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EL NIÑO
&
LONG-TERM ECOLOGICAL RESEARCH SITES

Edited by

David Greenland

on behalf of

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THE EL NIÑO PHENOMENON AT THE H.J. ANDREWS EXPERIMENTAL FOREST, OREGON

David Greenland

INTRODUCTION

The El Niño phenomenon and the Southern Oscillation, in which it is embedded, together represent one of the major factors in the world's interannual climatic variability. Often noted during El Niño events is a seesaw effect between the Southwest of the United States, which tends to be wetter and cooler than usual, and the Pacific Northwest, which tends to be anomalously drier and warmer. The discussion in this paper focuses on the Long-Term Ecological Research site of the H. J. Andrews Experimental Forest (HJA), taken to be representative of the Pacific Northwest. Elsewhere it has been shown that the site is quite representative of at least quite a large area of Oregon (Greenland, 1993). The HJA is a 6,400-ha forest of Douglas Fir, Western Hemlock, and Pacific Silver Fir located in, and typical of, the central portion of the western slope of the Cascade mountain range of Oregon. Because of the large scientific significance of the HJA, it is important to investigate the temporal variability of annual and seasonal temperature and precipitation values at the site and identify past times of anomalous climatic conditions. It is also important to establish the relationships between the climate of the HJA and key ecological processes. Within this context, this paper examines some of the potential relationships between El Niño/Southern Oscillation, decadal time-scale variation, and salmon population in the Pacific Northwest and related areas.

BACKGROUND

The El Niño/Southern Oscillation (ENSO) Phenomena

The El Niño (EN) is an unusual warming of the normally cool near-surface waters off the west coast of South America (Enfield, 1992). It is often accompanied by sea surface temperature (SST) warm anomalies off the coast of central and north America. The oceanic event of EN is usually embedded in the atmospheric phenomenon of the Southern Oscillation (SO), an oscillation in the value of the atmospheric pressure difference between the south east Pacific and the Indonesian area. This is often represented by the pressure difference between Tahiti and Darwin, Australia, which is called the Southern Oscillation Index (SOI). During "normal" conditions (and/or the opposite extreme of El Niño conditions, known as La Niña) SOI is positive while, during EN, the SOI is usually negative. Although ENSO is primarily a tropical occurrence, EN events frequently have effects in the extra tropics, such as the development in the northern hemisphere of a meridional circulation pattern called the Pacific North American (PNA) pattern (Yarnal and Diaz 1986). This can have a noteworthy effect on the climate of the HJA.

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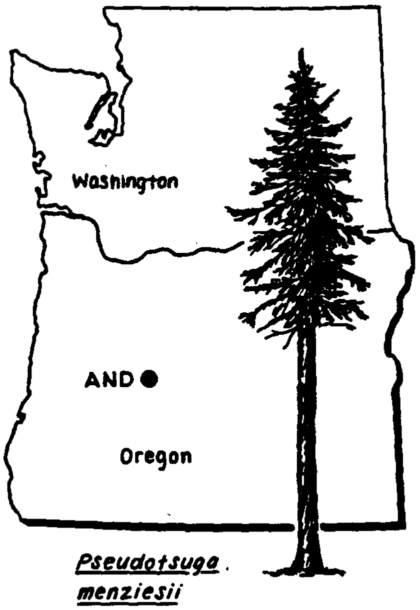

Figure 1. Location of the H.J. Andrews Experimental Forest, Oregon LTER site.

The Climate of the H.J. Andrews Experimental Forest

The primary meteorological station of HJA is at an elevation of 426 m (1,397 ft) at latitude 44° 15' N and longitude 122° 10' W. Bierlmaier and McKee (1989) have described the HJA climate as being wet and fairly mild in winter and warm and dry in summer. During the period 1973 to 1984, the average annual temperature was 8.5° C (47.3° F). Monthly temperatures ranged from 0.6° C (33.1° F) in January to 17.8° C (64.0° F) in July. The annual average precipitation was 2,302 mm (90.6 inches) 71% of which fell from November through March. Further details of the climatography of HJA may be found in Emmingham and Lundburg (1977, quoted by Bierlmaier and McKee 1989), Waring et al. (1978), and McKee and Bierlmaier (1987).

The Regional Climate of Oregon and the Pacific Northwest and the Importance of the Pacific Ocean

Regional climatologies of Oregon and the Pacific Northwest (PNW) have been given by Phillips (1960), Sternes (1960), the PNW River Basins Commission (1969) and Loy et al. (1976). No understanding of the climate of the PNW would be complete without reference to the seminal role played by interactions between the ocean and atmosphere in the area of the northern Pacific Ocean and, to some degree, the tropical and southern parts of the Pacific as well. Namias pioneered this concept in a long series of important papers (Namias 1969).

One way of approaching the importance of atmosphere-ocean interaction is by the use of teleconnective indices. Teleconnective studies are designed to investigate particular parts of the world; those studies relevant for the PNW are based on the Southern Oscillation Index (SOI), the Pacific-North American Index (PNA) and the Central North Pacific Index (CNP). These three indices exhibit a certain degree of intercorrelation (Cayan and Peterson, 1989). However, it should be noted that the strength of the teleconnective patterns is not necessarily stable over time. Ropelewski and Halpert (1986) have shown that, depending on the data used, the PNW is either in, or is on the southern edge of, an area having lower rainfalls when El Niños are in progress and in many of the months following the El Niño maximum. The PNA index designed by Leathers et al. (1991) following Yarnal and Diaz (1986) is the one used in this study. The PNA describes the amplitude of the 700 mb flow pattern over the United States, which has a basic pattern of troughs of low pressure in the eastern Pacific and the eastern United States, and a ridge of high pressure over the Rocky Mountain cordillera. The meridional extreme of the pattern produces positive PNA values (and potentially more southwest winds over the HJA), while the zonal extreme produces negative PNA values (and potentially more west winds over the HJA). Yarnal and Diaz (1986) demonstrated how strongly positive PNA and negative (reverse) PNA patterns are associated respectively with warm and cold El Niño Southern Oscillation (ENSO) events and, in turn, with precipitation and temperature anomalies on the west coast of North America.

Depending on the data used, the Pacific Northwest is either in, or is on the southern edge of, an area having lower rainfalls when El Niños are in progress and in many of the months following the El Niño maximum

Cayan and Peterson (1989) designed the CNP index as being the mean sea-level pressure (SLP) over the region 35-55° N and 170° E to 150° W. They show that streamflows in the West have correlations in the range 0.3 to 0.6 with SLP anomalies in the North Pacific. During times of a weak CNP, streamflows are high in Washington and Oregon. During times of a strong CNP, the polar front jet stream flows north of the PNW and periods of below-average streamflow are observed. This is also often observed during El Niño events (Cayan and Peterson 1989, Figure 9). All of the synoptic studies indicate quite clearly the linkages which exist between SSTs and particular pressure and teleconnective patterns in the Pacific Ocean and various aspects of climate on the West Coast and in the PNW.

COMPILATION OF THE SYNTHETIC RECORD

Multiple regression analysis (Greenland 1993) was used to compile a synthetic record of the monthly values of mean temperature and total precipitation at the HJA. These were from values at the stations which had been selected as a result of the previous screening procedures. The same multiple regression program was used to produce all correlation coefficients in this paper. The analysis was performed for the calendar year, the water year, and the winter part of the water year (October to April). This method of selecting seasons has obvious practical and hydrological advantages. As might be expected, the water year and winter water year correlations carry a higher degree of accuracy than those for the calendar year.

ANALYSIS OF THE SYNTHETIC & OBSERVED RECORD

Precipitation

The precipitation record from 1911 to 1991, as represented by the total annual precipitation by water year displays considerable interannual variability. The trends represented by the five- year running mean of the same data plainly shows the prolonged and severe drought of the 1930s and the wetter years of the late 1940s and the 1950s. The record exhibits greater variability in more recent years, with two peaks of precipitation centered on 1973 and 1984 and with droughts centered on the late 1970s, one which persisted through at least 1991.

Temperature

The observed and synthetic annual mean temperature record for the HJA from 1890 to 1991 also shows considerable interannual variability. Analysis of the record in terms of five-year running means displays a warming trend between the beginning of the record and the early 1940s, punctuated by two cool periods in the early 1910s and the early 1920s, respectively.

A cool period is seen from the late 1940s to the mid-1970s with the exception of one warm year (1958). Finally, a warming trend is seen from the mid-1970s to the present time, the magnitude of which, at least up to 1991, is similar to that of the warming trend at the beginning of the century.

Step Functions

Several investigators have identified step functions in certain of the meteorological time series during the period of the modern record. Ebbesmeyer et al. (1991) have investigated a step function occurring in biogeophysical time series of the PNW and the Pacific in 1976. Leathers and Palecki (1992) have identified a step function occurring in the value of the PNA index during the late 1950s and centered approximately on 1957. The 1957 step was also noticed in records of the mean height of sea level along the West Coast (Namias 1972). An analysis was performed to investigate whether such steps exist in the climatic data for the HJA Forest (Greenland 1993).

It was concluded that there is evidence in the HJA Forest record for the 1976 step but not for the PNA-related 1957 step. However, when we interpret the Andrews record in terms of pre- and post-1976 values, it is clear that the year 1976 was a marked turning point at the HJA for both temperature and precipitation. For approximately 15 years prior to 1976 the annual temperature trend had been downward. Since that time the annual temperature trend has been upward. In absolute terms, the 1977 water year (which includes the winter of 1976-77) had the lowest precipitation values in the entire record with generally higher values both before 1977 and after it (1976 was an El Niño year). The five-year running mean of these data places the turning point two years later. Clearly the atmosphere changed to a different mode of operation in the mid-1970s; this change is well represented in the HJA data, as well as that of many other parts of the PNW.

THE REGIONAL CONTEXT

PNA & CNP Indices

Correlations were made between the HJA data and the PNA and the CNP indices for the period 1948 to 1987. The results (Table 1), in the context of this kind of synoptic climatological analysis, indicate quite high correlations between HJA winter water year precipitation and both indices. Precipitation at the HJA for January, representing the winter months, also displays a weak but significant correlation with both indices. No relationships are seen for July, representing the summer months, or for the calendar year totals of precipitation. Annual and January mean values of temperature exhibit a very strong correlation with the CNP index. The relationship of January mean temperatures to the PNA index is also very strong, while the relationships for the year and for July are not so strong but are nevertheless significant.

Table 1. Correlation coefficient values between Annual, January and July mean temperature and precipitation totals at the HJA and selected general circulation indices for the period 1948-1987.

Precipitation		Annual or Winter Water Yr.		Jan		July	
Variable Regressed Against		r^2	Sig Level %	r^2	Sig Level %	r^2	Sig Level %
PNA	Annual	0.08	<95				
	Winter Water Yr.	0.25	99				
PNA				0.16	95	0.00	<95
CNP	Annual	0.04	<95				
	Winter Water Yr.	0.17	99				
CNP				0.10	95	0.06	<95
CNP	Annual (1914-1990)	0.03	<95				
	Winter Water Yr. (1914-90)	0.21	99				
CNP	(1914-1990)			0.11	99	0.03	<95
Temperature		Annual		Jan		July	
Variable Regressed Against		r^2	Sig Level %	r^2	Sig Level %	r^2	Sig Level %
PNA		0.12	95	0.40	99	0.11	95
CNP		0.45	99	0.40	99	0.04	<95
CNP (1910-1990)		0.44	99	0.31	99	0.05	95

Physically, when the PNA index is positive and high, a meridional circulation in the westerlies with a ridge of high pressure shunts storms to the north of Oregon (and the HJA) giving rise to relatively dry weather. This situation also brings in warm air with relatively high temperatures from the southwest. When the PNA index is negative, the zonal circulation in the westerlies brings in storms from the Pacific Ocean giving rise to wetter weather and rather lower air temperatures. These interpretations are also consistent with the CNP values which, when low, indicate that a well-developed Aleutian low-pressure zone will guide storms northward to British Columbia but, when high, will allow storms to travel more directly eastward into Washington and Oregon.

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SOI Index

A direct comparison of winter water year HJA values and SOI values suggests a relationship in which low SOI values (warm event, El Niño years) tend to be associated with low precipitation values and high SOI values (cold event, La Niña years) tend to be associated with high precipitation values at the HJA. The relationship is clear, although it is not very strong statistically (r^2=0.14, significant at 99%). The 1983 year, which had an extraordinary strong low SOI value, is a noteworthy outlier on the scattergram. Without the 1983 value the relationship is stronger (r^2= 0.23 significant at 99%). A similar, though stronger and reversed, relationship exists on an annual time scale between the SOI values and the annual mean temperature at the HJA Forest (with the inclusion of the 1983 data point r^2=0.24, significant at 99%).

An examination of HJA climate values for extreme SOI years sheds further light on this issue. Yarnal and Diaz identified a number of warm (El Niño) and cold (La Niña) event winters (December, January and February). During warm- event winters, HJA precipitation is near average at 0.03 SD of the long-term (1914-1991) mean and the temperature is well above (0.77 SD) the long-term (1890-1991) mean. During cold event winters, HJA precipitation is well above (0.69 SD) the long-term mean and temperature is below it (-0.33 SD). Halpert and Ropelewski (1992) defined warm event years as those in which the SOI index value remained in the lower 25% of the distribution for five months or longer and similarly defined cold events years by using the upper 25% of the distribution. By these definitions, at the HJA during warm event years, the annual precipitation is near the long-term mean (-0.02 SD), and the winter water year precipitation is slightly above the long-term mean (0.15 SD), but the following winter water year is markedly below the long-term mean (-0.32 SD). Also during warm event years, HJA temperatures are well above the long-term mean (0.45 SD). During cold event years, HJA annual precipitation is well above the long-term mean (0.48 SD), although the winter water year precipitation is near the long-term mean (-0.05 SD). Most striking, however, is that during cold event years the following winter water year is 0.88 SD above the long-term mean. Also, during the cold event years the annual mean temperature is notably below (-0.37 SD) the long-term mean.

Thus, it seems there are definite relationships such that during many warm events (El Niño years) the winter water year precipitation at the HJA Forest is relatively low and the annual mean temperatures are relatively high. During cold events (La Niña years), the winter water year precipitation at the HJA Forest is relatively high, especially in the winter water year following a calendar year with a cold event, and the annual mean temperatures are relatively low. These findings are consistent with those of Yarnal and Diaz (1986) and Redmond and Koch (1991). The latter noted for the PNW as a whole that precipitation is low and temperature is high during low SOI values with the opposite also being true. Interestingly, they found that the relationship tended to be strongest in the mountainous climate divisions. They point out that a combination of low precipitation and high temperature values implies a smaller than average snowpack during El Niño years.

With one exception, there were no significant correlations in either precipitation or temperature when the data were lagged at monthly intervals. The exception was a weak relationship between HJA January precipitation and the SOI value of the previous March ($r^2 = 0.10$ significant at 95%). The relationship is interesting enough to pursue at a later time using seasonal as opposed to monthly data.

SALMON POPULATION

Salmon population sizes are affected by climate on at least two times scales. The decadal time scale exhibits a relationship between the size of salmon catch and air and water temperature. The interannual scale shows the effects of El Niño events such that salmon catch is often relatively low during and after the events. Occurrences on the shorter scale are superimposed on those of the larger scale and events on the two scales are probably interrelated. In addition, salmon population sizes are affected by many non-climatic influences such as those related to human activity.

While salmon population sizes are affected by many non-climatic influences, they also seem to be affected by climate on at least two times scales

General and Decadal Climatic Effects

Salmon are affected by climate both when they are in the river part of their life cycle and when they are in the ocean part. While salmon are young, colder river water temperature slows down growth and warmer water accelerates growth (Netboy 1991). However, a temperature increase in rivers generally reduces survival because it could increase disease and fungal attacks in adults. It could also retard spawning to the point that the juvenile salmon are unprepared for marine life when it is time for them to move to sea (Neitzel et al. 1991). In the ocean, survival of hatchery smolts is greater in years of strong upwelling (which tends to be related to colder water) compared to years of weak upwelling (Pearcy 1992). The latter type of years are more often associated with El Niño conditions. The inverse relationship of warmer climate and decreased salmonids may hold up on the long time scale of the Holocene. There is limited evidence suggesting that during the Hypsithermal period of the Holocene salmon were less plentiful in the PNW (Neitzel et al. 1991). Besides being affected by temperature, a lack of water in the rivers can negatively impact suitable habitat availability. Consequently, a time of long-term drought such as in the mid- and late 1980s also has the potential to decrease salmon population size on the decadal time scale. Sharp (1992) claims that local populations of salmon throughout the western continental United States have suffered from drought recently. He uses the period 1976 to 1991 to define "recently." We may note that 1976 was the year of the step function in biophysical data series from the PNW.

It is not necessarily the colder water that affects the ocean salmon, but the related availability or non-availability of food resources, particularly zooplankton

It is not necessarily the colder water that affects the ocean salmon, but the related availability or non-availability of food resources, particularly zooplankton. The food resources, in turn, are affected by changes in ocean current location and areas of up- and downwelling. Such changes on the decadal time scale have been shown to be vitally important by Francis and Sibley (1991). Using data from 1925 to 1985, they clearly demonstrate a long-term direct association between air and water temperature and Alaskan Pink Salmon catches in the Gulf of Alaska. They also show an inverse relation between Pink Salmon catches in Alaska and Coho salmon catches off the coast of Washington and Oregon. The latter relation might be due to competition but it can also be explained by the north or south movement of the divergence (or bifurcation) zone between the Alaskan and California current and the greater or lesser affect of the currents related to that north-south movement. Hollowed and Wooster (1991) and Francis (1993) suggested an atmospheric model (symbolized here after the authors as HWF) in order to explain these conditions. The model is bimodal. That is to say, when the divergence zone (or bifurcation) is more to the north (HWF Type A) more cold subarctic current water can be brought into the Californian current and upwelling of nutrient-rich water is enhanced. But when the divergence point (or bifurcation) is further to the south (HWF Type B), more subarctic current water is taken into the Alaskan current and water off the Washington and Oregon coasts will be warmer. Type A is associated with a high CNP value, while Type B is associated with a low CNP value.

The model, if true, because of its foundation on air flow implicit with PNA and CNP indices, also explains the strong inverse relation found between annual temperatures at the HJA and the catch of Coho salmon off the coast of Washington and Oregon (Figure 2). There are also links between the interannual and the interdecadal time scales. Francis (1993) notes, for example, that Hollowed and Wooster have pointed out that the switch from the type A to the type B state has always occurred at the time of significant EN events.

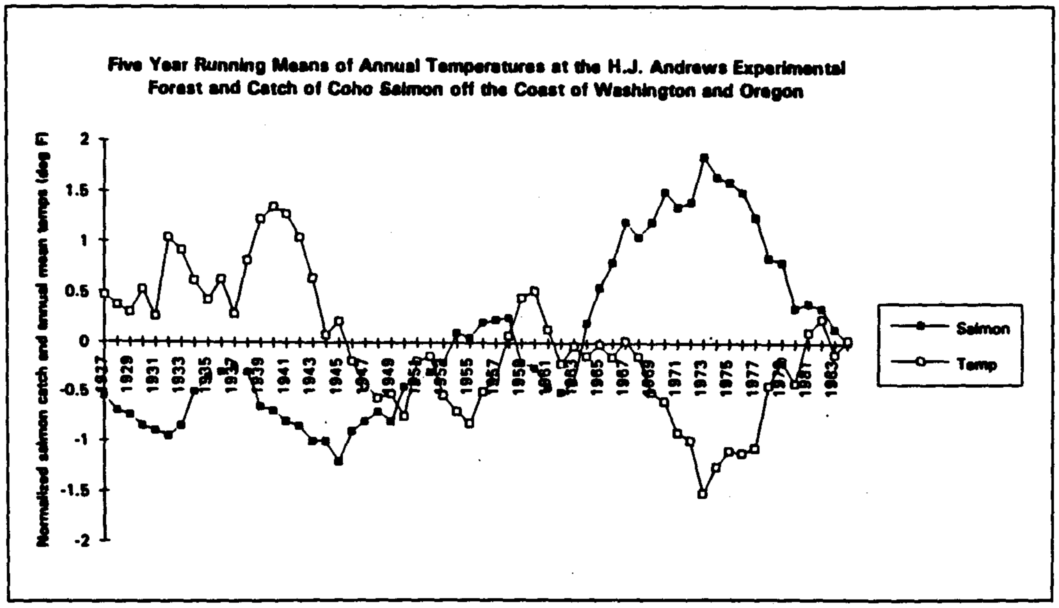

Figure 2. Five-year running means of annual temperatures at the Andrews Forest and the catch of Coho salmon off the coast of Oregon and Washington.

The Interannual Scale-El Niño Events

El Niño occurrences can impact salmon populations by providing anomalously warmer water and suppressing the upwelling which can provide nutrients. It should be noted, however, that no two EN events are identical and some are more pronounced than others. The 1982-83 EN event was a particularly strong one.

During the 1982-83 EN, salmon in the PNW appeared to be stalled in the estuaries because of the warmer water in the ocean (Rosemary 1993). The salmon in the estuaries were subject to disease and predation, which decreased the population. Also, reduced primary productivity off the coast impacted both juvenile and adult coho salmon (Pearcy 1992). During this EN event, 58% of the number of adults predicted to return actually died in the ocean. The same EN markedly decreased growth and fecundity of the salmon of that year. Warm ocean temperatures off the Oregon coast shifted the center of distribution of juvenile coho northwards to the coast of Washington.

There is evidence that the 1957-58 northern EN also negatively affected salmon, giving rise in 1960 to the lowest ocean landings of adults since 1917 (Pearcy 1992). In addition, the lingering 1991-92 EN has also negatively affected salmon catch (Finley 1993). Indeed, it has been established that years just following EN event years generally tend to be years of low coho catches (Miller and Fluharty 1992).

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Events on a decadal scale are comprised of events on shorter time scales. Thus, it is no surprise that the changing location of eastern North Pacific ocean current bifurcation is also seen on the interannual scale at the extremes of EN or LN. A northwards or southwards shift of the locus of bifurcation acts on salmon catch through the amount of zooplankton transported by the California current. Increased southward transport by the current is associated with increased zooplankton biomass. But during El Niño years the subarctic boundary may be shifted further to the south, and decreases in transport lead to low biomass and less food for juvenile salmon (Pearcy quoting Roesler and Chelton 1987). During such years, the divergence point between the California current and the Alaska current is to the south of its "usual" position and subarctic influence into the California current is decreased. In addition, the Aleutian low intensifies during the winter (presumably giving rise to low CNP and high PNA values) "producing a strong cyclonic circulation in the Gulf of Alaska that pushes warm water towards the coasts of Oregon and Washington" (Emery and Hamilton 1985). The reverse happens during LN years (Pearcy 1992).

CONCLUSION

The climate of the HJA is well coupled with hemispheric scale events in winter. This coupling has important implications for the climate of the HJA one or two, or possibly more, seasons ahead, thus allowing a new dimension in planning ecological experiments. An example of such coupling is manifested in the effect of climate on salmon numbers in the PNW. These numbers seem to be strongly controlled by EN events on the interannual scale and by air and ocean temperature on the decadal scale. The salmon population variation and its relation to climate is complex and deserves considerably more attention.

Acknowledgments

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