NPAFC

Doc. No. 289

Rev. No. 1

A comparison of the Aleutian Low Pressure Index and the Atmospheric Circulation Index as indices of Pacific salmon Abundance trends.

by

R. J. Beamish,[1] G.A. McFarlane, [1] D. Noakes, [1]
M. Folkes, [1] V.V. Ivanov, [2] and V. Kurashov[2]

[1]Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, B.C. V9R 5K6 Canada

[2]State Research Center of Russian Federation
The Arctic and Antarctic Research Institute
38 Bering St 199397
St. Petersburg, Russia

submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

CANADA

October 1997

This paper may be cited in the following manner:
Beamish, R.J. , G.A. McFarlane, D. Noakes, M. Folkes, V.V. Ivanov, and V. Kurashov. A comparison of the Aleutian Low Pressure Index and the Atmospheric Circulation Index as indices of Pacific salmon abundance trends. (NPAFC Doc. 289). ~~25~~24p. Department. of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C. Canada. V9R 5K6.

Abstract

The Aleutian low Pressure index (ALPI) is an index of the intensity of the winter low pressure in the subarctic Pacific. The index is the area of the Aleutian low less or equal to 100.5 kPa, averaged for the months from December to March and expressed as an anomaly from the long-term mean. The ALPI is virtually identical to the North Pacific Index (NPI) which is the area-weighted mean sea level pressure in a rectangular area of the North Pacific bounded by 30° to 65° N and 160°E to 140°W. The NPI is calculated for the five-month period from November to March expressed as an anomaly from the time series mean. The trends in the indices are opposite because the ALPI increases in area as the Aleutian Low increases and the NPI decreases as it is a measure of the low pressure which becomes smaller as the low pressure system intensifies.

The Atmospheric Circulation Index (ACI) is an index of the pattern of the westerly winds in the Northern Hemisphere. This Russian index is developed by classifying daily wind patterns over the Northern Hemisphere into three types. The types are then summed for each year. One type, the C type or meridional flow forms the index. The index is calculated from the data and cannot be directly compared to wind types.

When the ACI and ALPI are expressed in the same form and compared to recent total catches of pink, chum, and sockeye, after 1950, the trends are similar. The ACI fits the salmon data better than ALPI when the entire time series are used, but the fits are more similar when only data after 1950 are used. The close synchrony among these two indices is evidence of the linkages in climate around the Northern Hemisphere. The persistence in the indices is evidence of the existence of regimes. The synchrony in the timing of the change in trends is important for fisheries management as it indicates that relationships within ecosystems may change. The close association with Pacific salmon catches identifies the importance of natural factors in the regulation of abundance. The change in the climate indices in 1989 was consistent with a reduction

in the rate of increase in salmon production that occurred after the 1976-1977 regime shift. It is possible that another change occurred in 1996-1997 but it is too early to determine.

Introduction

There is an increasing literature documenting persistent patterns in the climate and related changes in the dynamics of fish populations (Venrick et al. 1987, Ebbesmeyer et al. 1991, Latif and Barnett 1994, Polovina et al. 1995, Roemmich and McGowan 1995, Ware 1995, Adkison et al. 1996, Gargett 1997, Gu and Philander 1997, Mantua et al. 1997, Beamish et al. 1997). Understanding the relationship between the dynamics of fish populations and their environment is critical as most management has been based on the assumption that fishing is the dominant factor affecting the trends in fish stocks. The issue of the relative importance of density related factors compared to the environment is not unique to fisheries management as the topic has been of general interest in ecology for decades. The basis for modern fisheries management developed from models that assumed that survival was related to density and as density increased beyond a certain point, survival would decrease. Factors that acted independently of density such as climate, often were considered to affect only the variability in the fundamental relationships.

Progress has been made recently, because the basic connection between climate and fish abundance is beginning to be understood. The emphasis on understanding mechanisms rather than just searching for relevant parameters in regression analyses is improving our understanding of the relative impacts of fishing and natural impacts. In this report, we compare two indices of global climate to Pacific salmon production, the Aleutian Low Pressure Index (ALPI) and the Atmospheric Circulation Index (ACI). We show that these very different indices, produce virtually identical results. Both indices are in the literature, but neither is in common use. One problem is that they are not readily available and another is that the forms of the two indices differ. Here we explain the development of both indices and compare them to Pacific salmon catch using similar formats.

Aleutian low Pressure Index

Beamish and Bouillon (1993) used an Aleutian low Pressure Index (ALPI) as an indicator of a major climate process that could affect Pacific salmon production. The Aleutian Low is the winter weather pattern in the North Pacific ocean that strengthens late in the year and weakens in the spring of the following year. The levels of low pressures affect the intensity of winter storms which in turn affect both mid-ocean and coastal productivity (Venrick et al. 1987, Gargett 1997). The ALPI is the area of low pressure (less than or equal to 100.5 kPa) in the North Pacific Ocean, averaged for the months from December to March and expressed as an anomaly from the long-term mean. Surface sea level pressures are obtained and the index is revised annually when the March data become available. The year of the index is the year from January to March. Sea level pressure data are available at the National Centre for Atmospheric Research, Boulder, Colorado, which we obtain from the web site, http://www.scd.ucar.edu/dss.datasets/ (also 10.1.html). The daily data are represented in a monthly format in 5° x 5° grids. The data set covers the Northern Hemisphere from 15°N to the North Pole, but we restrict our analysis to an area 20°N to 70°N and 120°E to 120°W. For this report we used data from 1899 to April 1997 (Appendix 1). Trenberth and Hurrell (1995) reviewed the data series and concluded that reliable data existed beginning in 1950, thus we consider that the indices are most reliable after 1950. We determined the area of the ALPI using the GIS software package "COMPUGRID" which plots isobar images of the North Pacific with a resolution of 0.5 kPa. The area of each 5° x 5° cell within the 100.5 kPa boundary is summed after automatically being corrected for the curvature of the Earth. We confirmed the computer generated estimates by visually checking monthly isobar plots to insure anomalous data outside of the Aleutian Low was not included.

In addition to the four-month anomaly, we compare each monthly anomaly pattern with the four-month index for the time series beginning in 1950. We also show the four-month anomaly index as a CuSum, as this is the form of the ACI.

The method of accumulating sums or CuSum (Murdock 1979) is a way of studying trends by including information from past data points and giving less weight to single values. The calculation is a simple addition of a data point to the sum of all previous data points. Each data point may have a constant (referred to as a target value) subtracted from it, to enhance visualization. The constant is usually the expected mean of the entire series. If there is a change in the mean within the data series as expected in a regime, there will be a shift in the slope of the CuSum chart. Thus, the average slope of a trend in the CuSum may represent a regime and the year of change in the slope of the CuSum chart is the year of the regime shift.

The ALPI from 1899 (Fig. 1A) increases from the early 1900s to the early 1940s. There is a trend of higher pressures (smaller areas of low pressure and a corresponding smaller index) up to the mid-1970s (Fig. 1B). There is a brief period from 1958 to 1963, where moderately low winter pressures occurred, but the general pattern was one of reduced areas of intense low pressures. The ALPI identifies a period of extreme low pressures from 1978 to about 1989 (Fig. 1B). The ALPi was slightly above average in 1990 and 1991, but by 1992 and 1993, it was apparent that the period of extreme low winter pressures was over. From 1992 until the present (1997) the ALPI is low indicating the area of intense winter low pressures was small. The CuSum charts from 1950 (Fig. 1C) show the general trend of reduced low pressures up to 1976 and the change to larger areas of winter low pressures up to 1988. The weaker lows of the 1990s appear as a change in slope of the CuSum chart beginning in 1989. Thus, there are three persistent trends since 1950; 1950-1976, 1977-1988, 1989-1997. The month that most closely approximated the ALPI was January (Table 1). January, February, and March sea level pressures were all closely related to the index of the Aleutian Low.

Table 1 Regression of ALPI (December to March) vs. months of the year from 1950 to 1997.

	J	F	M	A	M	J	J	A	S	O	N	D
ALPI (R^2)	0.60	0.48	0.27	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00
P	<.01	<.01	<.01	0.39	0.71	0.94	0.75	0.75	0.75	0.56	0.15	0.85

Trenberth and Hurrell (1995) used another index of the Aleutian Low Pressure system, the North Pacific Index or (NPI) which is the area-weighted mean sea level pressure in a rectangular area of the North Pacific bounded by 30 to 65°N and 160°E to 140°W. The NPI is for the five-month period from November to March and is expressed as an anomaly from the time series mean. When NPI and ALPI indices are compared either as smoothed trends (Fig. 2A) or as a regression (Fig. 2B), it is apparent that they are quite similar. To study climate, both indices are useful, but for climate and fisheries studies, the ALPI also provides information on the size and location of the low.

The Atmospheric Circulation Index

The Atmospheric Circulation Index is based on a classification system for wind patterns in the Northern Hemisphere. The classification system developed by Russian meteorologists (Girs 1971, Barry and Perry 1973) restricts the classification of wind patterns to three types. One type, termed the western circulation or W, describes winds that follow a zonal pattern (latitudinal) without prominent meridional (north and south) circulation. The W circulation is typified by relatively fast, east to west transfers of air masses. The C or meridional flows have dominant northwest and southeast patterns that form weak subpolar lows but a strong high over Siberia. The E, or easterly circulation (but also meridional) is similar in form to C but opposite in phase resulting in different locations of the troughs. In the Pacific, a separate classification was developed, but the basic patterns of flows were similar. In general, the E, W, and C types characterize changes that result from the redistribution of air masses, changes in the position of tropospheric centers of atmospheric pressure, and transfers of cold and heat. As the Russian literature may be difficult to locate, we suggest that readers refer to the recent paper of Moore and McKendry (1996). They used a computer-assisted map typing process (Yarnal 1984, 1993) to classify the dominant direction of the westerly winds flowing over British Columbia, Canada for the November to March period. Their approach identified 25 wind patterns at mean sea level, but 50% of these were described by three basic types that were similar to the Russian types E, (Moore and McKendry Type 1); W, (Moore and McKendry Type 3); and C, (Moore and McKendry Type 2). Moore and McKendry (1996) checked their typing system visually to confirm that the computer-assisted method was valid. The Russian method relies on a daily examination and visual classification of the Northern Hemisphere wind patterns by a team of trained specialists. We examined samples of the classifications made by the Russian specialists and Moore and McKendry and found that the classifications of the basic three types were similar.

In the Russian classification system, the proportion of days of each type were compared with long-term averages. When the annual anomalies for each type are examined, the W and E forms have strong linear trends that are opposite in phase and the C form has a distinct pattern from either the W and E types. An index of these patterns, the Atmospheric Circulation Index (ACI) is developed from the anomalies for each pattern type. As the anomalies will sum to zero, C=-(W+E). The ACI is the integral of the W+E anomalies or the -C anomalies. The integral is a cumulative sum or CuSum of the anomalies described earlier.

The number of days of zonal flows (W) increased until a decline started in the late

1930s (Fig. 3A). This decline continued until the late 1980s when the trend changes. The number of days of easterly circulation (E) followed a pattern that was opposite to the anomaly pattern of the zonal flows (W) (Fig. 3A). This means that when the number of annual days of zonal flows was declining from the long-term average, the number of meridional or E days was increasing above the long-term average. It is the meridional flow or the number of C days that exhibits the greatest fluctuations around the long-term mean. The index of the overall trend or the ACI (Fig. 3B) indicates distinct trends from 1903 to 1929, 1930 to 1940, 1941 to 1973, and 1974 to 1990. A recent change started about 1991.

Comparison of ALPI, ACI and Pacific salmon catch

We compared the trends in these two indices by producing the CuSum of the ALPI so that the forms of the two indices were the same (Fig. 4A). The two indices follow similar trends beginning about 1950 (Fig. 4A). Prior to 1950, there is a general similarity in trends, but the synchrony of the change in the trends is not the same. Because the SLP data is less reliable earlier than 1950, we compared the ACI and the ALPI CuSum after 1950 (Fig. 4B) and observed a close relationship ($R^2=0.66$; $P<0.01$). Visually, the ACI more closely resembles total catch of pink, chum and sockeye salmon when the data are compared for the entire time series (Fig. 5A, B). The similarities between the two series ACI and ALPI CuSum and total catch of pink, chum and sockeye salmon are much closer when the only data after 1950 are used in the comparison (Fig. 6A, B).

Discussion

The ALPI and the ACI are similar indices of climate when they are compared in the same forms. The ALPI is virtually the inverse of NPI even though NPI is determined for a fixed area of the subarctic Pacific. The NPI and ALPI have opposite trends because the NPI decreases as sea level pressures decrease, but the ALPI increases as the area of low pressure increases. The ALPI and ACI both are indices of total Pacific salmon production as represented by the total all-nation catch of pink, chum, and sockeye. Both indices are quite similar when compared after 1950 when sea level pressure time series become more reliable. While both indices model Pacific salmon production, they convey different information about mechanisms. The ALPI is associated with mid-ocean upwelling and on shore and along shore transport of nutrients and plankton. Thus, the ALPI can be directly related to Pacific salmon production and hypotheses about mechanisms can be tested directly. The ACI is a global index of westerly winds. It is not a measure of any particular wind pattern, but an aggregate of wind pattern data. As such, it is difficult to relate specific mechanisms to ACI. The ACI is an index of the intensity of the Aleutian low, but there is no wind type that is equivalent to -C. It is possible that E+W trends could be grouped to relate to changes in the intensity of the Aleutian Low and it may be possible to interpret ACI in relation to the combination of E and W wind types. The ACI is important because it is an index of global climate which links Pacific salmon production to global climate patterns.

The regional and global nature of the ALPI and ACI imply that future natural fluctuations in Pacific salmon abundance may continue to follow the trends in these indices. There was a change in these indices in 1989, that was seen as a flattening of the previous rapid rate of increase of Pacific salmon production that started after the 1976-1977 regime shift. It is possible that the recent climate changes in 1996-1997 may represent another change in the trend in these indices and a change in the production trend of Pacific salmon. However, the nature of the change in Pacific salmon production will relate to the changes that occur in the ecosystem. It may be expected that the change will be a decline in production, but it may be advisable to see how the indices change before forecasting long-term trends in Pacific salmon catch and escapement.

References

Adkison, M.D., R.M. Peterman, M.F. LaPointe, D.M. Gillis, and J. Korman. 1996. Alternative models of climate effects on sockeye salmon, Oncorhynchus nerka, productivity in Bristol Bay, Alaska, and the Fraser River, British Columbia. Fish. Oceanogr. 5: 137-152

Barry, R.G. and A.H. Perry. 1973. Synoptic climatelogy, methods and applications. First edition. Methuen & Company Ltd., London. 555 pp.

Beamish, R.J. and D.R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Can. J. Fish. Aquat. Sci. 50:1002-1016.

Beamish, R.J., C. Neville and A.J. Cass. 1997. Production of Fraser River sockeye salmon (Oncorhynchus nerka) in relation to decadal-scale changes in the climate and the ocean. Can. J. Fish. Aquat. Sci. 54: 543-554.

Ebbesmeyer, C.C., Cayan, D.R., McLain, D.R., Nichols, F.H., Peterson, D.H., and Redmond, K.T. 1991. 1976 step in the Pacific climate: Forty environmental changes between 1968-1975 and 1977-1984, pp. 115-126. *In*: J.L. Betancourt and V.L. Tharp [eds.] Proc. Seventh Annual Pacific Climate (PACLIM) Workshop, April 1990. Edited by Calif. Dep. Water Resour. Interagency Ecol. Stud. Program Tech. Rep. No. 26.

Gargett, A.E. 1997. The optimal stability “window”: a mechanism underlying decadal fluctuations in North Pacific salmon stocks. Fish. Oceanogr. 6: 1-9.

Girs, A.A. 1971. Long-term fluctuations of the atmospheric circulation and hydrometeorological forecasts. L., Hydrometeorological monographs, St. Petersburg, Russia. 280 p. (In Russian).

Gu, D., and S.G.H. Philander. 1997. Interdecadal climate fluctuations that depend on exchanges between the tropics and extratropics. Science 275: 805-807.

Latif, M., and T.P. Barnett. 1994. Causes of decadal climate variability over the North Pacific and North America. Science 266: 634-657.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Met. Soc. 78: 1069-1079.

Moore, R.D., and I.G. McKendry. 1996. Spring snowpack anomaly patterns and winter climatic variability, British Columbia, Canada. Water Resour. Res. 32: 623-632.

Murdoch, J. 1979. Control charts. MacMillan Press Ltd., London. 150 p.

Polovina, J.J., Mitchum, G.T., and Evans, G.T. 1995. Decadal and basin-scale variation in mixed layer depth and the impact on biological production in the Central and North Pacific, 1960-88. Deep Sea Research 42, 1701-1716.

Roemmich, D., and McGowan, J. 1995. Climate warming and the decline of zooplankton in the California current. Science 267: 1324-1326.

Trenberth, K.E. and J.W. Hurrell. 1995. Decadal coupled atmosphere-ocean variations in the North Pacific Ocean, p.14-24. *In* R.J. Beamish [ed]. Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Venrick, E.L., J.A. McGowan, D.R. Cayan, and T.L. Hayward 1987. Climate and chlorophyll a: long-term trends in the Central North Pacific Ocean. Science (Wash., DC) 238: 70-72.

Yarnal, B. 1984. A procedure for the classification of synoptic weather maps from gridded atmospheric pressure surface data. Computers and Geosciences 10: 397-410.

Yarnel, B. 1993. Synoptic Climatology in Environmental Analysis: A Primer. Belhaven, London

Ware, D.M. 1995. A century and a half of change in the climate of the NE Pacific. Fish Oceanogr. 4: 267-277.

Revised on May 26, 98

Appendix 1: The Aleutian Low Pressure Index (ALPI).

Year	ALPI
1899	-744.398
1900	1,559,642
1901	-204,527
1902	-19,744
1903	-4,590,171
1904	46,348
1905	-1,230,921
1906	-282,714
1907	-3,786,077
1908	-1,782,002
1909	96,411
1910	-2,754,508
1911	-2,394,846
1912	-178,314
1913	-1,390,446
1914	615,036
1915	-1,630,802
1916	-2,429,383
1917	-2,354,289
1918	1,296,843
1919	3,122,326
1920	-2,341,239
1921	-170,269
1922	-3,193,933
1923	-2,029,783
1924	1,166,623
1925	-758,308
1926	4,340,586
1927	1,202,848
1928	1,154,754
1929	1,554,637
1930	-2,220,864
1931	2,940,862
1932	-2,347,821
1933	-3,098,196
1934	2,982,486
1935	-1,090,239
1936	2,741,398
1937	-3,401,214
1938	-301,446
1939	583,874
1940	6,573,488
1941	5,713,537
1942	2,143,293
1943	-3,054,152
1944	1,576,798
1945	4,796,678
1946	3,048,188
1947	-2,280,489
1948	-2,676,208

Year	ALPI
1949	-1,103,683
1950	-1,968,527
1951	-1,436,627
1952	-2,929,671
1953	2,389,332
1954	-2,407,896
1955	-2,654,777
1956	-3,972,827
1957	-1,715,402
1958	2,368,462
1959	-2,192,458
1960	-466,652
1961	3,059,043
1962	-1,807,483
1963	2,506,163
1964	726,467
1965	-1,706,627
1966	-1,801,857
1967	-173,027
1968	-332,438
1969	-2,757,658
1970	3,787,423
1971	-2,344,221
1972	-4,588,314
1973	-1,929,658
1974	1,051,536
1975	-1,992,489
1976	-1,164,994
1977	3,078,787
1978	2,346,976
1979	-1,157,852
1980	1,685,868
1981	4,932,168
1982	-3,409,652
1983	7,145,269
1984	1,533,317
1985	-1,729,519
1986	5,388,862
1987	3,553,426
1988	1,156,554
1989	-2,718,227
1990	-918,114
1991	363,093
1992	2,088,337
1993	-1,100,532
1994	-635,233
1995	1,515,037
1996	798,581
1997	538,032
1998	4,707,449

Figures

Fig. 1 (A) The ALPI from 1899 to 1997 and a loess smoother (solid line). (B) The ALPI from 1950 to 1997 and a loess smoother (solid line). The time series mean is separate for each series and key reference years are identified. (C) The ALPI expressed as a CuSum and showing trends from 1950 to 1976, 1977 to 1988 and 1989 to 1997.

Fig. 2 (A) The lowess smoothed trend of NPI (standard deviation) and ALPI showing that the trends are inversely related. (B) Comparison of the ALPI and NPI (x-axis) as a regression ($R^2=0.67$, $p<0.01$).

Fig. 3 (A) The annual anomalies of the three types of westerly winds from 1899 to 1997. (B) The Atmospheric Circulation Index or the ACI.

Fig. 4 (A) The ALPI in the CuSum form, to compare to the ACI and (B) A simple regression of the CuSum values of the two indices from 1950 to 1997 showing the close relationship ($R^2=0.66$, $p<0.01$).

Fig. 5 (A) The ALPI in the CuSum form and (B) The ACI (already a CuSum index) compared to the total catch of pink, chum, and sockeye for the time series of salmon catches.

Fig. 6 (A) The ALPI in the CuSum form and (B) The ACI (already a CuSum index) compared to the total of pink, chum and sockeye for the time series from 1950 to 1996.

Fig. 7 (A) A comparison of the CuSum form of ALPI and total pink, chum and sockeye catch since 1950. (B) Comparison of ACI and total pink, chum and sockeye catch since 1950.

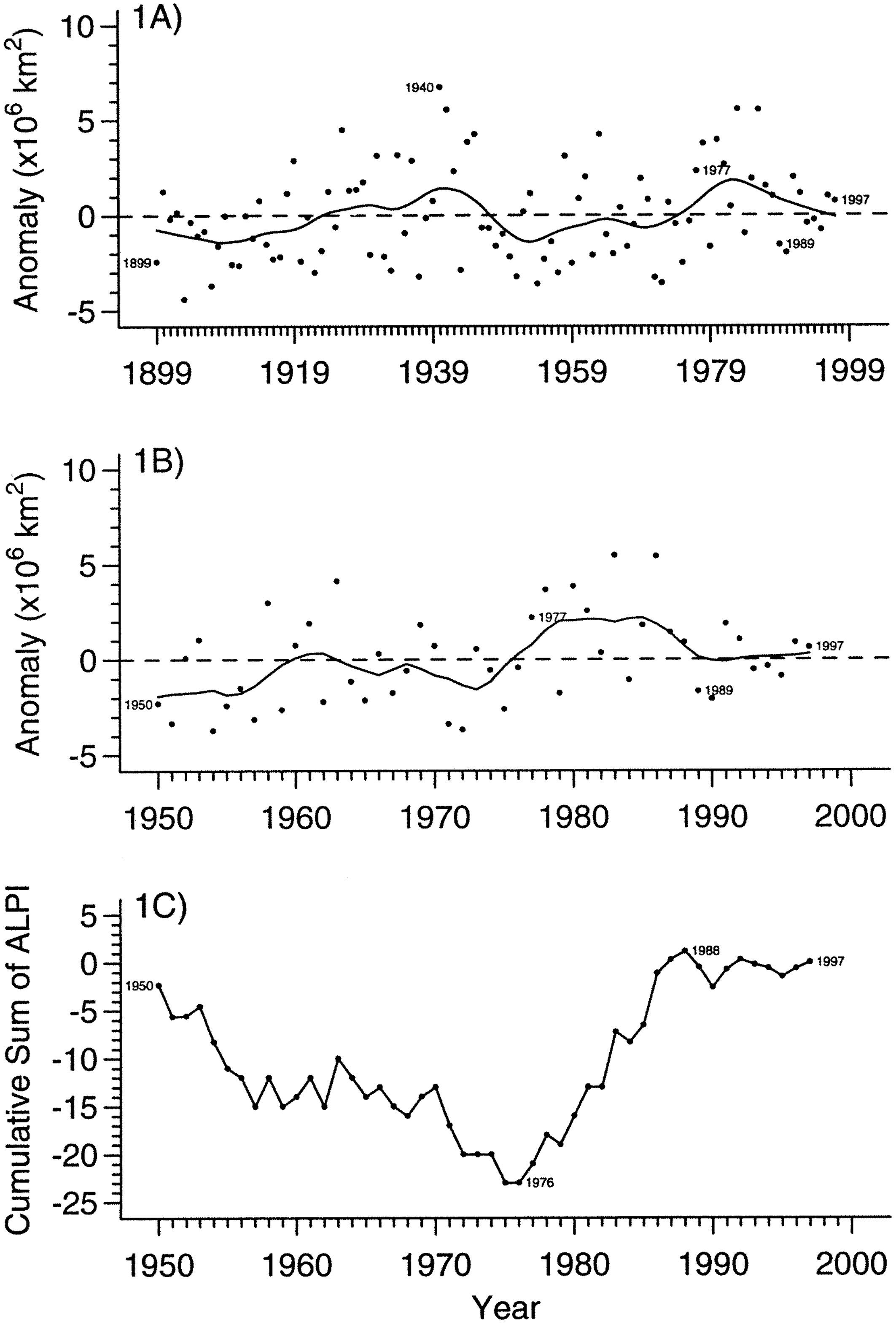
1A)
Anomaly (x10^6 km^2)
10
5
0
-5
1940
1977
1989
1997
1899
1899
1919
1939
1959
1979
1999
1B)
Anomaly (x10^6 km^2)
10
5
0
-5
1977
1950
1989
1997
1950
1960
1970
1980
1990
2000
1C)
Cumulative Sum of ALPI
5
0
-5
-10
-15
-20
-25
1950
1988
1997
1976
1950
1960
1970
1980
1990
2000
Year

FIG. 1

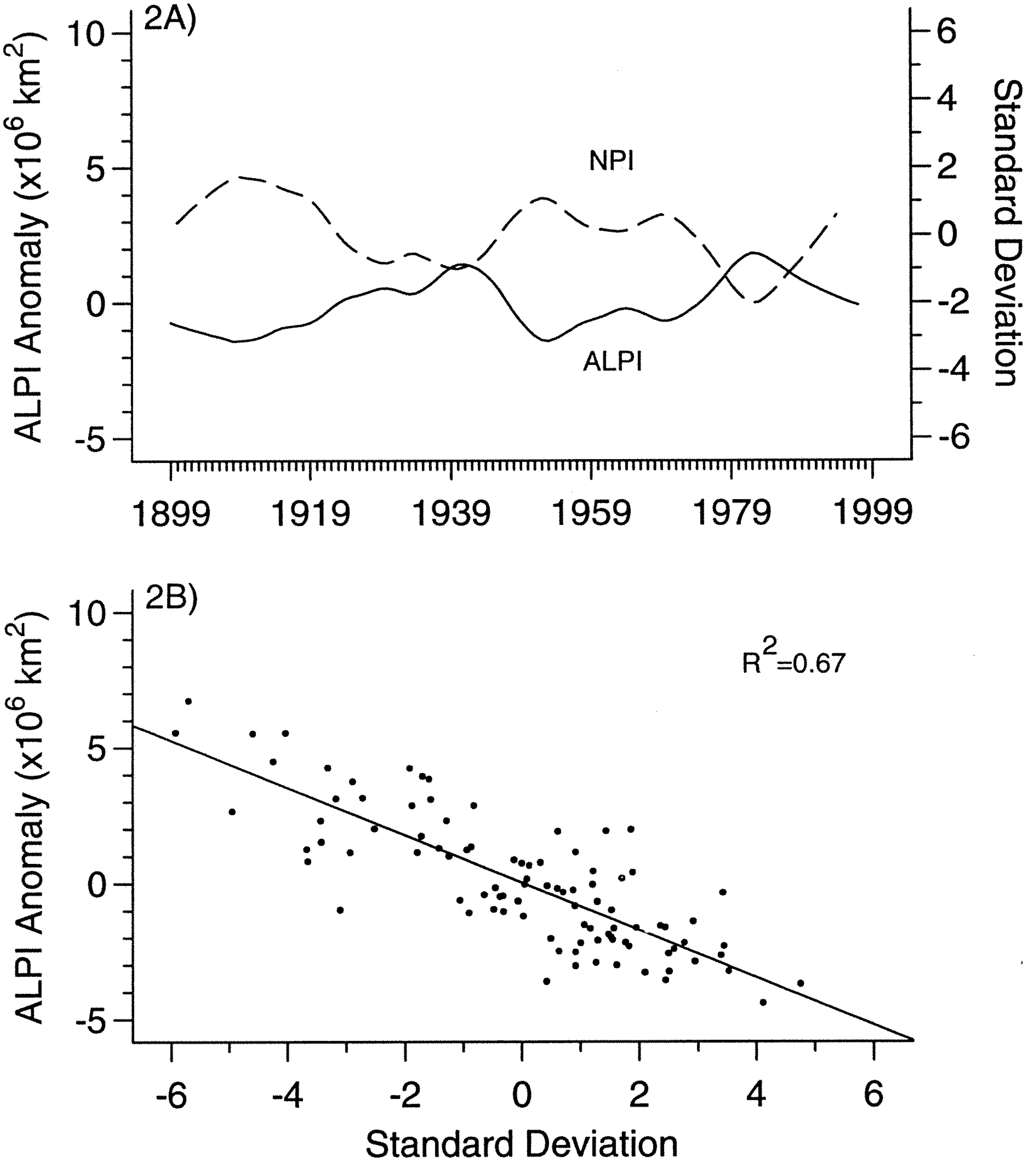
2A)
ALPI Anomaly (x10^6 km^2)
10
5
0
-5
Standard Deviation
6
4
2
0
-2
-4
-6
NPI
ALPI
1899
1919
1939
1959
1979
1999
2B)
ALPI Anomaly (x10^6 km^2)
10
5
0
-5
R^2=0.67
-6
-4
-2
0
2
4
6
Standard Deviation

FIG. 2

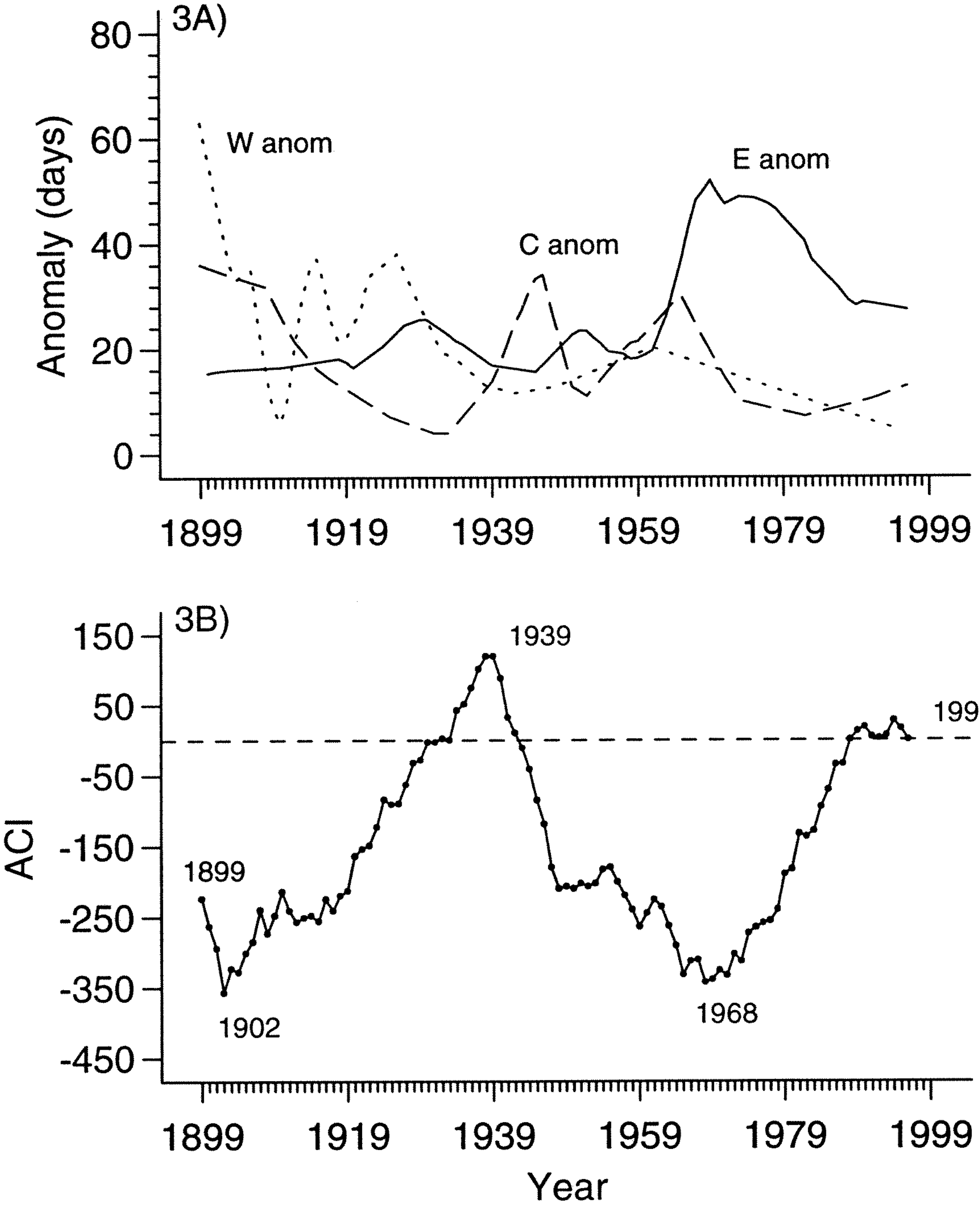
3A)
Anomaly (days)
80
60
40
20
0
W anom
C anom
E anom
1899
1919
1939
1959
1979
1999
3B)
ACI
150
50
-50
-150
-250
-350
-450
1939
1996
1899
1902
1968
1899
1919
1939
1959
1979
1999
Year

FIG. 3

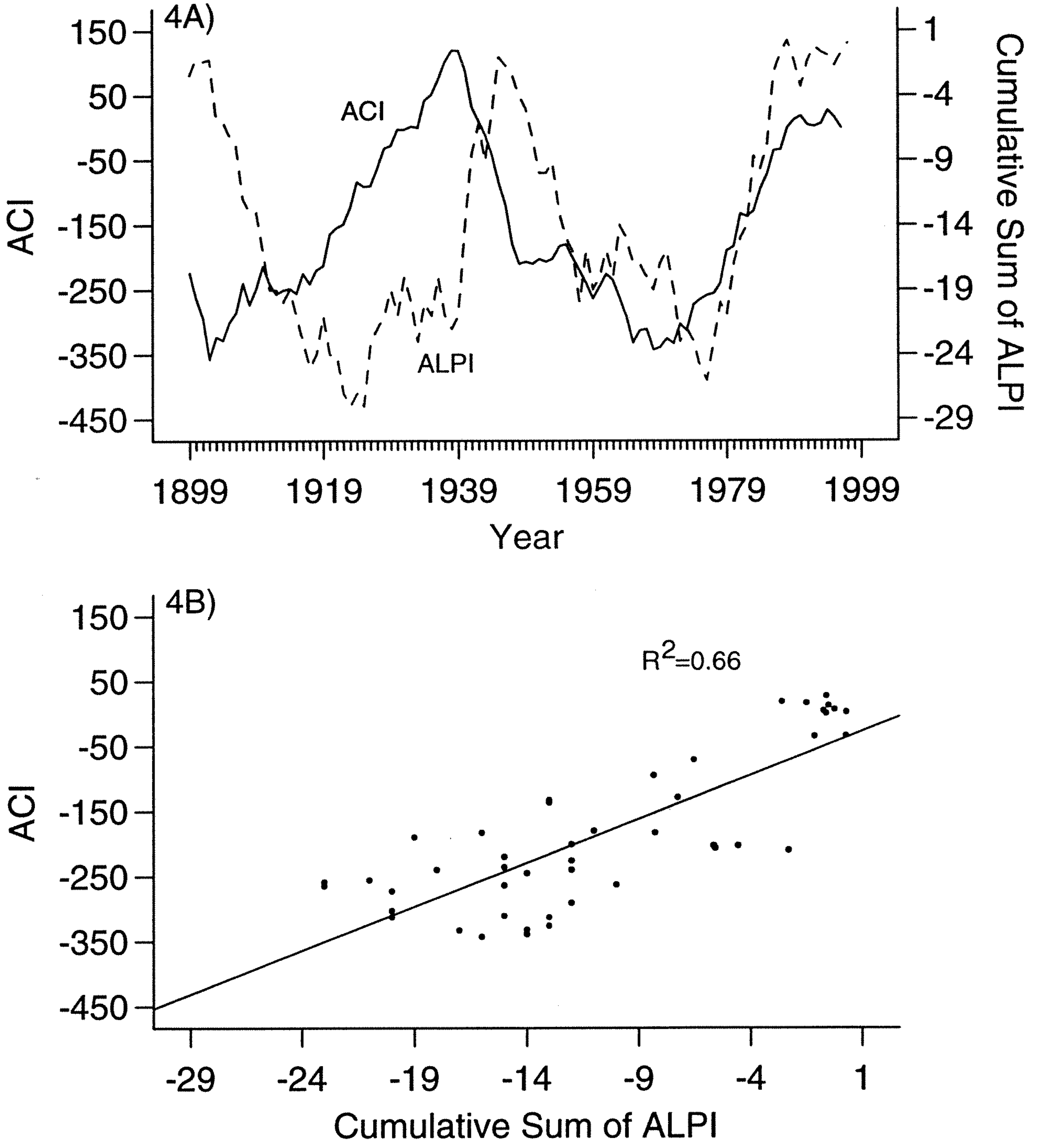
4A)
ACI
ALPI
ACI
Cumulative Sum of ALPI
150
50
-50
-150
-250
-350
-450
1
-4
-9
-14
-19
-24
-29
1899
1919
1939
1959
1979
1999
Year
4B)
R^2=0.66
ACI
150
50
-50
-150
-250
-350
-450
-29
-24
-19
-14
-9
-4
1
Cumulative Sum of ALPI

FIG. 4

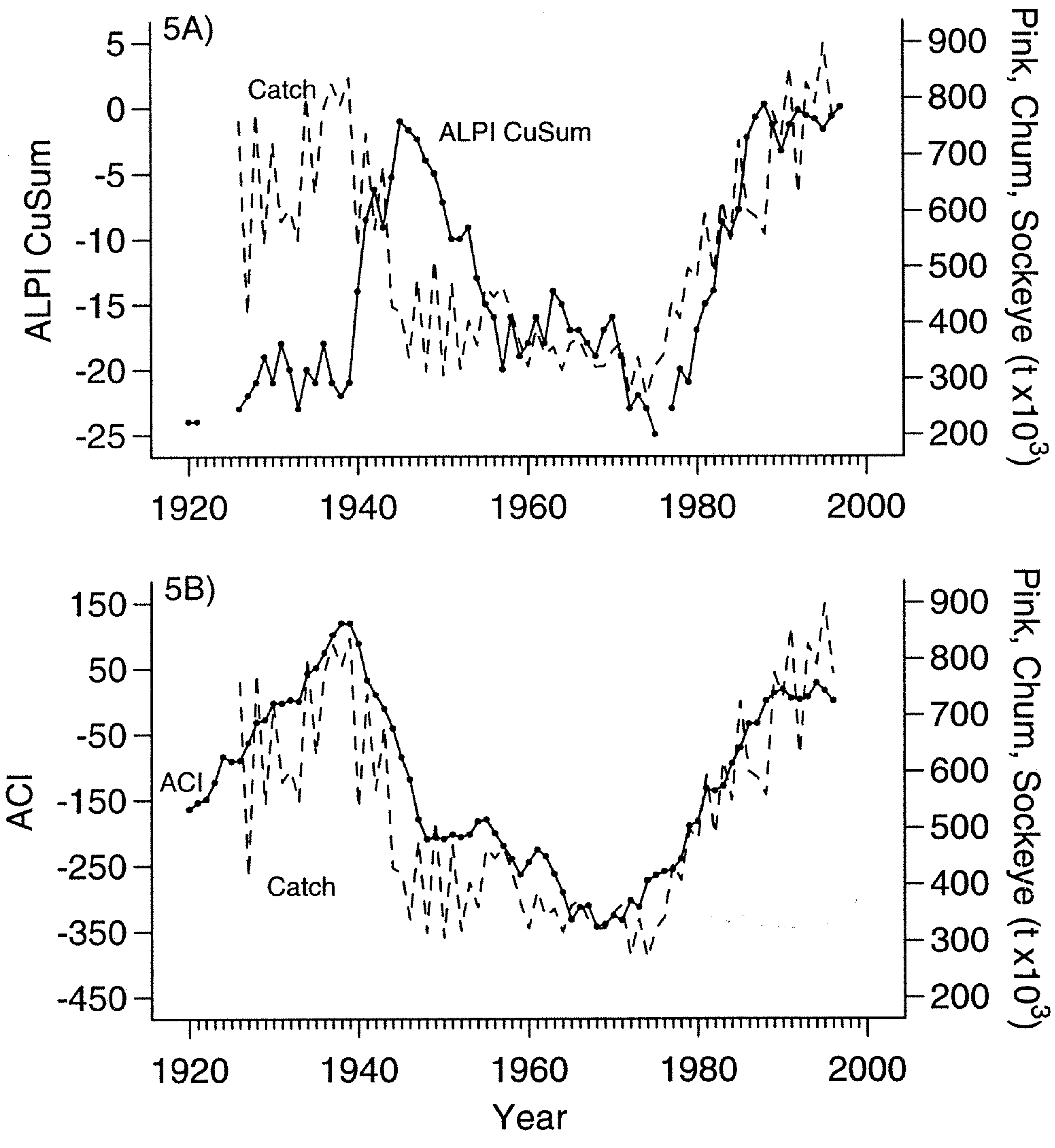
5A)
Catch
ALPI CuSum
ALPI CuSum
5
0
-5
-10
-15
-20
-25
Pink, Chum, Sockeye (t x10^3)
900
800
700
600
500
400
300
200
1920
1940
1960
1980
2000
5B)
ACI
Catch
ACI
150
50
-50
-150
-250
-350
-450
Pink, Chum, Sockeye (t x10^3)
900
800
700
600
500
400
300
200
1920
1940
1960
1980
2000
Year

FIG. 5

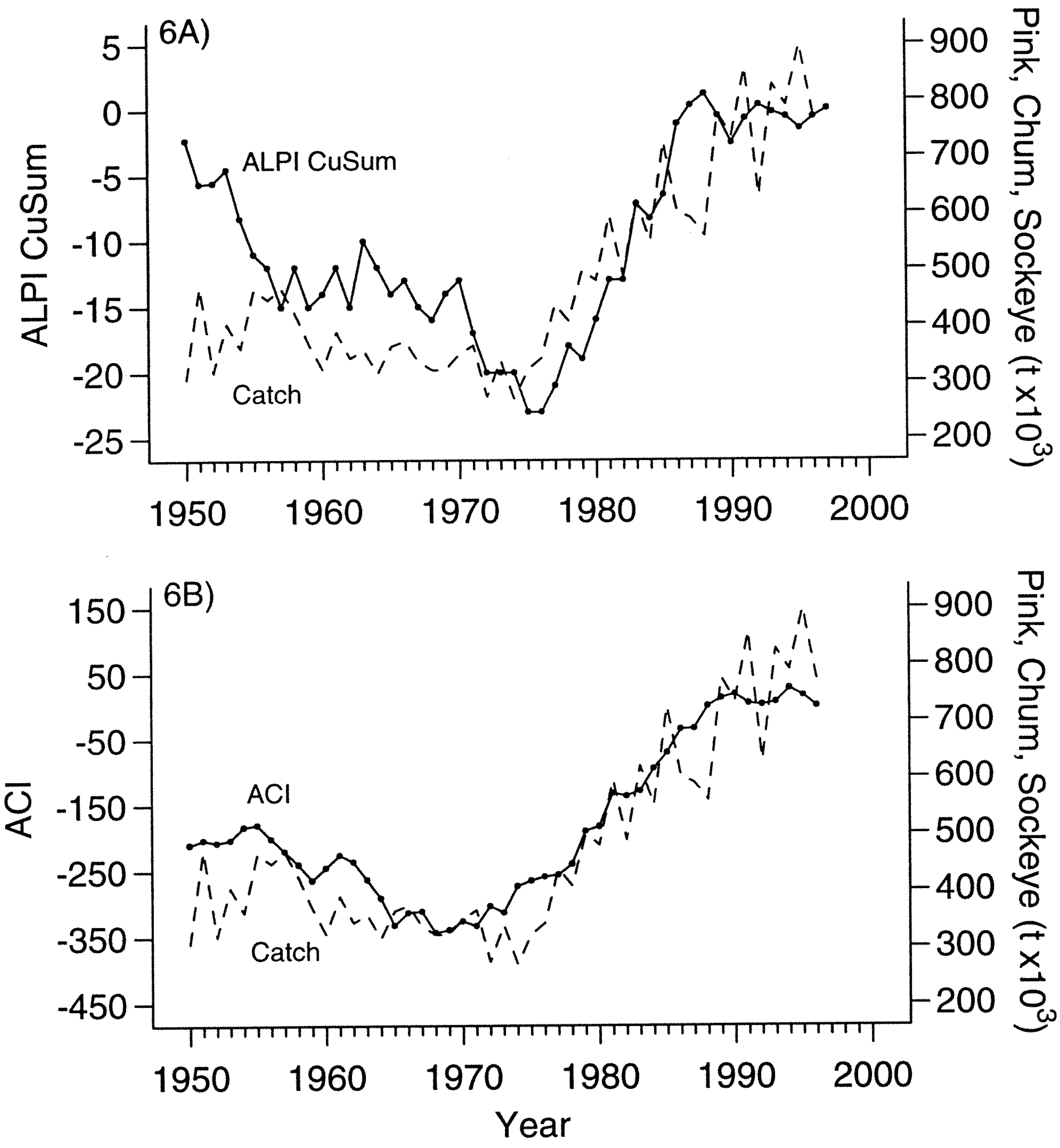
6A)
ALPI CuSum
ALPI CuSum
Catch
5
0
-5
-10
-15
-20
-25
Pink, Chum, Sockeye (t x10^3)
900
800
700
600
500
400
300
200
1950
1960
1970
1980
1990
2000
6B)
ACI
ACI
Catch
150
50
-50
-150
-250
-350
-450
Pink, Chum, Sockeye (t x10^3)
900
800
700
600
500
400
300
200
1950
1960
1970
1980
1990
2000
Year

FIG. 6

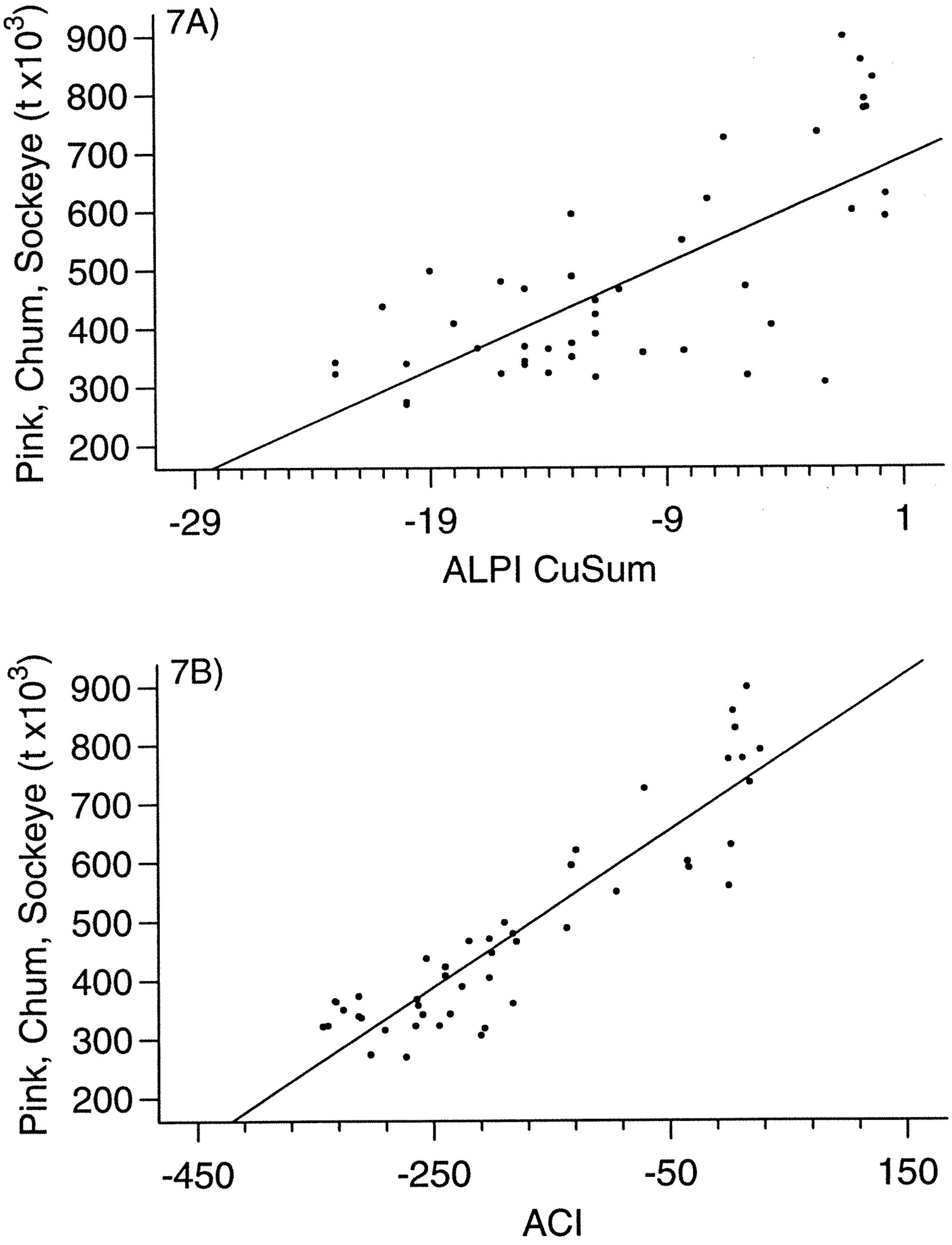
7A)
Pink, Chum, Sockeye (t x10^3)
900
800
700
600
500
400
300
200
-29
-19
-9
1
ALPI CuSum
7B)
Pink, Chum, Sockeye (t x10^3)
900
800
700
600
500
400
300
200
-450
-250
-50
150
ACI

FIG. 7