Influence of interannual climatic fluctuations on biological systems

GROWTH of conifers in western North America and the distribution of albacore tuna (*Thunnus alalunga*) along the west coast of North America are linked by large scale atmospheric flow patterns which are influenced by air–sea interaction processes over the eastern North Pacific. Although the systems respond to their respective environments during different times of the year there is strong evidence that they are reacting to the same climatic fluctuations.

Ring widths of conifers from a variety of semi-arid sites in western North America reflect climatic variations. The spatial anomaly patterns of tree growth have been related to large scale anomaly patterns of the general atmospheric circulation which, in turn, are related to anomaly patterns of sea-surface temperature (see, for example, refs 1 and 2).

Seasonal migrations of albacore tuna into and out of the coastal North American fishery and the population distribution along the coast are related to changes in the thermal structure of the eastern North Pacific which, in turn, are related to air–sea interaction events[3].

Although it would be desirable to know the yearly variations in the distribution of albacore abundance or the exact number of individuals in the population, the best source of available data is landing statistics compiled for various regions along the North American coast (J. A. Renner, personal communication). These data indicate albacore availability, or accessibility to the efforts of a fishery. A complex situation probably exists where fluctuations in landings result both from environmental influences affecting albacore migration routes (causing yearly variations in their geographical distribution along the coast) and from weather conditions affecting the location and success of the fishermen and/or the behaviour of the fish once they are distributed.

As an indicator of variations in albacore population distribution, the landings reported north of San Francisco were expressed as a percentage of those reported along the entire coast. This assumes the fishing effort is spread along the entire coast throughout each fishing season. Although a complete effort analysis has not been made, boats were operating consistently along the entire coast throughout the analysis period.

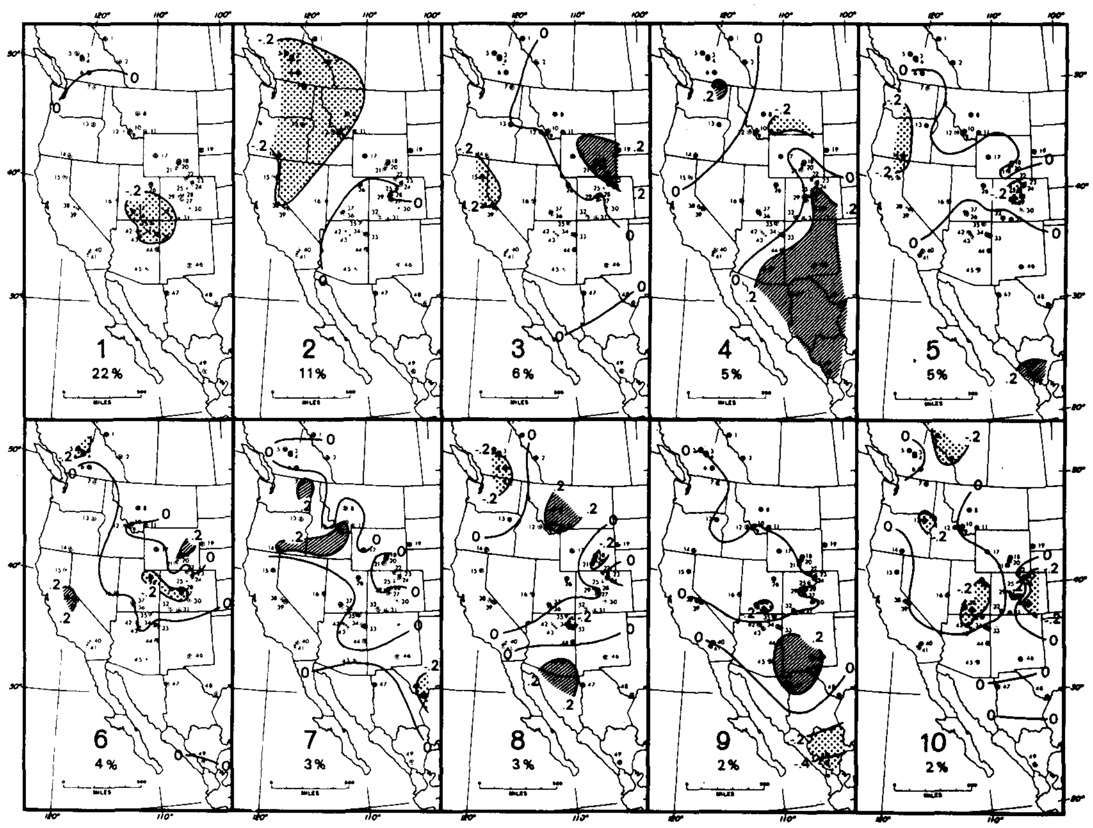
To determine whether spatial patterns of tree growth from 49 sites in western North America and albacore distribution both respond to the same variations in the ocean–atmosphere system, the large scale components of the ring-width variance were transformed into uncorrelated variables (amplitudes of principal component eigenvectors) and then put in stepwise regression to find which of these amplitudes were significant predictors (at the 95% confidence level) of albacore catch. This procedure gave the equation:

$$Y=35.12+5.76A_2+5.13A_8+8.56A'_4-6.17A'_9+11.54A'_{10} \quad (1)$$

where Y is the estimated percentage of albacore caught north of San Francisco, A and A' are eigenvector amplitudes corresponding to the catch year and the following year, respectively, and subscripts refer to the eigenvector number (Fig. 1). The regression accounted for 83% of the catch data variance in the calibration period (Fig. 2). The values of tree-growth eigenvector amplitudes for 1700 to 1938 were then substituted into equation (1) to estimate what the yearly albacore catch distribution would have been for this early period based on the patterns of tree growth (Fig. 3).

Although fishery statistics are available after 1961, tree-growth data for all 49 sites within the spatial network are not, and the only independent data available to check the validity of the reconstruction are incomplete fishery catch statistics between 1904 and 1937 (ref. 4). A qualitative comparison between both sets of data shows these common

Fig. 1 Maps of the first 10 eigenvectors of ring-width index. The percentage figures refer to the variance accounted for by the corresponding eigenvector. Numbered circles indicate ring-width chronology sites.



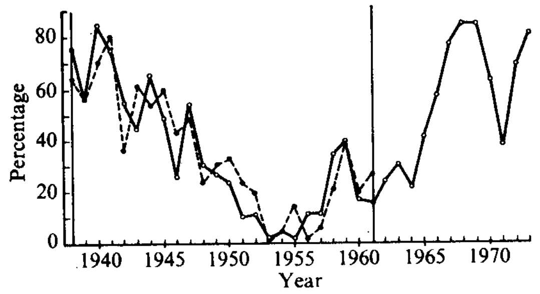


Fig. 2 Percentage of the total North American west coast albacore tuna catch taken north of San Francisco, estimated from landings data (———) and percentage catch taken north of San Francisco derived from the calibration equation applied to tree-growth data over the dependent data period (- - - - - -). Calibration included the following steps: (1) We computed the 49 by 49 correlation matrix which expressed the interrelationships among the 49 ring-width index series for the period of analysis (1700–1962). (2) The eigenvectors of the correlation matrix were then computed. These (orthogonal) eigenvectors may be expressed in map form as characteristic spatial anomaly patterns of tree growth. The 10 eigenvector patterns which accounted for the most variance (the large scale variance) were selected for further analysis. Maps of these eigenvectors are shown in Fig. 1. Linear combinations of these 10 eigenvectors can reproduce 64% of the ring-width variance for the 49 chronologies during the period of analysis. (3) Each of the first 10 eigenvectors was multiplied by the normalised tree-growth data at each site for each year from 1700 to 1962. The resulting matrix product consists of 10 time series of amplitudes which give the relative importance of each of the first 10 eigenvector patterns (the large scale patterns) in each year's tree-growth anomaly map. Being orthogonal to (uncorrelated with) each other they are easy to use as predictor variables in multiple regression. (4) Since trees respond to the climate of both the concurrent season and previous seasons, a prediction model was constructed including the 10 amplitudes corresponding to the same year as the catch data and the 10 amplitudes corresponding to the year following the catch data, for a total of 20 possible predictor variables. (5) Stepwise multiple regression was used to find those amplitudes that were significant predictors (95% confidence level) of albacore catch distribution for the years 1938–61.

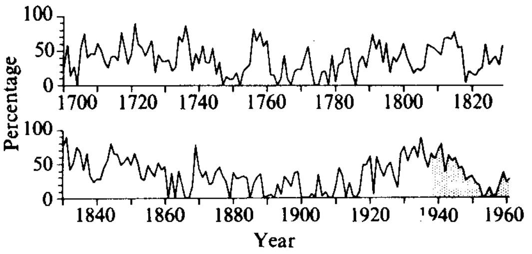


Fig. 3 Percentage of the total albacore tuna catch taken north of San Francisco, estimated from the calibration equation applied to tree-growth data for 1700 to 1961. Shading indicates calibration period.

characteristics: a fishery that was centred off southern California in the early 1900s; a sharp decrease in the availability of albacore to the southern fishery between 1917 and 1918; another decrease in availability of albacore to the southern fishery in 1923 when the total catch was the lowest since 1918; and a prolonged period of decreased availability to the southern fishing fleet after 1928. The reconstructed distribution data indicate that a fishery would have been centred quite far north after 1929 and through the late 1930s if boats had operated there during that period. The absence of albacore from the catch record for Oregon and Washington before 1937 and low catches for California after 1925 probably reflect the extreme northward and offshore population distribution indicated by the reconstructed data; the fish were just not available to salmon trollers that did operate close to shore north of California during this period[5].

We also examined the eigenvector patterns of tree growth that were chosen by regression to be associated with a high percentage of albacore caught north of San Francisco. The tree-growth pattern corresponding to the year of the catch

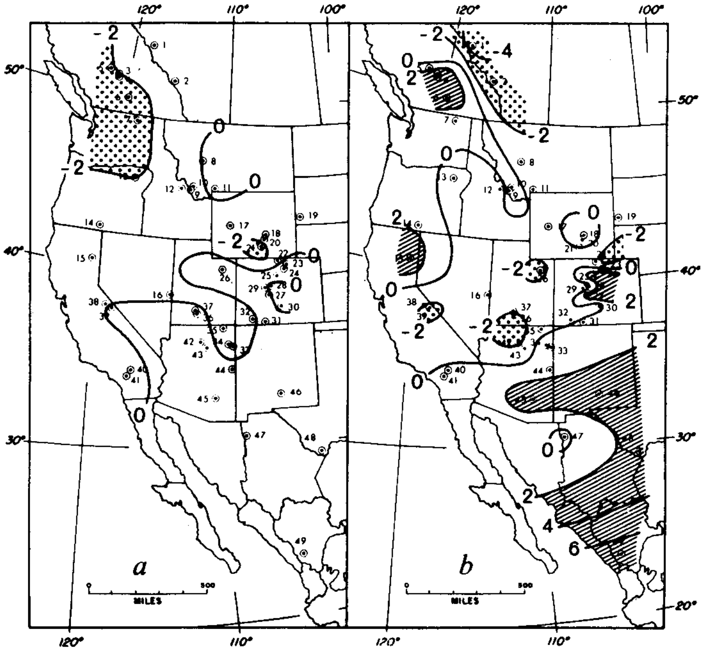


Fig. 4 Tree-growth anomaly patterns associated with above normal percentages of albacore caught north of San Francisco. Map *a*, corresponding to the year of the catch, is formed from the linear combination of eigenvectors 2 and 8 in equation (2); map *b*, corresponding to the year following the catch, is formed from the linear combination of eigenvectors 4, 9, and 10 in equation (3).

can be represented by a map composed of eigenvectors 2 and 8 as follows:

$$\text{map } a = 5.76\,(\text{eigenvector } 2) + 5.13\,(\text{eigenvector } 8) \quad (2)$$

where the numerical coefficients are taken from equation (1). Similarly, the tree-growth anomaly pattern corresponding to the year following a high percentage of albacore caught north of San Francisco can be represented as:

$$\text{map } b = 8.56\,(\text{eigenvector } 4) - 6.17\,(\text{eigenvector } 9) + 11.54\text{ eigenvector } 10) \quad (3)$$

These maps are presented in Fig. 4. The ring-width data were mostly from trees sited in arid localities, so that a wide ring would generally be associated with anomalously cool, cloudy weather and above normal precipitation whereas a narrow ring would reflect warm, sunny and dry conditions.

Below normal tree growth in the Pacific North-west (Fig. 4) is indicative of dry conditions associated with below normal cyclonic activity during the fishing season. Sunny and mild weather would favour albacore fishing in adjacent waters, as would above normal insolation regardless of weather. The resulting excess of stored heat in the ocean would be given up through evaporation during the following autumn and winter and lead to increased cyclonic activity and precipitation along the coast north of San Francisco. These conditions would lead to increased tree growth during the following growing season (Fig. 4).

Autumn and winter climatic anomaly features, combined with spring climate and the year-to-year autocorrelation of tree-ring widths, produce the other ring-width anomaly features in Fig. 4 for the following growing season. Narrow ring widths south of San Francisco, for example, imply below normal precipitation—an expected feature since winter precipitation in the Pacific North-west is negatively correlated with winter precipitation in southern California[6].

The reconstructed values of albacore catch distribution data (Fig. 3) and inferred population distribution also seem to exhibit long term changes over intervals of 100 yr or more, which suggest the possibility that long term fluctuations in the ocean–atmosphere system may be involved.

The success of the calibration of tree rings with albacore catch indicates the possibility of relating tree-ring variations to any type of biological variations which are affected by large scale climatic fluctuations. Such relationships may be quantified and used to reconstruct objectively other climatically-caused biotic variations in the past.

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