PACIFIC NORTHWEST COASTAL TEMPERATURES: INVESTIGATION OF INTERDECADAL CYCLES AND BIOLOGICAL IMPLICATIONS

by

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Investigations regarding interdecadal climate cycles have surged in the past several years providing alternative perspectives into the forcings on climate change. The possible couplings between the various patterns of these physical processes (oceanic, atmospheric), terrestrial, and biosphere regimes are of substantial importance. This study seeks to explore the relationship between the ocean and the land-surface on a regional scale. It is hypothesized that Pacific Northwest coastal sea surface temperatures and surface-air temperatures are temporally identical, or merely offset by a time lag, with the same pattern and period. Correlation and regression analysis were completed for the chosen sites, and significant positive correlation (r: 0.843) was determined. The similar cycles of the marine and terrestrial environments have significant biological implications. The progress with and problems of biological climate patterns is discussed along with the importance of proxy indicators, and relevancy to fisheries and management.

Introduction:

Human sustenance and livelihood depend upon an ability to predict climate. It is, therefore, essential to form a basic understanding of natural climate variability. Climate predictions are largely based on the history of weather observations averaged for various periods of time (Cushing, 1982). These records are constructed into databases for future study. Time series, ranging from daily to millennial, are used to determine the cause of observed climate events. Of recent interest is the decade to century (interdecadal) approach, which characterizes long-term natural variability of the climate system. Trends emerging on this time scale may allow human activities to be distinguished from natural climate changes (Natural Climate Variability, 1995).

Interdecadal climate variations produce characteristic patterns or trends in ocean, atmosphere, land-surface, and biosphere climate. Pooling the information gathered on each of these systems illustrates the interdisciplinary nature of climate variability, and allows prediction of climate change to be more effective. Many studies tend to focus on one element, and expand to implied associations with another element, yet much of the current research on interdecadal cycles has involved only the ocean and the atmosphere (Natural Climate Variability, 1995). Most projects begin by observing the historical record of each component, then strive to understand and model the ocean or atmosphere as a separate unit within the larger climate system. The ultimate goal is to predict ecosystem climate change. However, this is only accomplished through careful consideration of all elements of climate. It is the goal of this study to apply the methodologies of past ocean-atmospheric studies to the coastal ocean-land interface, and to consider the implications of these studies to the biological realm.

Summary of Past Investigations: (all **bold** words in text are defined in the Glossary of Terms)

The Atmosphere

Fluctuations in the atmosphere are interesting to scientists because of the extensive documentation of several major climate events. These include the sudden decrease of rainfall over the Sahel in 1970, the Dust Bowl years of the 1930's in North America, the diminished intensity of tropical storms off the Eastern United States throughout the 1960's and 1980's, and the increased wet weather of the 1970's and 1980's over most of the United States. Through a broadened access to climate records, researchers are finding that climate fluctuations, revealed in records from day-to-day weather forecasting, exhibit rates of fluctuation much larger than interdecadal variability. Therefore, data archaeology efforts such as the Comprehensive Ocean-Atmosphere Data Set (COADS) seek to tabulate atmospheric variables so as to provide data sets that are reliable and adequately reflect climate variability (Karl, 1995).

Drought and flooding are of specific interest in studies devoted to the mechanisms of atmospheric forcing because climate cycles that induce catastrophic events are important to the people living in the region. A substantial amount of research devoted to understanding the Sahel drought, was brought on by reports of severe famine and death in the African communities. Some studies suggested that the initiation of the drought should be explained as a regional manifestation of global-scale climate variability, and that the drought's persistence is from a positive feedback mechanism of atmosphere-land interactions (Shukla, 1995; Nicholson, 1995). As atmospheric investigations pointed to a need for comprehensive research (coupled systems), studies on climate events in the ocean began to take shape.

The Ocean

Large-scale climate changes in the North Atlantic and North Pacific Ocean have been established in a variety of ways since the mid-1970's (Russell, 1971; Cushing, 1982). The North Atlantic Oscillation (NAO) is a regional atmospheric circulation defined by sea level pressure where the governing winds of the Atlantic (westerlies) exhibit marked oscillations in intensity over time (Hurrell, 1995; Deser; 1996; McCartney, 1996). The North Pacific region experienced a large-scale climate shift during the winter of 1976-1977, resulting from the abrupt deepening of the Aleutian Low. Storm tracks shifted southward and increased in intensity, while relative sea surface temperatures also migrated (Miller, 1994). Cross continent comparative studies were also completed on both the Atlantic and Pacific Oceans in order to determine distinct subdomains of fluctuating climate (Krovnin, 1995).

These patterns of periodicity emerge from long records of easily measured variables such as sea surface temperature or salinity. Until recently, distinct problems existed with the availability of oceanic data for establishing long-term climate variability. Measurement techniques continue to improve, with the use of **acoustic tomography**, satellite measurements, expendable **CTD's**, **radar altimeters**, **scatterometers**, and **synthetic aperture radar** (Hall, 1995). Collective efforts of several industries and independent observers have lengthened data sets for interdecadal climate investigations. Some of these contributions include the **hydrographic** data from the CalCOFI (California Cooperative Oceanic Fisheries Investigations) and Japanese fisheries cruises, expendable **bathythermograph** (XBT) data from weather and merchant ships, and vast archives of temperature and salinity data from isolated stations, such as Panulirus station, off the coast of Bermuda (Hall, 1995). Interest in oceanography has heightened in recent years because of the influx of such studies that find distinct cycles in ocean climate. These patterns suggest predictability. As understanding of the physics underlying ocean circulation increased, interesting similarities to atmospheric circulation were noted, and a demand for coupled climate system models emerged.

Coupled Systems

In order to capture all facets of climate variability on an interdecadal time scale, ocean, atmosphere, land-surface, and biosphere climate must be viewed in their relationship to each other. Many studies, therefore, took the next step and attempted to consider the properties of both the ocean and atmosphere together. However, in this comprehensive approach, coupling of two well-known systems produced a final picture with unexpected and unaccounted-for properties (Sarachik, 1995). Therefore, different coupling techniques were developed.

In several studies, limited or incomplete data sets in one area (e.g. sea surface temperatures) resulting from poor resolution over time, were substituted with comparative values from another data set (Royer, 1993). In other cases, previously established trends in global temperatures were reevaluated with the use of coupled ocean-atmosphere data to produce a much different and more significant account of the trends in worldwide temperature fluctuations (Folland, 1984). One investigation established interdecadal cycles in surface temperature by combining observed sea surface temperature data with land-surface air temperature data to produce a global assessment of changes since the late nineteenth century (Parker, 1994). Other studies used the advantage of coupled systems (primarily temperature data of the ocean and atmosphere) to identify specific time intervals and climate shifts indicative of interdecadal oscillations (Miller, 1994; Kang, 1996, Deser, 1996).

The coupled system increased in value as previously ambiguous relationships between the ocean and atmosphere were understood, and mechanisms for the observed cycles were established. For example, previously identified changes in surface-air temperatures were shown to arise from surface fluxes, vertical mixing, and moisture advection (by anomalous winds) within the ocean system (Trenberth, 1995). Significant changes in the biota, which are of grave impact on society, may now be associated with some degree of certainty to changes in the coupled ocean-atmosphere climate system. Continued research in coupled relationships between ocean, atmosphere, land-surface, and biosphere entities remains essential to make confident analyses about the nature and possible prediction of natural climatic variability.

Personal Investigation:

The present study applies the approach of a coupled system to a specific region termed the Pacific Northwest (Lat.: 37°N Long.: 122°W to Lat.: 49°N Long.: 124°W). This region of the investigation is bound in the northern extreme by Neah Bay and Port Angeles, Washington and in the southern extreme by Pacific Groove and Santa Cruz, California. This geographic area experiences relatively similar climate, and is, therefore, appropriate for small, region-specific projects. Previously mentioned studies have successfully interpreted interdecadal global climate change through analysis of existing temperature data sets. Adequate temperature records of the area were available for both land and sea, and were, therefore, found to be highly valuable and most relevant to this study. The intent is to examine temperatures along the coast of coupled marine and terrestrial locations, and to compare the inherent interdecadal patterns over the past century. I hypothesize that the observed Pacific Northwest coastal sea surface temperatures and surface-air temperatures are temporally identical (or merely offset by a specific time lag) with the same pattern and period.

The personal impetus of this study is that significant correlation between marine and terrestrial temperatures provides additional support for influences on the regional biota. As marine and terrestrial temperatures may be coupled, similar inference exists for the ecosystem. Marine and terrestrial biological distributions and abundance may also respond with identical or lagged oscillations to the temperature changes. The interdisciplinary projections of this study allow for speculations on alternatives that might enhance understanding of climate variability, and separate human-activities from natural climate cycles.

Materials and Methods:

The discrepancies that tend to exist when many stations are used in global climate studies are much less likely to have as substantial an effect when smaller station networks are used to detect regional climate change (Karl, 1987). Fluctuating marine-terrestrial variables (i.e. temperature, salinity, precipitation) need to be continuous throughout the entire region, and allow for a simple comparative analysis of temporally identical periodicity. Several site-specific data sets were available for inspection, allowing for city-sites to be chosen based on their proximity to the coast.

After my careful review of Pacific Northwest temperature data, two data sets produced the most manageable and extensive coastal temperature records. Scripps Institute of Oceanography Shore Station Database reports sea surface temperature, salinity, and density data from seventeen marine stations lining the West Coast of the United States. Eight of these stations were chosen to represent Pacific Northwest sea surface temperatures of the past century. Surface-air temperature data for the land-surface of the Pacific Northwest was found in the United States Historical Climatology Network (USHCN) Serial Temperature and Precipitation Data through Oak Ridge National Laboratory. Cities from the USHCN were coupled to the marine stations based on their proximity to the marine station and relative elevation. The Scripps Marine Station data used consistent sampling techniques throughout and provided **metadata** for inspection. The USHCN data, which had been developed by Thomas R. Karl and associates, was previously corrected for urbanization, instrumental adjustments, time of observation bias, and other discontinuous inhomogeneities (i.e. location movements) (Karl, 1986; 1987; 1988).

We selected the appropriate databases, and completed site coupling. The limiting database was the Scripps Marine Station data. Data for each of the marine stations was recorded in the Scripps Marine Station database at different times throughout the past century; therefore, each correlated terrestrial site from the USHCN was only allowed to influence the representative surface-air data as much as its coupled marine site. For example, Pacific Groove marine station was coupled to the nearby city of Santa Cruz. The temperature record for Pacific Groove began in 1919. Therefore, the city of Santa

Cruz influenced the representative terrestrial data starting in 1919, even though the temperatures for Santa Cruz extended back to 1873. The following are the remaining seven marine stations and their date of initiation followed by the coupled terrestrial city site in parentheses: Santa Cruz, 1955 (Santa Cruz); Farallon Islands, 1925 (Berkeley); Bodega Bay, 1957 (Petaluma); Trinidad Bay/Beach, 1975 (Eureka); Crescent City, 1955 (Brookings); Charleston, 1966 (North Bend); and Neah Bay, 1955 (Port Angeles) (Figure 1).

We created a representative database of sea surface temperatures versus surface-air temperatures on Microsoft Excel 7.0 Spreadsheets. Reported monthly mean temperatures were averaged to annual mean temperatures in both marine and terrestrial regimes which produced a comprehensive data set that extended to 1919 in both sea and air temperatures. Simple correlation analysis was performed between the Pacific Northwest Total, and between each coupled site. Following this, regressions were performed on the Pacific Northwest Total, where surface-air temperature data was regressed on sea surface temperature data, and then tested for time lag significance. In the latter, surface-air temperature data was again regressed on sea surface temperature data but lagged progressively from one to fifty years. R-values were then plotted to test for a monotinically declining function or a significant rise and fall. Visual chart analysis was then performed for annual, five-year, and decadal simulations of the representative total Pacific Northwest temperature ocean-terrestrial coupled interactions.

Results:

A regional map of the Pacific Northwest including each of the coupled sites is shown in Figure 1. The total representative values for the annual sea surface temperatures and surface-air temperatures of the Pacific Northwest are shown in Figure 2. The two regimes are positively correlated and are highly significant ($r=0.843$; $p<0.001$). The contribution of each coupled site to the total representative temperature values of the Pacific Northwest are shown in Figure 3, where each coupled site is limited by the initiation of the marine sea surface temperatures in the Scripps Marine Station database. The correlation values for each of the coupled sites are listed in Table 1. All of the coupled sites show high positive correlation, and produced varying degrees of influence (dependent on time interval and degree of proximity to each other) on the total Pacific Northwest temperatures.

Successive fifty-year regression tests were completed and r-values are listed in Table 2 and plotted in Figure 4 to show any noticeable time lag. LAG (0) remains the most significant and positively correlated time interval ($r=0.843$). LAG years 1-23 are relatively low, while LAG year 24-50 slope upward to a maximum r-value: 0.523 in year 36. These results may be indicative of other low-frequency variations, but do not indicate a significant time lag between sea and air temperatures.

The climate variability of the marine-terrestrial coupled system shows a positive correlation on the time scales of five-year ($r=0.850$) and decadal ($r=0.870$) averaged sea surface and surface-air temperatures for the total Pacific Northwest. The graphs of these two time scales are shown in Figures 5 and 6 respectively. As the averages tend toward larger time scales, regional correlation becomes more significant, as seen in the decadal time scale.

Discussion:

The observed high correlation between values for coastal marine (sea surface) and land (surface-air) temperatures implies that the coastal areas are temporally similar, where high temperature values of the sea surface at the marine stations will correspond to high temperature values of the surface-air in coastal cities. It has been well documented that both the sea surface temperatures and the surface-air temperatures of the Pacific Western regions are cyclic, with highly significant decadal frequencies (Karl, 1987; Krovnin, 1995). It can be inferred that the marine and terrestrial temperature indices have temporally identical cycles. This can also be visually suggested in the annual, five-year, and decadal graphs of sea surface and surface-air temperatures for the past century (Figures 2, 5, 6). The corresponding r-values for each of these systems shows increasing correlation of the marine and terrestrial systems as the time-scale progresses from annual to decadal (r=0.843 to 0.870). Small spatial studies, such as of the Pacific Northwest, are considerably variable on the annual time scale (Figure 2). Significant and obvious trends are more noticeable on longer time scales. This is the advantage of interdecadal studies (Figure 6).

The possibility of a significant time lag between the ocean temperatures and comparative land temperatures was not highly significant at any LAG year from (1) to (50) years (Figure 4). The highest correlated years were at LAG year (0) (r = 0.852), which reinforces the relationship found in the initial regression of sea surface and surface-air temperatures. Interesting anomalies seem to occur throughout the r-value plot, which are not indicative of a **monotinically declining** function, and could be suggestive of low-frequency variations. First, there are small fluctuations occurring from LAG years (4) through (6), and from LAG years (9) through (11). Temperatures 4-6 and 9-11 years from now will be similar to current temperatures with a value of 0.1 correlation. This is not substantial, but the mere fact that there are these slight increases rather than a consistent decrease toward zero, suggests signals of interannual (such as an ENSO cycle) and decadal patterns. Second, LAG years (23) through (36), display a large and steady increase in positive correlation until an r-value of 0.523 in LAG year (36). The r-values taper off slowly from this point. It is important to realize that signals in this regression analysis occurring farther away from the current year, may be associated with the continuous lack of data as the temperatures are lagged farther and farther from the point of origin. This large signal may, therefore, be displaying true correlated interdecadal frequencies, but is strengthened by the design of the regression analysis. In either case, the presence of low-frequency variations in a LAG year regression analysis is not a representation of a true time delay from the sea surface temperatures to the surface-air temperatures, but may be a manifestation of interannual and interdecadal cycles.

These correlations suggest some interesting extrapolations. The temperature relationship in the Pacific Northwest may exist in other regions around the globe. Those with long-term temperature records for their coastlines should be examined. The temperature regimes of different parts of the earth will be specific to the surrounding ocean and wind currents. For example, the Eastern United States north coast is bound by weather patterns that are quite distinct from the Pacific Northwest, regardless of the similar Latitude range. The temperature relationship may also be reversed where the land induces the sea or may show a positively significant lag time. Once a variety of regions are analyzed, the correlation values or any established time lags may be compared on a global scale. This provides evidence for teleconnections between regions that may not have been noticed in previous global climate investigations (Krovnin, 1995). There are several regions with established regional temperature sets, which include Plymouth coast in England, the Atlantic coasts (Eastern United States and Europe), the coasts surrounding the Sahel region of the African continent, and the Pacific coasts (Southern region of the Western United States, Japan, and China).

Interdisciplinary Extension:

These physical relationships should have biological consequences. Investigations describing obvious patterns in marine and terrestrial organisms have existed for many years. The rapid adaptations of insects to low-frequency changes in climate, were indexed from sediment cores, and insect assemblages were found to follow major climate events in the Quarternary period of geological history (Elias, 1995). Extensive records on the distributions and abundance of net **phytoplankton**, **zooplankton**, **planktonic** stages of bottom-living fish, and intertidal organisms (zone-forming seaweeds, barnacles, mussels, reefbuiling worms, **limpets**, sea urchins, **dog-whelks**, starfish) in the western English Channel off Plymouth, England have been established at various time intervals since 1924. Analyses of the time series shows cycles that parallel fluctuating sea surface temperatures in surrounding waters (Russell, 1971; Southward, 1995). Physiological studies show temperature changes to have a marked influence on the fecundity and metabolic rate of individuals. This effect (**Q_{10}**) strengthens the relevancy of established physical-biological interactions involving an individual, but cannot be extrapolated to an entire community (McGowan, 1995). One study conducted in the Northwestern Hawaiian Islands (particularly the French Frigate Shoals) found that strong linkages existed between atmosphere-ocean mixing, and productivity across several trophic levels. The densities of **chlorophyll *a*** (indicative of phytoplankton abundance), spiny lobsters, coral reef fishes, sea birds, and monk seals, all responded to the climate event in the central North Pacific (1970's), but with differing lags and intensities (Polovina, 1994). The complete effect of climate change on the intricate pathways of species survival (ratio of birth rates to death rates) is compounded by a highly interactive food web.

Several problems exist when applying climate change to ecosystems. The most relevant to this study are investigations regarding coastal marine food webs. They are often large and interdependent. Initially, the use of Lotka-Volterra equations designed specifically for predator-prey interactions were criticized as being too simplistic for the complications of the marine ecosystem (McGowan, 1995). However, models designed for a greater degree of complexity yielded simulations that were far too detailed for simple interpretation. Marine food webs are defined on aggregate levels, where lower **trophic** levels are groupings of taxa (e.g. phytoplankton) and top organisms are represented individually. This causes some properties of the food web to be highly skewed. Some food webs also have waists, where a single species (often a **copepod**) may dominate the next trophic level down. This intermediate filtering of lower trophic levels determines the dynamics of the food web, and is often overlooked (Rice, 1995). In order to quantify the extrinsic perturbations of climate change on population biology, a greater number of time series involving the most easily measured quantities of individual life cycles and related climate cycles is required. It has also been found that significant changes in population dynamics are detected on the scale of generations, which is why interdecadal studies have become so valuable in recent years (McGowan, 1995).

Proxy Data

The difficulties with resolving climate change in ecosystems, do not, however, negate the relevancy of biological data. Observed cycles of several species are found to parallel many variables of climate change such as temperature, salinity, and wind circulation patterns. The biological time series of distributions and abundance may serve as proxy data sets for cases when the climate record is severely lacking. Proxy indicators are especially appropriate for detecting periodic or near-periodic variation, large and pronounced climate signals (pronounced drought, floods, warm or cold periods, etc.) and gradual trends or characteristics found only in long, continuous records (Sorooshian, 1995).

The use of proxy indicators for detecting climate variability is a relatively new science, and the known list of biological proxy indicators is still fairly low. However, fossil assemblages, tree-ring reconstructions, coral records, plankton, and fish are currently being pursued for the information in their life histories. Improved techniques in fossil coring, drilling, dating, and extraction have emerged from the demand for high-resolution records. Fossil assemblages now provide proxy time series of sea-surface and bottom temperature, alkalinity of local water, and major front locations (Sorooshian, 1995).

The idea of tree-rings as valuable sources of information was developed in the early 1900's, when an eleven-year sunspot was recorded in southwestern United States tree-rings. Over the century, tree-ring reconstructions improved to yield records that date back several thousand years, providing information on temperature, precipitation, pressure patterns, drought, and runoff (Sorooshian, 1995). An excellent example, is the 2290-year reconstruction from tree-rings of Tasmanian warm-season temperatures that were analyzed for decadal-scale fluctuations (Cook, 1995). However, only the warm-season appears in the instrumental record of tree-rings, and there is potential bias in long-term variability due to the longevity of the trees, the ecology of the site(s), and the data processing methods required to remove the "age-effect" of the trees (Jones, 1995).

Corals grow at a rate of more than 1cm/year, three orders of magnitude greater than the deposition rate of sediments in the deep sea. This allows the geochemical coral record to be resolved from seasons to centuries. Through the ratios of key atmospheric and oceanic elements in their skeletal chemistry (carbon, oxygen, cadmium, barium, manganese, and strontium), coral bands provide information on sea surface temperature, upwelling, rainfall, and winds. Single region cores from the Galapagos Islands, Tarawa Atoll, Gulf of Mexico and several others across the globe may be pieced together to form a comprehensive regional or global perspective of climate change (Cole, 1995; Slowey, 1995; Sorooshian, 1995).

In 1939, phytoplankton and zooplankton abundance was recorded in the North Atlantic between Scotland and Ireland in what is known as the Continuous Plankton Recorder (CPR) surveys. By 1965, much of the North Atlantic (north of 45^{o}N) was sampled monthly by twenty merchant ships and sixteen weather ships. Initially this effort was begun to prepare composite biogeographic maps (spatial variations in species abundance and diversity patterns), outlines of community structure, and analysis of temporal variations in plankton populations (McGowan, 1995). As the time series extended, interannual variations began to appear. Approximately fifty percent of the observed changes in production cycles were attributed to the physical environment. A similar program, CalCOFI (California Cooperative Oceanic Fisheries Investigations) began in 1949 as a large environmental study of the California Current. Its target of larger, more efficiently sampled zooplankton parallels the CPR data in many respects, but CalCOFI also measures physical and chemical properties of the California waters. Recent studies found that change in population growth is clearly associated with large-scale shifts occurring in the mass transport of the California Current system (McGowan, 1995). These shifts have a strong temperature signature, so the change in population growth can be seen as correlated with temperature. Other independent research (Scripps Institute of Oceanography pier data) has found various significant correlations of total diatoms and dinoflagellates with sea-surface and surface-air temperatures. Plankton surveys may serve well as an index of climate change (McGowan, 1995).

Fisheries and Management

Significant relationships involving recruitment or density of commercial fish stocks, are worldwide economic and environmental concerns. Numerous studies have endeavored to prove a significant correlation between fish and climate change. An almost universal consequence of earlier studies has been that individual species' population sizes vary on factors of ten or more throughout time, with little if any correlation to physical climate variables (McGowan, 1995). However, recent studies have found that a distinct relationship exists between climate change and fish catch. Analysis of several salmon species' catch were found to significantly fluctuate in accordance with the 1976-77 Pacific Ocean climate shift (Beamish, 1992; Beamish, 1996). At any rate, careful analysis of significant parallels found between climatic events and fisheries are key to producing efficiency in fisheries management.

Fisheries are managed on an annual basis, yet climatic change effects fish stock recruitment from decade to decade. The dilemma is that fisheries managers cannot strictly incorporate climate variability into their decisions (Cushing, 1982). However, allowing for the direction of environmental change may make managers more effective in their fish stock assessments (National Research Council, 1998). Parameters governing the life cycle of a fish display the balance of natural versus anthropogenic influence that must be considered in fisheries management. Fish stock decreases through fishing devices such as the hook and line, drift net, trawl, or purse seine. Natural events which may include lack of oxygen, red tides, or low and high temperatures may also cause increased death rates (Cushing, 1982). Estimates of mortality rates need to consider both fishing and natural causes to make accurate assessments of density. Growth, which depends on food availability, is often determined from annual increments of weight taken from sampled systems. The weight of a particular year class fluctuates throughout the year, and ages of recruitment may be exposed to early fishing pressures. A steady state model of yield per recruit needs to include the changes in growth per year class to determine when a fishing season may begin. The declines in recruitment of a specific year class also present a difficult problem since there is an integral climate cycle involved. "Russell observed marked changes in the abundance of macrozooplankton in the English Channel between 1924 and 1971, and suggested that local changes in abundance resulted from distributional changes associated with recurring climatically-driven oceanographic changes in the North Atlantic Ocean" (National Research Council, 1994). This pattern was termed the Russell cycle and is induced by high and low-pressure cells that cycle on scales of ten to twenty years. Poor recruitment years may be followed by several more poor recruitment years, and managers must consider this interdecadal climate effect if fisheries are to remain stable over time.

Conclusion

There are many avenues for future exploration of interdecadal climate change. Proxy indicators must be pursued and expanded because a wide variety of climate information remains to be discovered in these records. Development of the concurrent measurement of physical and biological properties, and improvement of ecosystem and fisheries models will allow management practices to be efficient and foster sustainable marine resources (Hofmann, 1998).

The regional study of Pacific Northwest coastal temperatures demonstrated that a substantial amount of information is gathered from a relatively simple experimental design. The LAG regression displayed interesting rises and falls that may be indicative of interannual and interdecadal climate patterns. Expansion of such an experiment may lead to the establishment of global interdecadal climate change. Only through coordinated research on national and international levels can a complete understanding of natural climate variability be obtained.

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Glossary of Terms:

acoustic tomography: mapping of ocean floor features through sound reflection

bathythermographic: measurements of temperature and pressure

chlorophyll *a*: a waxy blue-black microcrystalline green plant pigment, $C_{55}H_{72}MgN_4O_5$, with a characteristic blue-green alcohol solution

copepod: crustacean approximately 2mm long with a single eye in the midline at the front end (Meinkoth)

CTD's: electronic instrument that measures conductivity, temperature, and depth and provides a virtually continuous vertical sampling of the water column (Hall)

dog-whelks: gastropods with a spiral shell that live on sand or mud flats (Meinkoth)

hydrographic: measurements of oceanic and physical conditions (e.g. temperature and salinity)

limpets: gastropods with an oval body and oval shell that live on rocks and breakwaters near low-tide line (Meinkoth)

metadata: technical description of data collection methodology

monotinically declining: steadily decreasing

phytoplankton: microscopic algae suspended in that part of the water column of lakes and seas that is penetrated by light (Ruppert)

planktonic: larval stage of fish (in this case) in which they live suspended in the water column but are unable to counter water current because of small size or insufficient motility (Ruppert)

Q_{10}: the ratio of the rate of a reaction at a given temperature to its rate at a temperature 10°C lower (Eckert)

radar altimeters: devices that determine absolute distance between satellite and sea surface, provides information on wave conditions and currents (Hall) scatterometers: devices that five information on wind speed and direction over sea-surface (Hall)

synthetic aperture radar: (SAR) device used to map or image a variety of dynamical features at the sea-surface and upper ocean (Hall)

trophic: individual level within a food chain (Eckert)

zooplankton: microscopic animals that are free-swimming or suspended in the water of both oceans and freshwater lakes (Ruppert)

Table 1: r-Values for Pacific Northwest and Coupled sites

Site	r-value
Total Pacific Northwest	0.84298452
Trinidad/Eureka	0.916334439
Farallon Islands/Berkeley	0.660192193
Pacific Groove/Santa Cruz	0.695949478
Bodega Bay/Petaluma	0.556433412
Santa Cruz/Santa Cruz	0.79389473
Crescent City/Brookings	0.803010635
Charleston/North Bend	0.679555701
Neah Bay/Port Angeles	0.815449286

Table 2: r-Values for LAG Years 0-50

LAG (X)	R-VALUE	LAG (X)	R-VALUE
0	0.84298452	26	0.304667835
1	0.115112589	27	0.328729453
2	0.029951312	28	0.36195317
3	0.024536524	29	0.383643881
4	0.076843117	30	0.41487354
5	0.07623593	31	0.433411222
6	0.103028943	32	0.448097748
7	0.092545144	33	0.46590288
8	0.038428821	34	0.487078205
9	0.08189172	35	0.508456348
10	0.076591883	36	0.523335434
11	0.072200101	37	0.473340735
12	0.032386646	38	0.435059775
13	0.014488281	39	0.433825032
14	0.019034818	40	0.458563141
15	0.050294223	41	0.458978808
16	0.02071213	42	0.430757771
17	0.005225476	43	0.419902947
18	0.012692849	44	0.4085865
19	0.043565607	45	0.411018688
20	0.049069986	46	0.384265466
21	0.091877325	47	0.365730011
22	0.127271885	48	0.384062555
23	0.21607051	49	0.376685246
24	0.231478269	50	0.388564781
25	0.27346325		

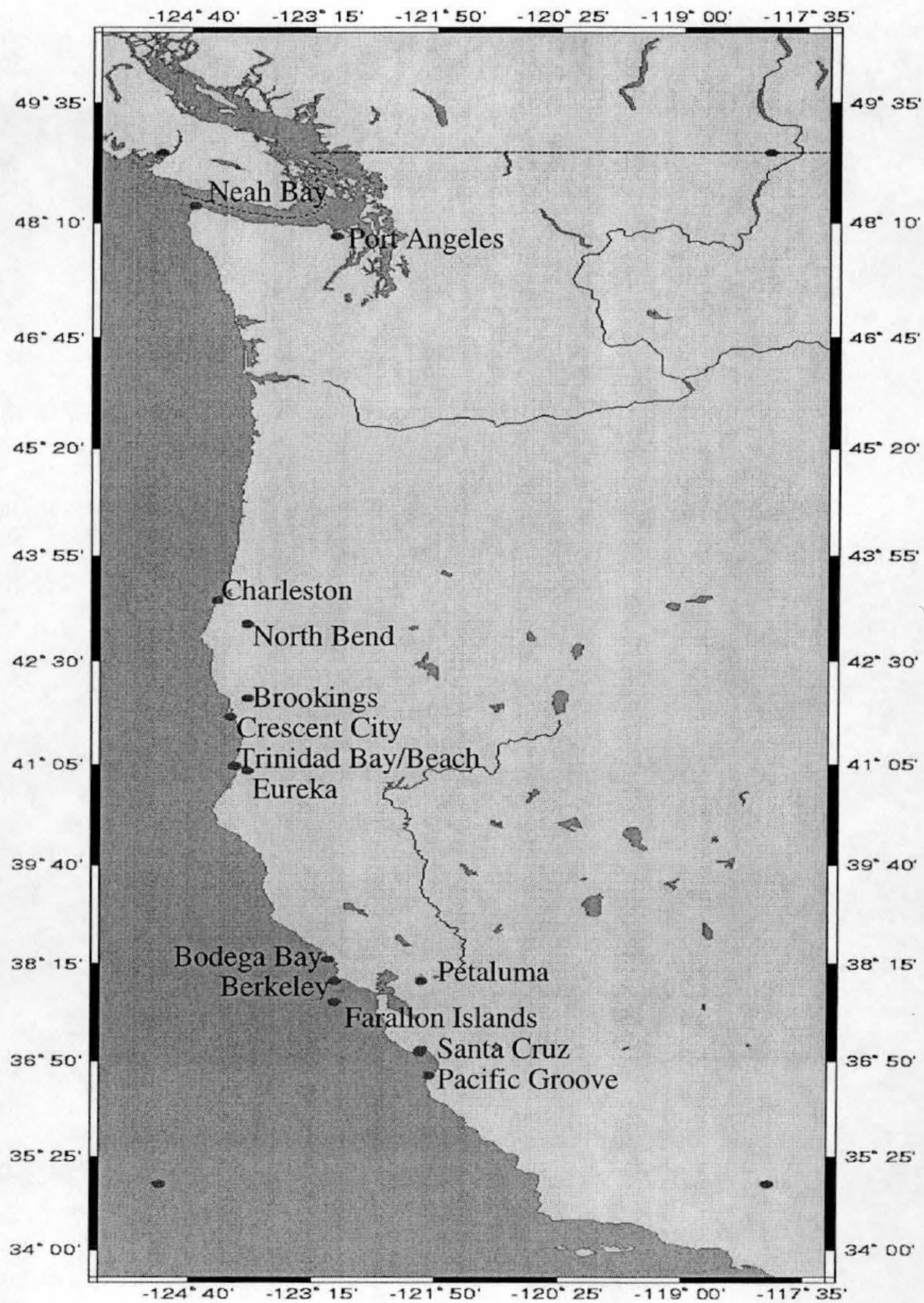

Figure 1: General Map of the Pacific Northwest (Reference: Map Generator, Whalenet, http://www1.wheelock.edu/expanded-menu.html)

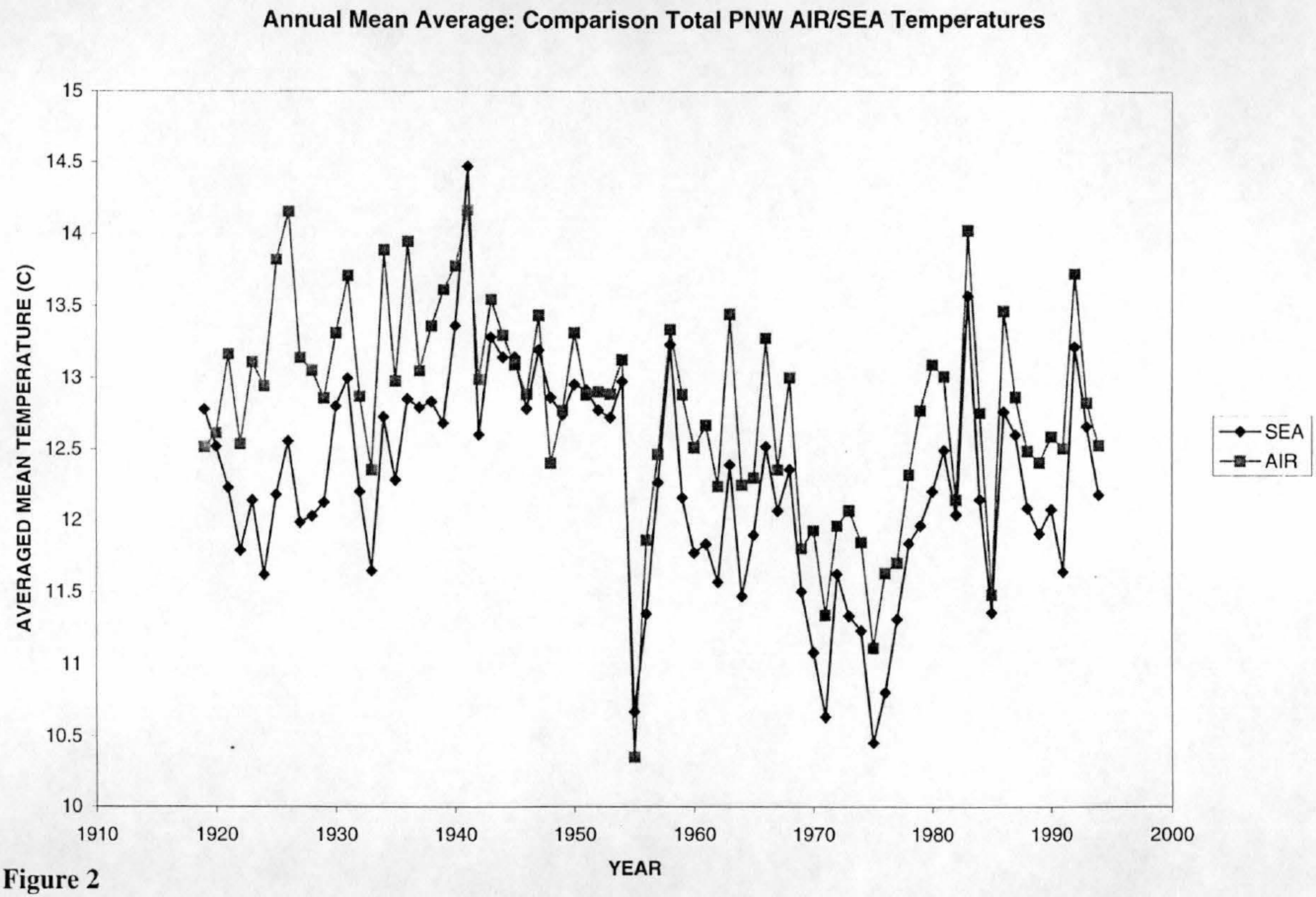
Annual Mean Average: Comparison Total PNW AIR/SEA Temperatures
AVERAGED MEAN TEMPERATURE (C)
YEAR
SEA
AIR
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Figure 2

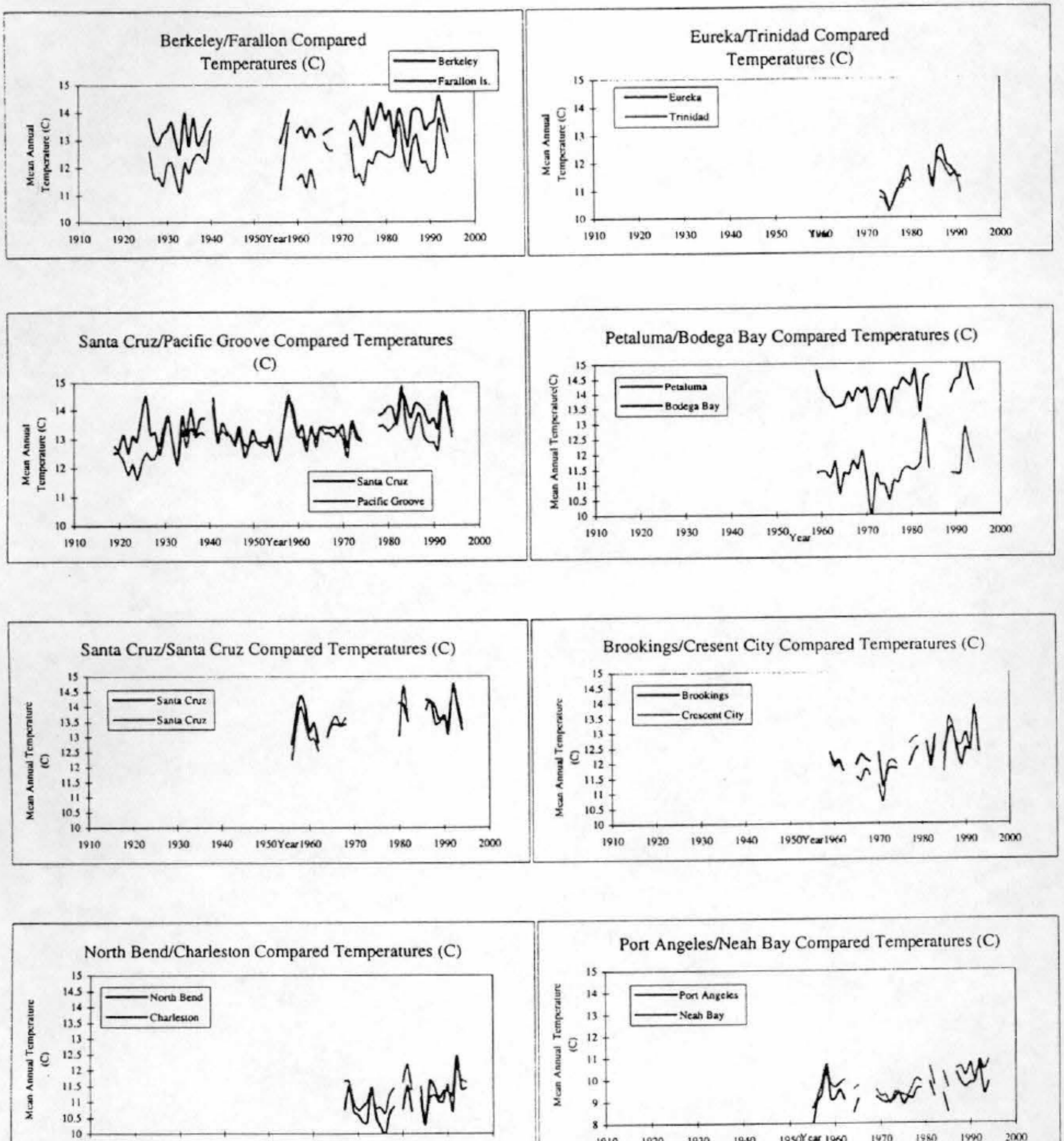

Figure 3: Site Coupled Comparison: Sea Surface and Surface-Air Temperatures (C)

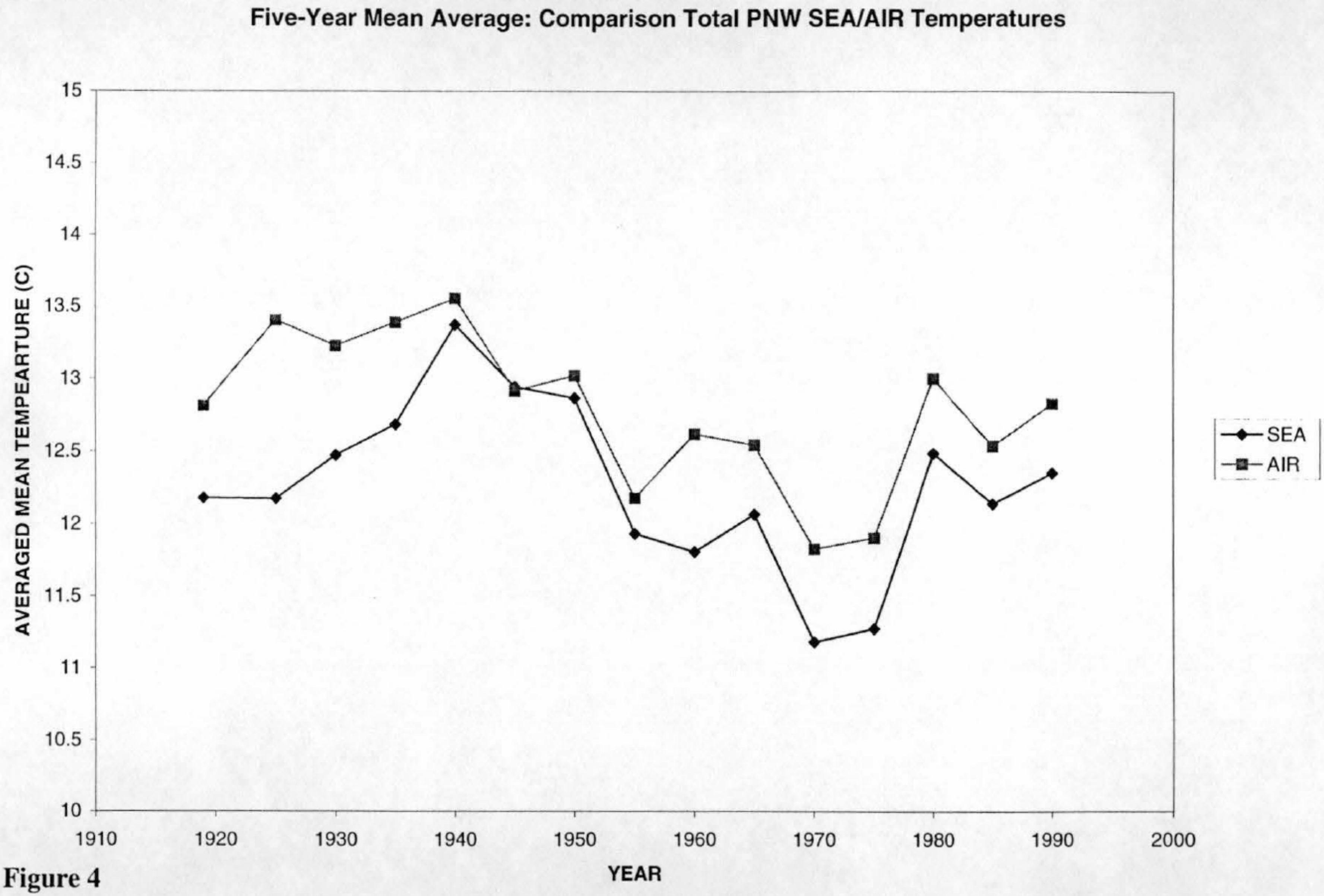
Five-Year Mean Average: Comparison Total PNW SEA/AIR Temperatures
AVERAGED MEAN TEMPEARTURE (C)
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR
SEA
AIR

Figure 4

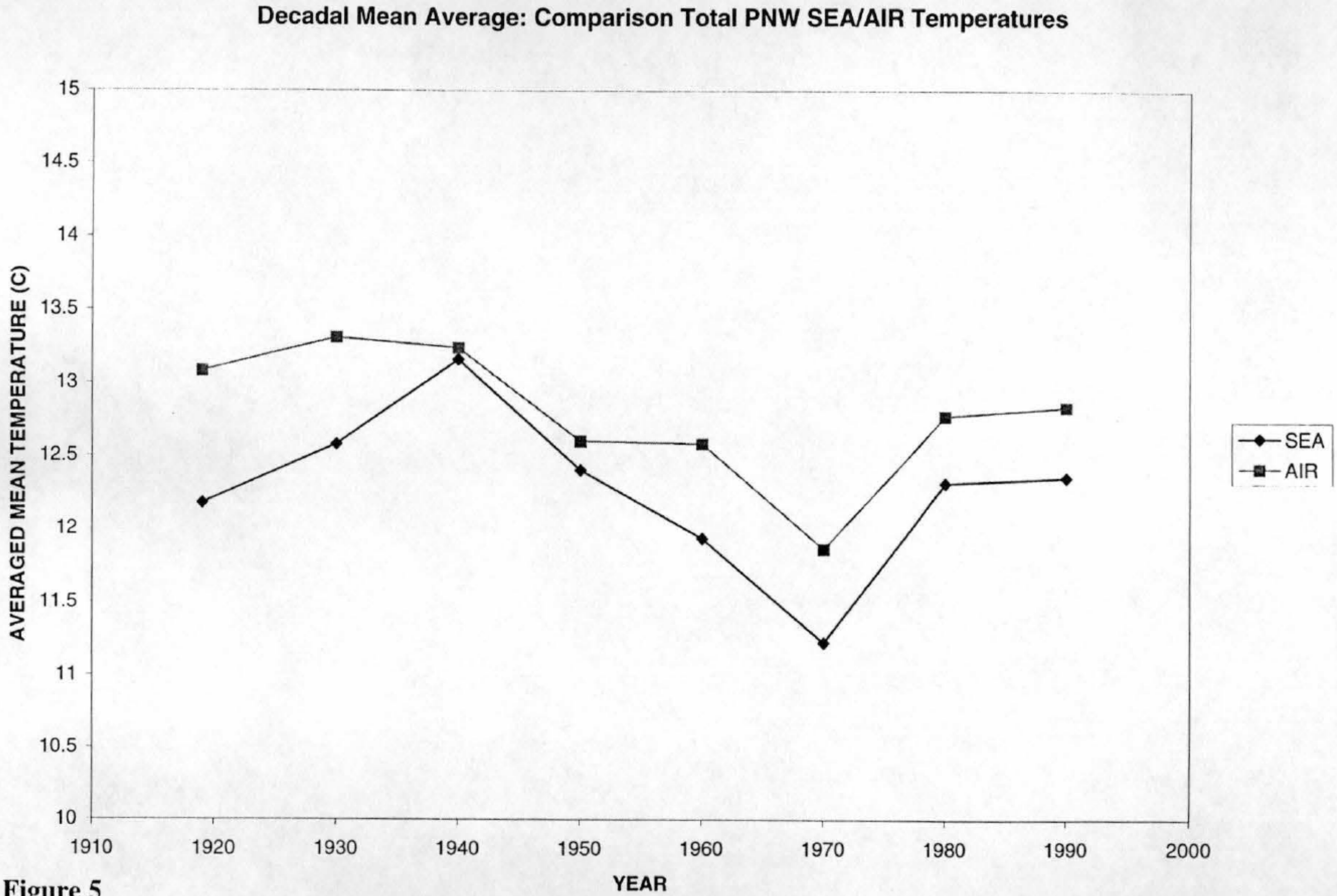
Decadal Mean Average: Comparison Total PNW SEA/AIR Temperatures
AVERAGED MEAN TEMPERATURE (C)
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
YEAR
SEA
AIR

Figure 5

Annual r-Value Comparison: Fifty Year LAG Test

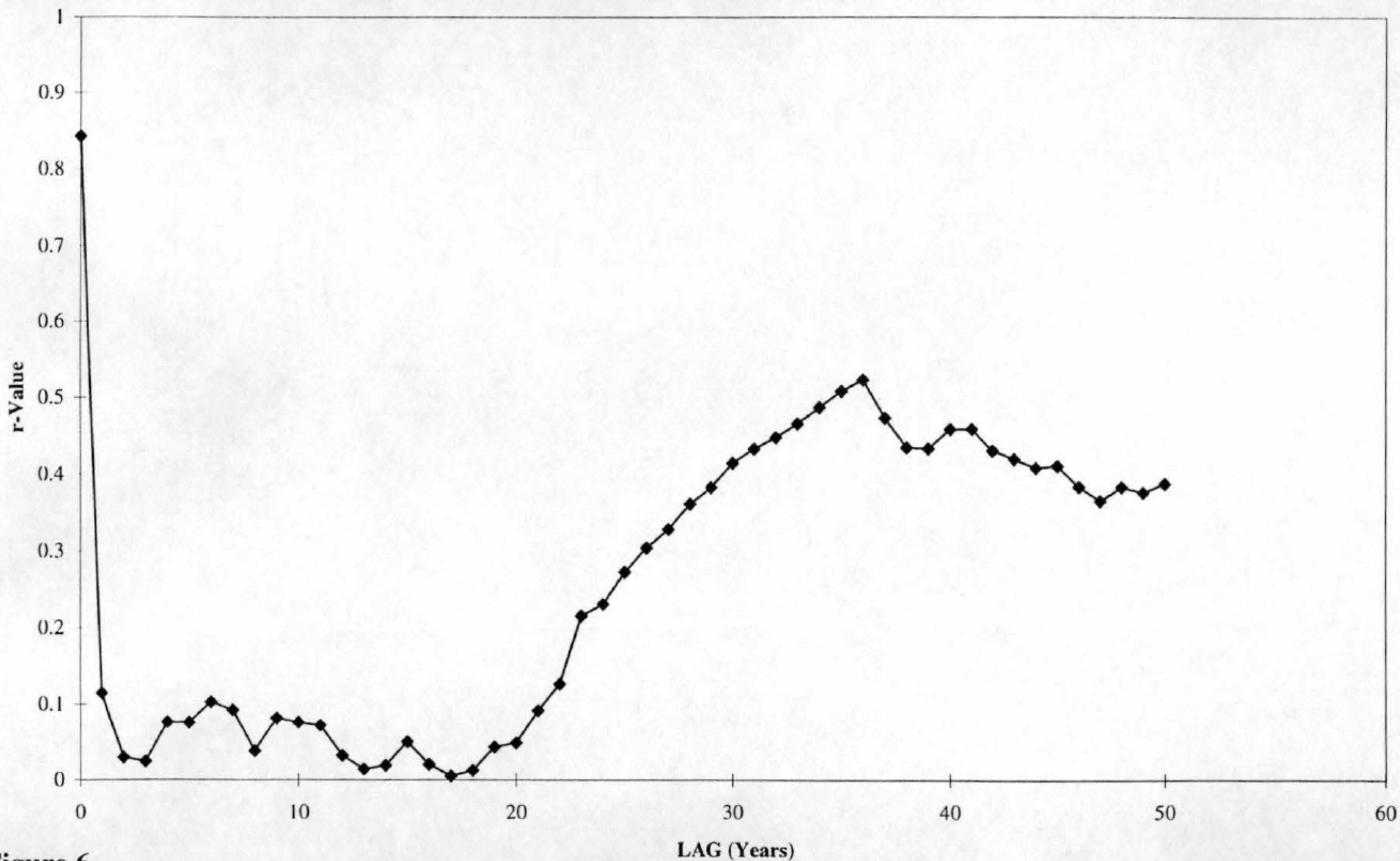

Figure 6