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Trends in coho marine survival in relation to the regime concept

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Abstract

The marine survival of coho in the Strait of Georgia, Puget Sound, and off the coasts of Oregon decreased abruptly after the pattern of the Aleutian Low changed in 1989. This large scale, synchronous change indicates that trends in coho marine survivals were linked over the southern area of their distribution in the northeast Pacific and that these linkages were associated with a common event. The pattern of April flows from the Fraser River also changed abruptly about the same time as the changes that occurred in the Aleutian Low and was used as an indicator of regional climate change. These large scale, persistent trends in a biological or physical time series that shift quickly from one state to another can be considered to be regimes. The persistence and synchrony inherent in the regime concept can be used to conclude that the current trends of low coho marine survival may not change as long as April flows remain high.

Résumé

Le taux de survie en mer du saumon coho dans le détroit de Georgia, dans la baie Puget et au large des côtes de l'Oregon s'est abaissé subitement, à la suite d'une modification de la dépression des Aléoutiennes en 1989. Le synchronisme de tels événements sur une grande échelle suggère l'existence d'un lien entre les tendances parallèles du taux de survie du coho en mer au sud de son aire de distribution, dans le nord-est du Pacifique, et que ce lien serait en outre associé à un événement unique. Presque en même temps que la variation de la dépression des Aléoutiennes, a subitement eu lieu une altération de l'écoulement d'avril dans le Fraser, laquelle a servi d'indicateur de changement climatique sur une base régionale. Ces transformations biologiques et physiologiques à grande échelle qui persistent dans le temps et fluctuent rapidement d'un état à un autre peuvent être considérés comme des régimes. En se fondant sur la persistance et le synchronisme inhérents au concept de régime, on peut conclure que le taux actuel de survie du coho en mer ne s'améliorera pas tant que l'écoulement d'avril restera élevé.

Introduction

Traditionally, the ocean environment was viewed as having random-like impacts on the marine survival of salmon. More recently, persistent trends in the climate/ocean state that quickly shift abundance trends in Pacific salmon have been described (Beamish and Bouillon 1993, Hare and Francis 1995, Mantua et al. 1997). The periods of persistent states can been considered to be regimes (Namias 1953, Steele 1996) that show linked and synchronous responses in physical and biological time series. There is an accumulating literature that provides convincing evidence and support for the regime concept (Venrick et al. 1987, Ebbesmeyer et al. 1991, Polovina et al. 1995, Gu and Philander 1997, Mantua et al. 1997, Minobe 1997).

Persistence is an important property of regimes and it is this characteristic that may provide an opportunity to forecast the general trend in the marine survival of aggregates of coho (*Oncorhynchus kisutch*) stocks. Forecasting future trends in the abundance or productivity of fish populations has not been a particularly successful part of fisheries science. However, being able to provide even general trends in abundance would provide important advice to managers and to industry. Such advice is especially urgent as some coho stocks are at very low abundance at the southern limit of their distribution in the eastern North Pacific. A difficulty with long-term forecasting has been the tendency for relationships between the dynamics of fish populations and environmental parameters to break down. One possible explanation for these apparent failures is that when regimes shift, the dynamics of ecosystems change and new parameters become surrogates for the processes regulating abundance. Use of the regime concept would ensure that relationships within a particular ecosystem state are emphasized. Another reason to consider the regime concept in fisheries management is the growing recognition that management must progress from single species to ecosystems. Ecosystem management will require an understanding of how climate in general and global warming in particular will alter the general mechanisms that affect the interrelationships of key fish species. The regime concept will emphasize the importance of understanding the linkages between climate and marine ecosystems.

In this analysis, we consider the possibility that long-term forecasting could be achieved by matching persistent states in the dynamics of the climate/ocean ecosystem with levels of in marine survival of coho as well as showing that recent changes are associated with climate change. The measures of marine survival are relatively straight forward and generally accepted among biologists. There may be some concerns about using the survival of hatchery coho as a general estimate of marine survival for both wild and hatchery fish. However, for most of the period examined in this study the numbers of hatchery coho released have been large (Beamish et al. 1997) and probably exceed wild production, indicating that hatchery survival estimates represent a large percentage of the coho that enter the ocean. Finding an index of the dynamics of the climate/ecosystem linkage is more difficult. One approach is to calculate a statistical index (*i.e.,* a single variable) that integrates several important climate or ocean parameters using a multivariate analysis (*e.g.,* principal components analysis). However, the selection of parameters for the analysis may be based more on availability than on their direct relevance. Another approach is to use a single parameter whose variability over time integrates several environmental signals for the region of interest. In this analysis, we use total April discharge from the Fraser River as a proxy for a suite of environmental and climate conditions such as winds, air temperature and winter snowfall in the British Columbia region. It also reflects the timing of the spring plankton bloom (Yin et al. 1997) and nitrate entrainment in the Strait of Georgia (St. John et al. 1993). We propose that it is a variable that integrates, or reflects changes in the environment for coho at the southern limit of their distribution, including ocean conditions for the Strait of Georgia. We use April flow only as an index of the regime state of the ocean/climate conditions and not as a factor that directly affects coho marine survival. We associate April Fraser River flows with the Aleutian Low which is an accepted index of climate variability throughout the subarctic Pacific and the Bering Sea (Trenberth and Hurrell 1995). This climate system develops each winter and is one of the most persistent climate patterns on the Earth. The position and the intensity varies but the low remains a major factor affecting the oceanography and productivity of the subarctic Pacific (Venrick et al. 1987, Brodeur and Ware 1992, Gargett 1997).

Methods

Fraser River flow data were obtained from the Water Resources Branch, Environment Canada and were expressed as the average monthly flow in m^3/sec. The Aleutian Low Pressure Index (ALPI) used here is a slightly modified version of the index used in Beamish et al. (1998a). The index is the average monthly area in the north Pacific that is less than 1000.5mb, averaged for the 4 months December through March. The average monthly index is recorded for the January year and is expressed as an anomaly using a fixed mean from 1950 to 1997 (Fig. 1). In previous analyses we did not use a fixed mean. The ALPI is virtually identical to the inverse of the North Pacific Index (r^2 = 0.81, $p<0.001$) of Trenberth and Hurrell (1995).

Marine survival estimates for coho were determined using hatchery released coho that were tagged with a coded wire inserted in the nose (Table 1). The survival estimate was made by expanding the coded wire tags (CWT) recovered by the appropriate tagging percentage and calculating the percentage of total hatchery fish that survived. For the Strait of Georgia, the brood year survival of all releases directly or indirectly into the Strait of Georgia was calculated by determining the number of hatchery fish released into the Strait of Georgia (e.g. MRP database, Kuhn et al. 1988) from all hatchery production areas (including the Quinsam hatchery) and dividing the release estimate into the estimate of the number that were caught in fisheries or returned to spawn. For Puget Sound, marine survival was calculated from CWT data stored at the Pacific States Marine Fisheries Commission regional mark information system. Marine survival was the number of 3-year-old returns divided by the number of smolts released. CWT's were selected for hatcheries with consistent long-term hatchery practices. Releases from hatcheries that were suspected of having high disease levels or releases that were experimental were not used. No late releases and no fry release data were used. Anomalies were computed for each of three regimes and averaged (Table 1). The Oregon Production Index or OPI measures the survival of coho that enter the Pacific Ocean from California, Oregon, and southern Washington, north to Willapa Bay. The index is determined by summing the Washington, Oregon, and California smolt releases into the area and dividing this number into the estimated adult and jack returns. Private releases are not part of the index. Data from 1961-1969 are from McGie (1984) and data from 1970-1995 are from PMFC (1997). All survival estimates were subtracted by the mean of the time series and divided by the standard deviation to produce standardized anomalies.

The change in the trend in a time series was identified using a cumulative sum (CuSum) plot (Murdoch 1979). The calculation is a simple addition of a datum point to the sum of all previous datum points starting at year t=1. Each data point was subtracted from the time series mean to identify a cumulative deviation trend. A positive slope of the CuSum indicates an above average or an increasing trend while a negative slope represents a below average or a decreasing trend. The analysis is sensitive to changing trends in a time series and is a useful way of objectively identifying the change points in a time series. A step intervention analysis (Noakes 1986, Hipel and McLeod 1994) was used to study the timing and significance of changes in the April flow and the standardized coho survival anomaly time series. If survival data earlier than 1977 were limited, we tested only for the 1989-1990 shift. The CuSum analysis of the ALPI (Fig. 1) and April Fraser River flow data (Fig. 2) was used to identify potential years when there was a shift in these time series.

Results

Climate related trends

Two shifts in trends were identified in the CuSum plots for the Aleutian Low Pressure Index (ALPI) and April flow data series, at about 1976-1977 and 1989-1990. The 1976-1977 shift is consistent with observations from other studies (Ebbesmeyer et al. 1991, Mantua et al. 1997, Minobe et al. 1997). The CuSum of the ALPI shows that changes in trends occurred about 1989, 1977, 1945 and 1923 (Fig. 1). The CuSum of the ALPI was compared with the CuSum of the Pacific Decadal Oscillation (Mantua et al. 1997) and the change points in the trends were almost identical (Fig. 1). As both the Aleutian Low and the PDO are recognized as indicators of the climate/ocean environment in the subarctic Pacific (Gargett 1997, Mantua et al. 1997), we used the years 1977 and 1989 to compare with coho marine survival, as coho marine survival data are available only since the 1960s and 1970s. Since the mid-1960s, the pattern of the Aleutian Low can be grouped into three periods. The period prior to 1977 was characterized by weak lows. Beginning in the late 1970s there was a period of intense lows that lasted until 1988. Since 1989, the lows have been of average intensity without extreme fluctuations (Fig. 1). Intervention analysis identified both 1977 and 1989 as periods of significant shifts ($p<0.05$) in the ALPI. The magnitude of the shift in 1977 was slightly larger than the shift in 1989 and opposite in sign with both shifts being roughly 3 standard deviations from the mean level. The pattern of April flow is shown dating back to 1912, (Fig. 2) and as an anomaly from 1912. There were no statistically significant changes in mean level of the April flow time series about 1945 or earlier in the data series. Also, the change in the late 1970s was not statistically significant at the 5 percent level when both the 1977 and 1990 shift were tested simultaneously. The shift in 1990 was significant ($p<0.05$) with April flows increasing roughly 45% starting in 1990. Between 1972 and 1978, there was an oscillating pattern of positive and negative April flow anomalies. Beginning in 1978 the standardized anomalies were consistently negative until 1987 when there was a change to predominately positive April flow anomalies (Fig. 2).

Coho survival trends

Coho survival estimates were available beginning in 1972 (1970 brood year) for coho entering Puget Sound, 1974 for the Strait of Georgia, and 1960 for the Oregon Production Index, OPI, (Table 1, Fig. 3). The changes in the trends of the standardized anomalies in the earlier part of the time series using the CuSum graph occurred about 1978 for the OPI, 1980 for the Strait of Georgia, and 1981 for Puget Sound (Fig. 4A, B, C). The trends in the CuSum graph in the Strait of Georgia and in the OPI were similar showing an early above average survival, changing to average or a slightly below average period and then a change in the 1990s to a period of low survival. The trends in Puget Sound prior to the 1990s are opposite to the trends in the other two areas, but similar in the 1990s. The intervention analysis of the standardized anomaly series identified a significant shift in 1990 in the Strait of Georgia and Puget Sound survival trends and in 1991 in the OPI ($p<0.05$) with decreases in survival of approximately 65%, 40% and 80% respectively. Because the OPI survival estimates begin in 1960 (1958 brood year) we also tested for a shift in the late 1970s and identified a significant change in 1977 ($p<0.05$) from the 1991 shift when tested separately. The decrease in survival rate due to the change in 1977 was roughly 42%. However, the shifts in 1977 and 1991 in the OPI were not significant at the 5 percent level when both interventions were incorporated into a single model.

An analysis of covariance (ANCOVA) was used to test for significant differences in slopes for regressions between April flows and coho survival. ANCOVA did detect significant ($p<0.0001$) differences among regime slopes for the regression between April flow and Strait of Georgia and OPI coho survival. For the Strait of Georgia analysis, the slopes for the pre-1977, 1977-1989 and the post-1989 regime regressions were significantly ($p=0.0062$, 0.0025 and 0.0355 respectively) different than an overall slope for the whole time series. The slope for pre-1977 was steeper than the other two slopes, and the slope for 1977-1989 was steeper than the slope for post-1989. For the OPI, the slopes for the pre-1977 and the 1977-1989 regimes were significantly ($p=0.0001$ and 0.0147 respectively) different than a common slope for the whole time series. As with the Strait of Georgia analysis, the slope for pre-1977 was steeper than the slope for 1977-1989. The ANCOVA of April flow and Puget Sound coho survival was non-significant at a $\propto=0.05$, but was significant at $\propto=0.1$ ($p=0.076$). The slopes for the three regimes were similar to those for the other two regions.

Future Survival Trends

The interval between the change points in the CuSum analysis is identified as the period of persistent and coherent environmental conditions that we consider to be a regime. In the 1990s, we showed that the high April flows were an index of the current environmental conditions. Accordingly, we propose that as long as April flows remain high, coho marine survivals will continue to be low. The CuSum analysis is sensitive to changing trends and can be used to identify when a trend is changing. In Figure 5, we examine patterns in the Fraser River April flows, and the potential to detect true regime shifts with the CuSum analysis. The mean April flows for the 1989-97 regime (Fig. 5A) was approximately 32% higher than the previous regime (2585.7 ± 615.19 vs. 1955.38 ± 408.75), whereas both were higher than the long-term (1912-1997) average. The preliminary estimate of the 1998 April flow is lower than the previous two years, and approximately 68% of the post-1989 regime mean. This decrease shows up in the CuSum (Fig. 5B) as a deflection but not necessarily a true change in trend, as similar single year deflections were observed earlier. If we postulate a continuation of the 1998 April flow rate for 1999 and 2000, the resulting CuSum graph shows a change in trend after 2 years, and clearly after three years of reduced flows (Fig. 5B).

Discussion

The estimated marine survivals of coho salmon from the three areas ranged from 21.8% in the Strait of Georgia in the ocean entry year 1973 to 0.4% in the OPI in 1992. In the Strait of Georgia and the OPI, marine survival was stable or declined slightly from 1978 to 1989. About 1990/1991, there was a major decline in survival in all areas that range from 40% to 80%. This recent change represented a significant and synchronous decrease in survival trends in all three areas from 40 to 80%. The synchrony in the change indicates that a common event affected the survival of juvenile coho throughout their southern distribution. Because these coho rear as juveniles in the Strait of Georgia, Puget Sound, and off the west coast of the states of Washington, Oregon, and California (and off the west coast of Vancouver Island), the common event would most likely be climate driven changes in the specific marine rearing environments. The common event could be the range of factors that cause mortalities including predation and disease, but as there also was synchrony in the changes in trends in the three areas in the late 1970s, we propose that the recent decline in coho marine survival is linked to a change in the climate/ocean environment that became less favourable for coho survival after 1989.

There is good evidence of a major regime shift in the climate/ocean environment in 1977 (Ebbesmeyer et al. 1991, Beamish and Bouillion 1993, Miller et al. 1994, Hare and Francis 1995, Mantua et al. 1997, Minobe 1997, and Zhang et al. 1996). There is also sound evidence of a change in climate indices about 1989 as we show in this study, but the existence of a change at this time has not been identified in some studies (Mantua et al. 1997). Despite a lack of understanding of the nature of the 1989 change, there was a distinct change in the pattern of the Aleutian Low that we identify as a significant change in our index of intensity. As the Aleutian Low has been shown to be closely associated with the oceanography and productivity of the subarctic Pacific, (Venrick et al. 1987, Brodeur and Ware 1992, Sugimoto and Tadokoro 1997, Minobe 1997, Nitta and Yamada 1989) it is to be expected that changes would occur in the marine environment when the pattern of the low changes. Regionally, we showed that the pattern of April flows from the Fraser River was associated temporally with changes in the pattern of the Aleutian Low. A linkage between annual trends in west coast river flows and climate regimes has been demonstrated in other studies (Mantua et al. 1997, Moore and McKendry 1996), thus, it is not unexpected that a climate shift could advance the timing of the beginning of the spring freshet (Thomson 1981) from the Fraser River. April flow, therefore, was used as a regional indicator of climate change. Thus we conclude that the change in climate in 1989, altered the marine ecosystems in a manner that coho marine survival, on average, declined abruptly to extremely low levels.

Abrupt changes in the climate/ocean environment that result in shifts in productivity can be crucial if the changes ultimately lead to a reduced productivity which goes undetected. We use the regime concept to conclude that the period after 1989 is a different regime for southern coho than prior to 1989. However, we use indicators of change and the actual changes in the ecosystem when regimes shift remain to be identified. Our interpretation of a regime is one of multi-dimensional changes. The concept is not new (Namias 1953, Steele 1996), but the concept of large scale, persistent trends in productivity of fishes that can shift from one state to another is a new concept in fisheries management. A regime change does not need to be an oscillation or cyclic, but can be a change to a different state rather than a reversal of conditions. The regime change may not cause the same response to a species in all ecosystems, a very important consideration in understanding the application of regime shifts to fisheries management. We cannot explain why there was a different trend in marine survivals between Puget Sound and Strait of Georgia coho prior to 1989, but the different response is an indication of the need to interpret impacts through the dynamics of an ecosystem. There are other examples of opposite responses by similar species in different areas of the ocean after a regime shift. After the 1977 regime change, the productivity of chinook and coho in the northern area of their distribution improved while the productivity in the southern area did not (Hare et al. 1998). We also note that in the Strait of Georgia, herring abundance improved after the 1989 change whereas herring abundance off the west coast of Vancouver island did not (Schweigert et al. 1997). We know that the 1977 climate shift had opposite effects on river flow and snow pack levels north and south of about mid-British Columbia (Moore and McKendry 1996, Mantua et al. 1997). Thus, it is a component of the regime concept that opposite responses of the same species or physical factors may occur in adjacent ocean environments. We propose that the ecosystems respond to the regime shift in different ways and that the dynamics of the response are a function of the biological and physical inertia in the system as well as the state of the ecosystem at the time the regime shift occurs.

The concept of a multi-dimensional shift in states rather than an oscillation or a cycle is a different interpretation that some have reported. Other studies have proposed that cycles or oscillations tend to switch abruptly ocean environments from one state to another (Minobe 1997, and Mantua et al. 1997). Minobe (1997) proposes that associated with these switches are longer periods of 50 to 70 year cycles that he considers to be an unexplained natural oscillation in the climate/ocean environment. Baumgartner et al. (1992), Ware (1995) and others also found these longer-term oscillations in their analyses. Ware (1995) identified 4 persistent time scales in an analysis of climate in the northeast Pacific. He identified a similar 50 to 75 year period, and three other periods of 20-25, 5-7, and 2-3 years. Ware (1995) identifies 1989 as a year of major climate change in the northeast Pacific, and suggests that the 1990s are in a cooling phase. According to Ware (1995), 20-25 year oscillations occur for natural reasons, possibly associated with similar oscillations in the tropical Pacific. Transitions from warm to cool conditions occur gradually. Ware (1995) believes that since 1989 the climate is moderating and that the falling temperatures will reach a minimum around 2001. At this time, he believes coho marine survival will begin to improve because the cooler climate is associated with ocean conditions more favourable to coho marine survival. The low point in the cycle apparently stimulates a trend which would change again about 2014 at the peak of the warm period. Common to all views, is the concept that long-term trends in climate cause persistent and large-scale changes in the abundances of fishes. The cause and nature of the changes remains speculative, but there is agreement that changes occur and that they have major impacts on the dynamics of important fish stocks.

If the current regime persists and if April flows remain high, it is likely that marine survival will not improve. Preliminary estimates for April 1998 indicate that the flow is lower than in recent years. The CuSum approach can be used to help visually to detect changes in the trends in climate indices. For example, relatively low flows in April for two consecutive years is sufficient to detect a change, but it remains to be determined how to be certain that the change represents a new regime. We note, that another change in regimes could change the dynamics in a way that the response among the three areas is not identical. The regime concept, however, can be useful in management as it identifies periods of persistent survival trends, that is, the concept provides a general index of survival as continuing to be above average, average, or below average. More useful, would be an ability to identify immediately when a regime changes and be able to forecast specific marine survival rates in the new regime. Identifying specific marine survival rates will require a better understanding of the interrelationships among species within an ecosystem and within a regime, particularly how associations within a regime affect growth and predation. Identifying when a regime changes probably is best accomplished by identifying the mechanisms that causes fluctuations in the trends in climate such as seen in the pattern of the Aleutian Low.

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Figure Captions

Figure 1. (A). The Aleutian Low Pressure Index (ALPI) from 1889 to 1998 and the loess (f= 0.2) smoothed trend (solid line). The vertical dashed lines in A,B,C, are the 1977, 1947 and 1925 regime shift dates (Minobe 1997, Mantua et al. 1997). (B). The CuSum of the ALPI, showing that the changing trends occur at the identical periods as indicated in A, and that the 1989 change is consistent with (C) the CuSum form of the Pacific Decadal Oscillation Index. The 1998 value for the ALPI is included, but the PDO is from 1900 to 1977. In 1998, there was an intense low relative to both previous levels in the 1990s and the lows in the 1980s.

Figure 2. April flows in the Fraser River at Hope, British Columbia. (A) The total data series expressed as m^3/sec from 1912 to 1998. The 1998 value is preliminary. (B) Average monthly flow (as m^3/sec) from 1972 to 1997. (C) The standardized anomaly of the time series in B. (D) The CuSum of times series in C, showing the changes in the trend in 1984 and 1992.

Figure 3. The standardized anomaly for the marine survival of coho salmon released into the Strait of Georgia (A.), Puget Sound (B.), and the Oregon Production Index (C.).

Figure 4. The CuSum form of the April flows (dashed line) compared to the CuSum form of the coho marine survivals (solid line) from (A) the Strait of Georgia, (B) Puget sound, and (C) the OPI. The year is the year that coho entered the ocean and all values are standardized anomalies.

Figure 5. The sensitivity of the CuSum analysis to changes in April flow (A) Mean April flows from 1972 to 1998. The 1998 value (open diamond) is preliminary. The dashed lines represent the average flow rate of the time series I (from 1972 to 1988) and time series II (from 1989 to 1998). (B) The 1972 to 1998 CuSum graph (solid line), and the resulting CuSum graphs if the 1998 April flow is also assumed for 1999 (dashed line) and for 1999 and 2000 (dotted line).

Table 1: Coho marine survival data

		Strait of Georgia			Puget Sound[1]			Oregon Production Index (OPI)[2]		
Ocean Year	Brood Year	Survival	Anomaly	Standardized Anomaly	Survival	Anomaly	Standardized Anomaly	Survival	Anomaly	Standardized Anomaly
1972	1970				4.78	-3.33	-.991	4.25	.99	.42
1973	1971				3.84	-4.27	-1.271	7.97	4.71	1.99
1974	1972	13.04	3.66	.77	6.33	-1.78	-.530	4.03	.77	.33
1975	1973	21.81	12.43	2.60	7.48	-.63	-.188	9.26	6.00	2.54
1976	1974	10.37	.99	.21	12.61	4.50	1.338	2.26	-1.00	-.42
1977	1975	16.94	7.56	1.58	3.57	-4.54	-1.351	4.56	1.30	.55
1978	1976	15.18	5.80	1.21	5.05	-3.06	-.911	3.13	-13	-.05
1979	1977	14.89	5.51	1.15	12.11	4.00	1.189	3.12	-.14	-.06
1980	1978	10.34	.96	.20	10.67	2.56	.761	2.91	-.35	-.15
1981	1979	8.64	-.74	-.15	10.63	2.52	.749	3.21	-.05	-.02
1982	1980	8.89	-.49	-.10	9.06	.95	.282	1.54	-1.72	-.73
1983	1981	7.65	-1.73	-.36	11.25	3.14	.933	2.09	-1.17	-.49
1984	1982	9.98	.60	.13	9.92	1.81	.538	1.91	-1.35	-.57
1985	1983	5.71	-3.67	-.77	13.95	5.84	1.737	7.26	4.00	1.69
1986	1984	7.80	-1.58	-.33	14.14	6.03	1.793	2.07	-1.19	-.50
1987	1985	11.53	2.15	.45	8.46	.35	.103	4.45	1.19	.50
1988	1986	8.12	-1.26	-.26	8.03	-.08	-.025	4.50	1.24	.52
1989	1987	8.03	-1.35	-.28	10.37	2.26	.672	1.65	-1.61	-.68
1990	1988	6.11	-3.27	-.68	5.62	-2.49	-.742	4.85	1.59	.67
1991	1989	6.11	-3.27	-.68	5.93	-2.18	-.649	1.12	-2.14	-.90
1992	1990	5.77	-3.61	-.75	6.73	-1.38	-.411	0.56	-2.70	-1.14
1993	1991	5.38	-4.00	-.84	6.73	-1.38	-.411	0.51	-2.75	-1.16
1994	1992	2.83	-6.55	-1.37	5.27	-2.84	-.846	0.42	-2.84	-1.20
1995	1993	1.18	-8.20	-1.71	2.17	-5.94	-1.768	0.59	-2.67	-1.13

[1] Survival is the average survival determined separately for three areas (Stillaguamish-Skagit, Hood Canal, South Sound). The anomaly and standardized anomaly were determined separately for each area and averaged, not from the average survival.

[2] Only the data since 1972 are listed in the table and the anomaly is for the period in the table. Survival data from the ocean entry year 1960 (Broodyear 1958) to 1971 are 4.57, 2.82, 5.68, 4.53, 0.78, 7.48, 9.36, 6.67, 5.92, 7.73, 0.93, 4.74 respectively.

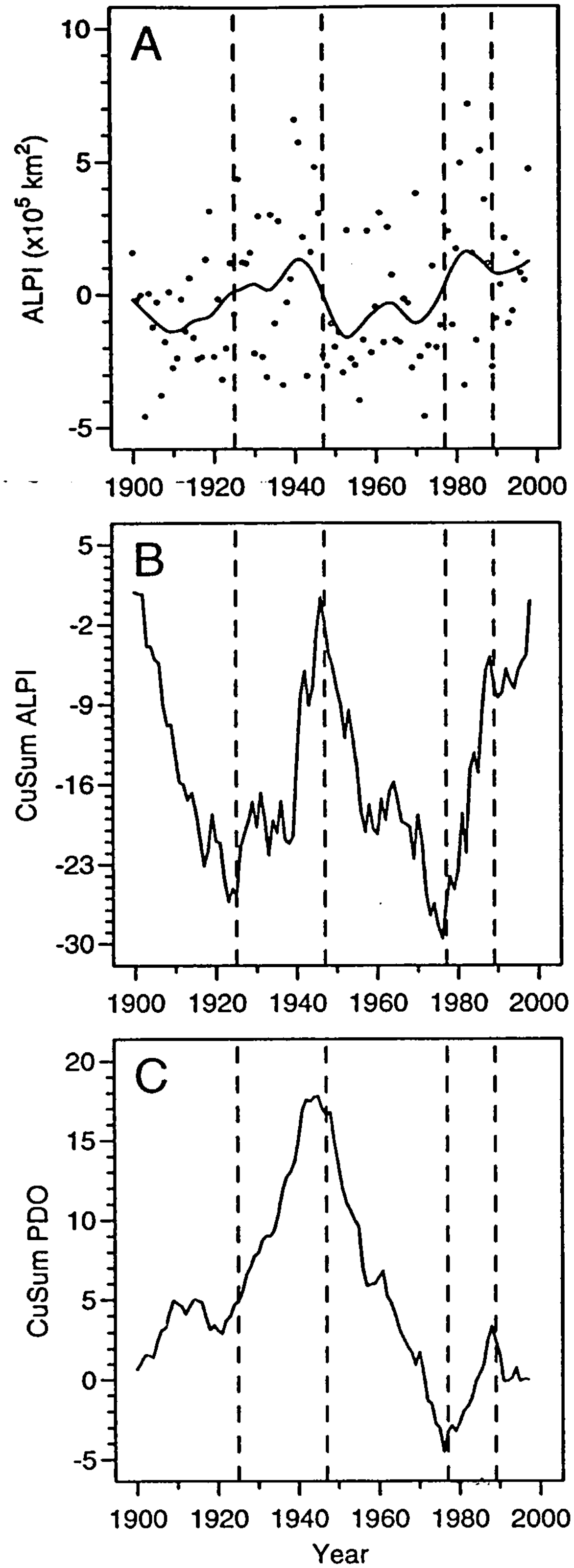

A
ALPI (x10^5 km^2)
10
5
0
-5
1900
1920
1940
1960
1980
2000
B
CuSum ALPI
5
-2
-9
-16
-23
-30
1900
1920
1940
1960
1980
2000
C
CuSum PDO
20
15
10
5
0
-5
1900
1920
1940
1960
1980
2000
Year

Figure 1

Figure 2

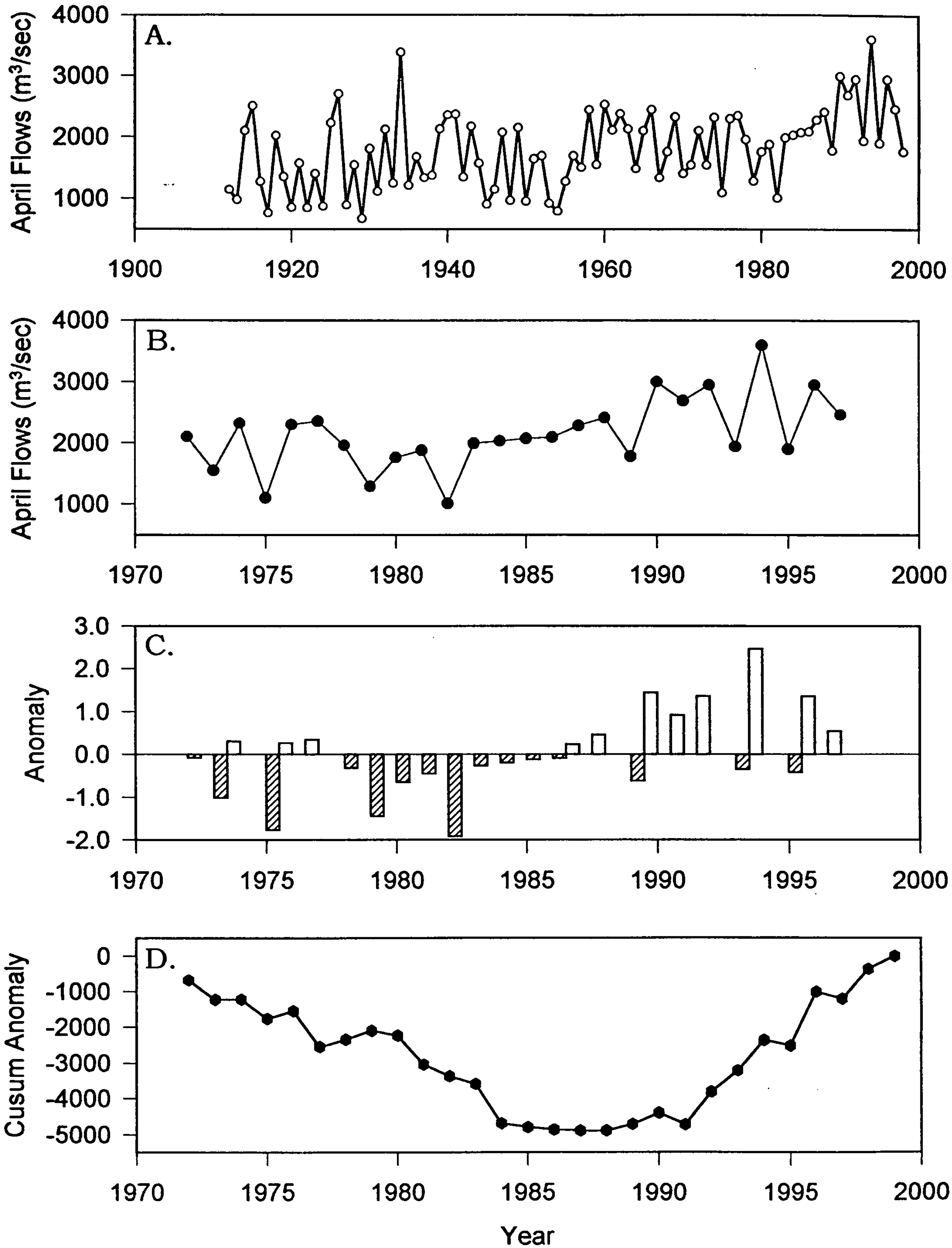

A.
April Flows (m3/sec)
4000
3000
2000
1000
1900
1920
1940
1960
1980
2000
B.
April Flows (m3/sec)
4000
3000
2000
1000
1970
1975
1980
1985
1990
1995
2000
C.
Anomaly
3.0
2.0
1.0
0.0
-1.0
-2.0
1970
1975
1980
1985
1990
1995
2000
D.
Cusum Anomaly
0
-1000
-2000
-3000
-4000
-5000
1970
1975
1980
1985
1990
1995
2000
Year

Figure 3

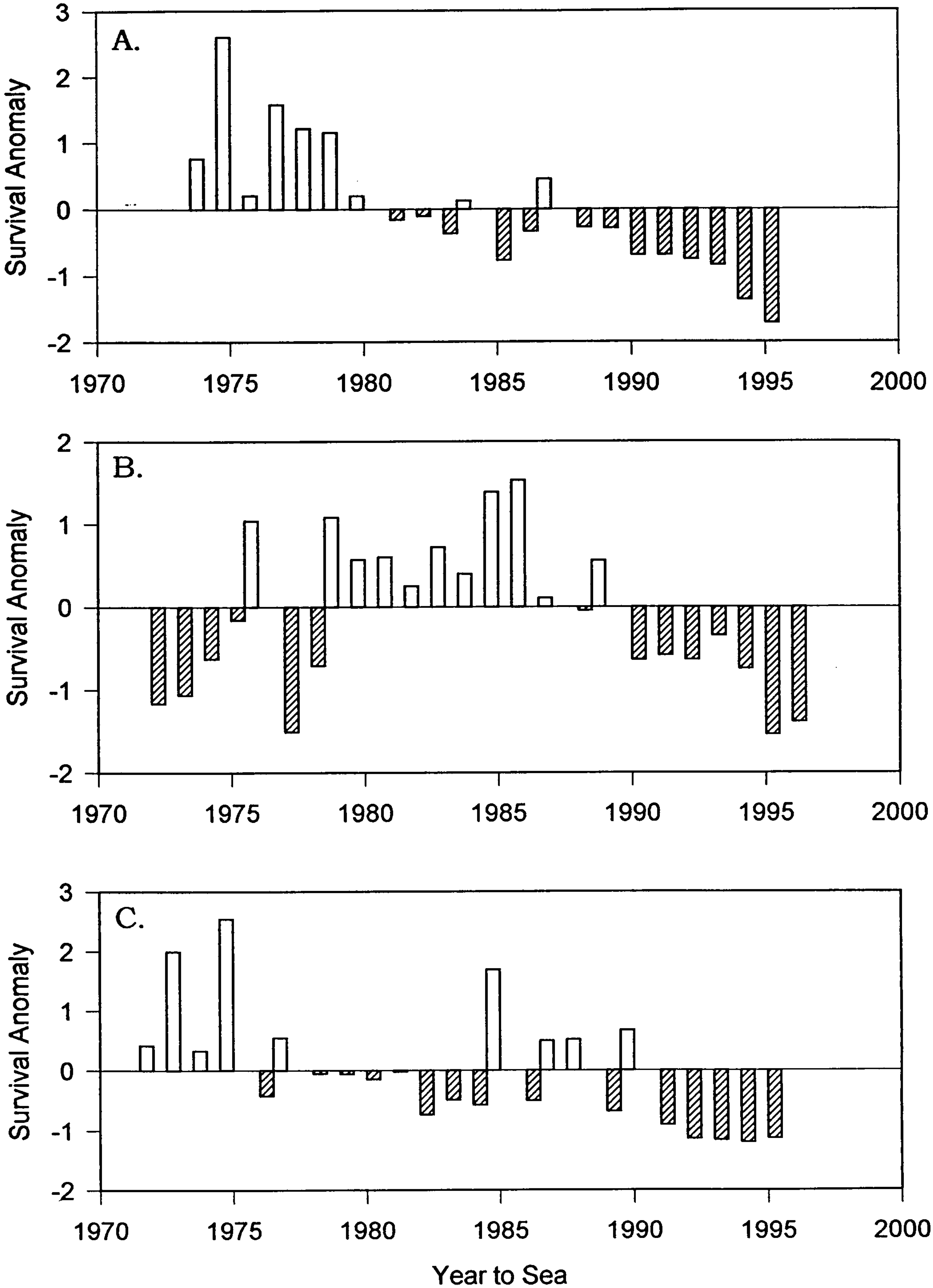

A.
B.
C.
Survival Anomaly
3
2
1
0
-1
-2
1970
1975
1980
1985
1990
1995
2000
Year to Sea

Figure 4

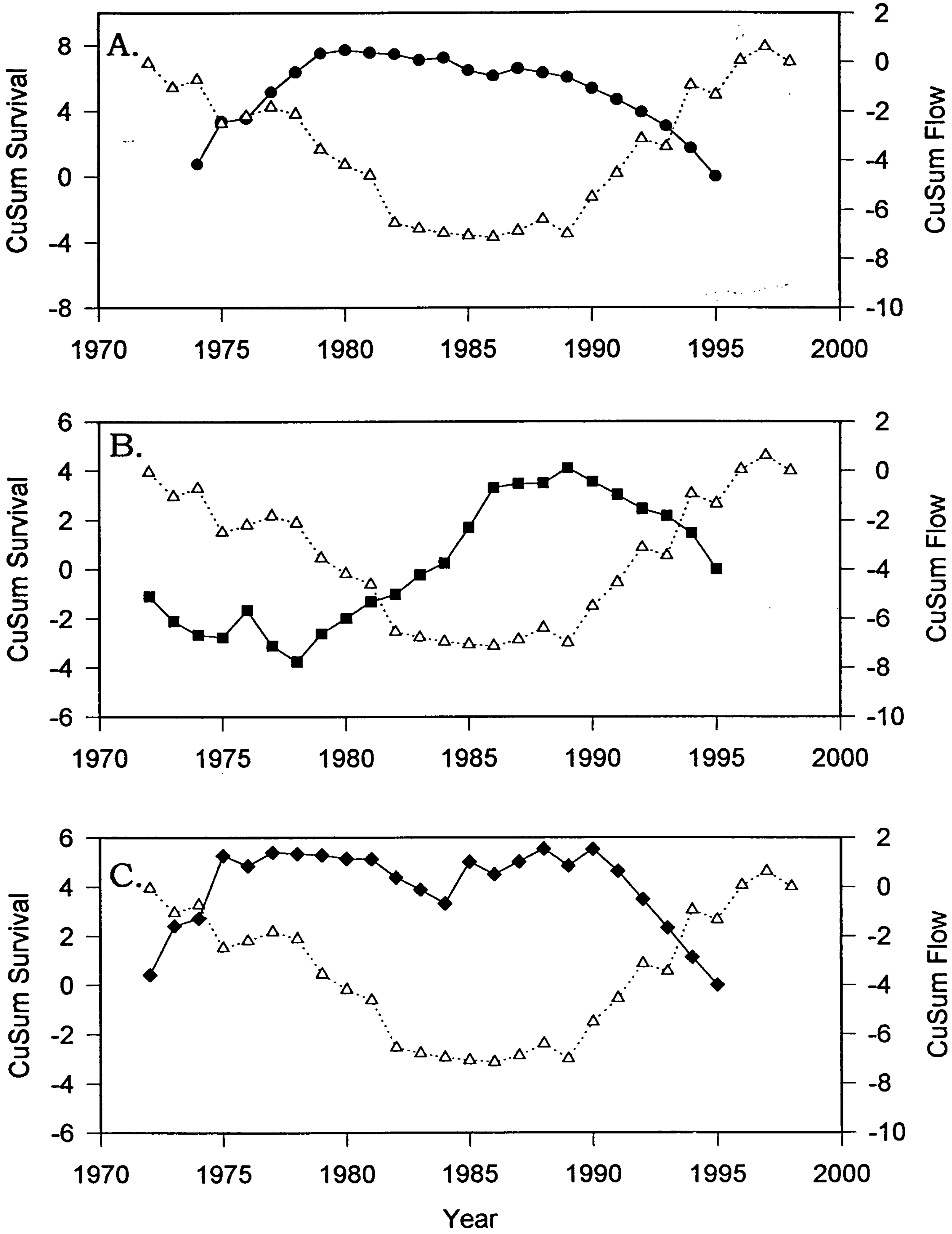
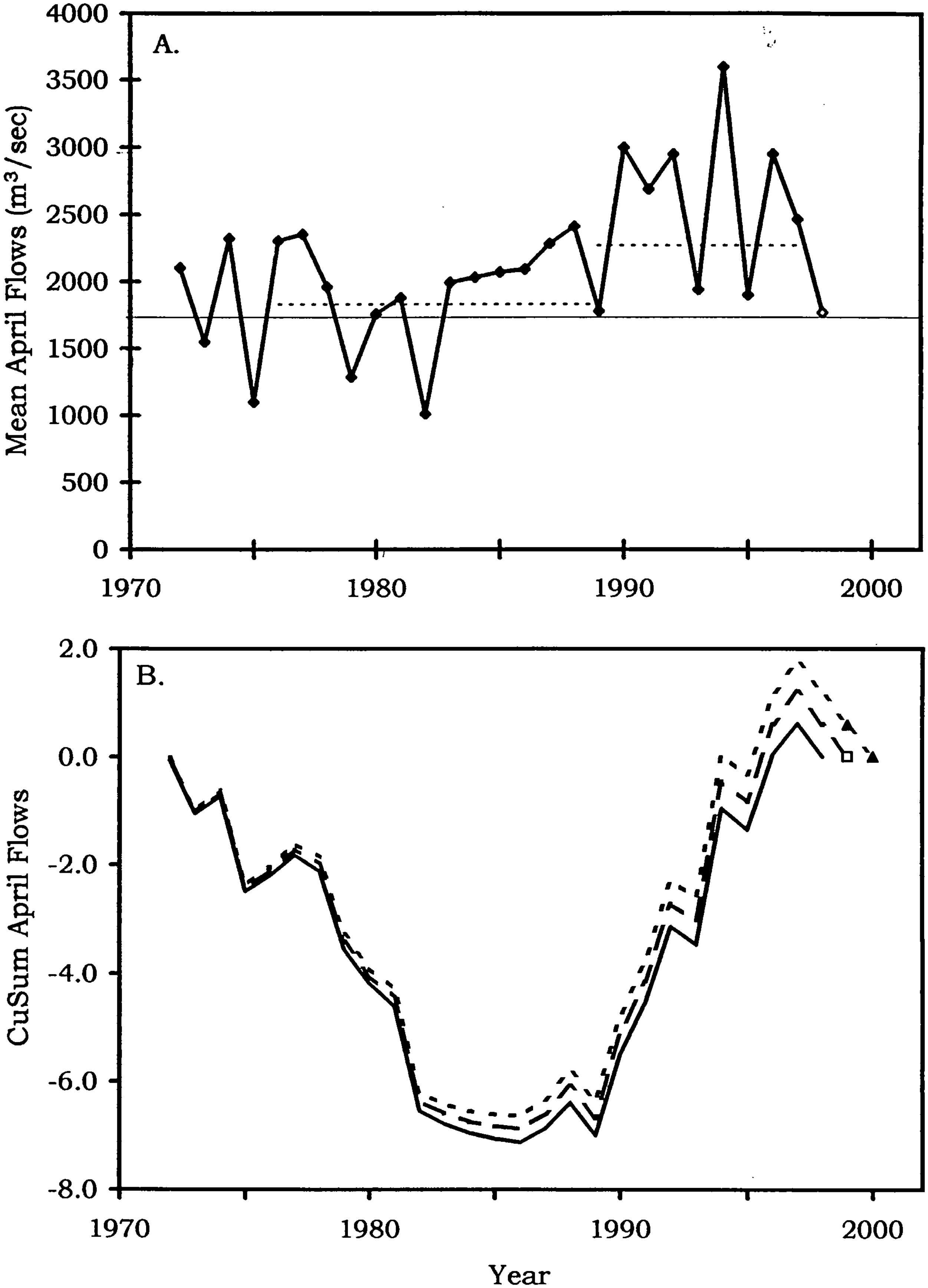


Figure 5


A.
Mean April Flows (m3/sec)
4000
3500
3000
2500
2000
1500
1000
500
0
1970
1980
1990
2000
B.
CuSum April Flows
2.0
0.0
-2.0
-4.0
-6.0
-8.0
1970
1980
1990
2000
Year