not used when the coefficients of the regression line were calculated.

The relationship between site index and degree days above 5°C was highly significant ($P \leq 1$ percent) for areas south of Yakutat (Fig. 4). Yakutat, Prince William Sound, and Kodiak were significant outliers and were not used in the regression.

DISCUSSION

Growing season temperature is known to be an important factor in tree physiology and growth. Physiological activities in plants begin at a certain threshold temperature, increase with increasing temperature following the law of Van't Hoff and Arrhenius, and cease at an upper maximum temperature. Temperatures, as an integrator of many climate-related functions important to plant growth, have been of practical use in the agricultural industry for many years in planning for timing of crop production, despite their limitations (Holmes and Robertson 1959). This simplified approach, however, has been of limited use in explaining growth processes in very detailed studies of plant growth (Cleary and Waring 1969, Sarvas 1966, Wang 1960). As refinements in measurements and application continue

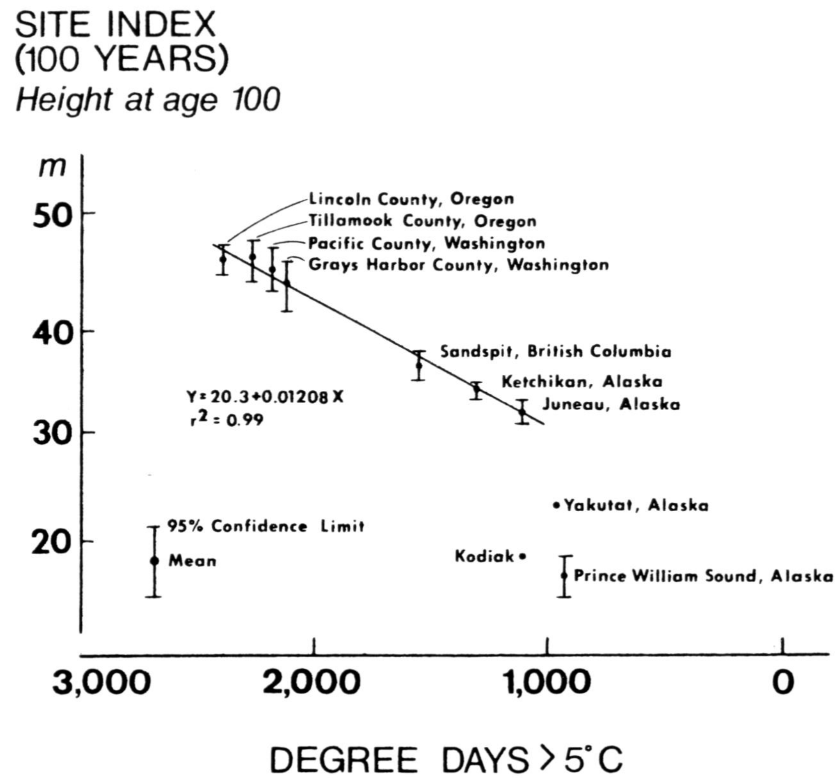

FIGURE 4. Relationship between site index of Sitka spruce and degree days greater than 5°C for areas along the North Pacific coast. Yakutat, Prince William Sound, and Kodiak were not included in the regression.

to improve, heat units are proving useful in explaining physiological development and ecological relationships of forest trees (Sarvas 1965, 1966).

Within the range of Sitka spruce average site index is highly correlated with latitude and with growing season temperatures expressed in degree days. Site decreases northward at the rate of about 1 m per degree of latitude. Average site is much lower than predicted near the northwestern end of the range of Sitka spruce, which emphasizes the importance of environmental factors other than temperature during the growing season.

Average site index for spruce in the Yakutat area is about 25 m, some 5 m below the predicted value for the latitude or the mean annual number of growing degree days. Much of this difference might be explained on the basis of soil development. The soils of the Yakutat forelands were formed over very deep deposits of glacial sands and gravels following the retreat of the Yakutat Bay lobe of the Malaspina Glacier facing Yakutat Bay and the now extinct glacier that occupied Russell Fjord. These outwash soils are very youthful, the oldest being less than 700 years old.[5] Most of the terrain is level.

The soils at Yakutat are relatively infertile as most nutrients are contained in the very thin surface organic layer. They are also undergoing constant change

[5] Billings, R. F. Soil management report for the Yakutat forelands based on reconnaissance soil survey 1970. 51 p., illus. North Tongass National Forest, U.S. Forest Service, Alaska Region.

primarily because of uplift and changing drainage patterns. None of the soils have reached equilibrium within their environment. In contrast, most mature soils in southeast Alaska are 5,000 to 10,000 years old.

Prince William Sound is another area where average site is lower than predicted, averaging only about 19 m. Little is known of the soils and climate of this large area.[6] The climate is classified as "humid-maritime" but it grades to continental along the area's northern and western boundaries. Northern areas adjacent to the large ice fields of the Chugach and Kenai Mountains are cooler in winter and warmer in summer than are southern areas. The growing season is relatively short in Prince William Sound, and a heavy snow pack often stays on much of the area well into the growing season.

The soils in Prince William Sound are similar to those found in southeast Alaska but shallower. Some soils found at the upper elevations in southeast Alaska are found near sea level in Prince William Sound. Soils tend to be older in eastern Prince William Sound than in the west. To the east, soils are about 8,000 years old; to the west, 4,000 to 5,000 years old.

Apparently, younger soils, heavy snow pack at the beginning of the growing season, and cool soils all contribute to low average productivity for this area.

The causes of low productivity on Kodiak Island and adjacent Afognak Island are less easily explained. Both islands have a history of glaciation followed by about 16 ashfalls of 0 to 5 cm in thickness. In 1912, an exceptionally deep ashfall averaging 10 to 15 cm was deposited (Griggs 1922, Martin 1913, Curtis 1955). Following retreat of the glaciers, much of the lowlands was covered with wind-blown silt. The ash has incorporated well with the silt, and the natural accumulation over several thousand years has resulted in deep soils in many places.

Sitka spruce, the only native conifer on Kodiak and Afognak Islands, is relatively new to the islands. Its range is continuing to expand to the south and west at the rate of about 1.6 kilometers per century (Griggs 1934), and many stands are composed of first generation trees. Origin of the first spruce seed to reach these islands is not known, but wind patterns and ocean currents suggest the seed came from the north, from the Kenai Peninsula, or western Prince William Sound. Thus, the forests of Kodiak and Afognak Islands may not yet be fully adapted to the environment, could contain a high percentage of trees whose genetic heritage is adapted to a shorter, cooler, growing season, and, therefore, might be incapable of making full use of the local climatic potential.

Growing season temperatures for Adak in the Aleutian Islands and for Cold Bay on the western Alaska Peninsula are far cooler than predicted for their latitudes and cooler than for other sea-level areas within the natural range of Sitka spruce. Lower temperatures result from maritime conditions. As the Alaska current flows northwestward in summer along the Gulf of Alaska coast, it becomes cooler because of latitude and the influx of cold water from glacier-fed streams. As the current begins its southwestward flow in the northern Gulf of Alaska, it is considerably cooler than it was at the same latitude while flowing northward and westward. For example, the average sea surface temperatures in August for the Adak and Cold Bay areas are 8–10°C versus 13–14°C for the same latitudes along the coast of British Columbia and southeast Alaska. Since wind from almost any direction at Adak and Cold Bay brings air of maritime origin, surface sea temperatures greatly influence air temperatures in these areas.[7]

These areas are well beyond the natural range of tree growth, but Sitka spruce

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[6] Sheehy, T. J. 1975. Soils report. Upper Prince William Sound, Chugach National Forest, U.S. Forest Service Alaska Region.

[7] Personal communication from James L. Wise, Associate in Climatology, University of Alaska, Anchorage, Alaska.

has been shown to grow and reproduce at Unalaska (Bruce and Court 1945, Lutz 1963) and has performed better than any other species planted. This indicates that the present westward range of Sitka spruce is not limited by low summer temperatures.

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