NPAFC

Doc. 633

Rev.

Recent returns of Pink salmon to the Fraser River indicate the importance of relating stock to recruitment on a regime scale

by

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Submitted to the

North Pacific Anadromous Fish Commission

by

CANADA

September 2002

This paper may be cited in the following format:
Beamish, R. J. 2002. Recent returns of Pink salmon to the Fraser River indicate the importance of relating stock to recruitment on a regime scale. (NPAFC doc. 633). Fisheries and Oceans Canada, Science Branch – Pacific Region, Pacific Biological Station, Nanaimo, B.C., Canada. V9T 6N7. 23p.

Abstract:

Catches of Pink salmon produced in the Fraser River traditionally are equivalent to approximately 60% of the Canadian commercial catch of this species. Historic abundances may have been as high as 60 million fish, but a natural obstruction in 1913 dramatically reduced production which was 6.5 million fish in 1959 when catch data became reliable. Since that time, total abundances have fluctuated between approximately 2 and 22 million fish. The relationship between the spawning stock and recruitment for the time series from 1959 to 2001 shows no obvious pattern and fits a Ricker curve poorly. However, the stock and recruitment relationships are much more informative when estimated separately for the climate/ocean regimes of 1947 to 1976, 1977 to 1988, 1989 to 1998 and 1999 to present. The most obvious relationship between stock, recruitment, and regimes occurred around the 1989 and 1998 regime shifts when there were significant changes in trends in productivity. The new regime shift was associated with an exceptional return of at least 20 million fish in 2001, from one of the lowest spawning abundances in 1999. The historic high escapement of at least 20 million fish in 2001 occurred during the present regime that should remain productive for Pink salmon. The returns in 2003 from this record high escapement may also be of historic importance if abundances return at pre-1913 levels.

Background

Pink salmon (*Oncorhynchus gorbuscha*) are the most abundant of the Pacific salmon and apparently the most recently evolved (Neave 1958). Their short life-span of two years between spawnings, as well as their abundance and extensive distribution makes them a desirable species for studies of environmental impacts such as greenhouse gas induced climate change on the long-term populations dynamics of all Pacific salmon. In Canada, annual total catches of Pink salmon averaged 19.7 t or approximately 14.7 million fish from 1959 to 2000. Catches of Pink salmon produced in the Fraser River traditionally are equivalent to approximately 60% of this average, although some of the catch is by the United States. The stocks of Pink salmon in the Fraser River, virtually all spawn in odd numbered years. The reason for the persistent dominance of these "odd year stocks" and the general phenomenon of dominance among Pink salmon stocks remains as one of the most intriguing mysteries in Fisheries Science. Bill Ricker (1962) wrote "I for one am about ready to give up the search for a unique cause of dominance and concentrate rather on identifying which cause or causes operate on each individual stock. If there is a remaining mystery, it may be this: when dominance can be caused by so many factors, why are there some pink stocks in which it does not occur and has never occurred?"

The difficulty in understanding the life history strategies of Pink salmon may result from the time scale that we use to study responses compared to the mode of environmental variability that actually influences Pink salmon behaviour. Perhaps the mechanisms that cause the natural responses are not clear on an annual time scale. Perhaps the time scale needed to interpret changes in both abundance and behaviour are longer than the career span of scientists or longer than the available time series of fishery data. There is evidence that the abundance of Pacific salmon is related to longer-term trends in climate (Beamish and Bouillon, 1993). There also is ample evidence of the existence of persistent trends in climate and ocean states that shift abruptly on a decadal scale (Fig. 1A, Beamish et al 2000, McFarlane et al 2000, Hare and Mantua 2000, Benson and Trites 2002). Recent regime changes occurred about 1925,1947,1977,1989, and 1998 (Fig. 1A, B). This means that over the past 100 years there have been 6 regimes, including the most recent period that started in mid-1998. However, reliable catch and escapement information does not appear until the 1950s, reducing the relevant number of regimes to 4. It is important to note that the years in which climate indices indicate regime changes occurred may not be the same years that first affected the dynamics of a population of a particular species.

In 2001, there was large return of Pink salmon to the Fraser River (Fig. 2A,B). Management policy resulted in an exploitation rate on this return that was very low, resulting in a spawning escapement that was approximately two times the highest estimated escapement on record (Fig. 2B). This exceptional return was the production from one of the lowest escapements on record. Clearly there was an increase in the marine survival of Pink fry entering the Strait of Georgia in 2000. This increase in marine survival coincided with a major shift in the trend of climate indicators (Fig 1A,B). For example, the synchrony of the changes in the length-of-day (Beamish et al 1999) and sea level height in the Gulf of Alaska (Lagerleof and Cummins personal communication) is evidence that this shift in May of 1998 was large scale, perhaps even global (Fig. 1B). A possible relationship between trends in climate that shift quickly from one state to another and trends in Pink salmon productivity would change how we evaluate the relationship between spawning stock size and recruitment of fish. It was Bill Ricker (1958) that reported that trends in environmental impacts could have important consequences in his recently developed relationship between stock and recruitment. He wrote "As a practical matter at the present time, however, the kinds of weather which affect Pacific salmon reproduction have not been shown to have recognizable trends certainly none that are predictable in advance; so the random-series model seems the best kind to use for this group of fish" (Ricker, 1958). Ricker (1958) assumed that the mode of climate variability that affected Pink salmon, and Pacific salmon in general, was annual. However, if there is a mode of variability that is longer and is at a regime scale, then the influences that affect the dynamics of an unfished population are not random around the mean of the total time series. This means that the effects of fishing could be better understood if the analysis is restricted to the mode of climate variability that best captures the mean effect of climate and ocean conditions on marine survival. The accumulating evidence that trends in climate exist (Hurrell 1995, Thompson and Wallace 1998, Beamish et al. 2000, Hare and Mantua 2000), and the unexpected high return of Pink salmon to the Fraser River in 2001, indicate that it is an appropriate time to revisit the relationship between spawning stock size and the resulting recruitment that Bill Ricker (1958) looked at 44 years ago.

Methods

Catch and escapement data for Pink salmon stocks were obtained from the Pacific Salmon Commission (PSC, 1988, 1990, 1996, 1999, 2001) for the period 1959 to 2001 (Table 1A,). Catch and escapement data of uncertain quality were also available for earlier years from Vernon (1958), Neave (1962), and Ricker (1989). Ricker (1989) estimated the average total number of Pink salmon returning to the Fraser River from 1907 to 1913 as 47 million fish, with the exploitation rate of 70%. The average numbers from 1915 to 1921 were estimated to be 10.9 million and from 1925 to 1931 to be 12.5 million. The yearly estimates up to 1957 (Table 1B) were calculated using the data and method reported in Ricker (1989). Trends in production were grouped according to the regimes 1947 to 1976, 1977 to 1988, 1989 to 1998, and 1999 to present. Regimes may be reported as the years that Pink salmon entered the ocean. Average weights are available but are not included in Table 1 and weight is not used in this analysis. In general, regime shifts result in complex changes and reorganization of ecosystems. It is therefore plausible that delays in biological responses would be observed. Consequently, the juvenile Pink salmon that went to sea in 1990 may have been influenced by ocean conditions characteristic of the 1977 to 1988 regime. Pink salmon returns in 1991 therefore were grouped in both the 1977 to 1988 regime and the 1989 to 1998 regime.

Results

The larger total returns from 1907 to 1913 and the abrupt decrease in 1915 (Fig. 2A) reflects the lost recruitment resulting from the rockslide at Hell's Gate in 1913 that prevented Pink salmon from spawning in areas above the slide. The estimates of total return from 1907 to 1913 are only approximate, but are sufficient to indicate the potential productivity of the total population. If Ricker's (1989) estimate of an exploitation rate of 70% is approximately correct then the average total escapement from 1907 to 1913 would be 14.3 million fish (30% of 47.7 million) (Fig. 2B). Similarly, the average escapement from 1915 to 1921 would be 3.27 million fish and from 1925 to 1931 3.75 million fish. The escapements in Fig. 2B up to 1959 were estimated from the catch data reported in Ricker (1989) and using a 70% exploitation rate and should be considered to be only approximate estimates. The recorded escapement of approximately 20 million Pink salmon in 2001 is the largest in the time series beginning in 1907. If the actual escapement is considerably larger, as reported by some observers, the number of spawning pink salmon in 2001 may have approached levels that existed prior to the start of commercial fishing and before the 1913 Hell's gate slide.

If the total returns are grouped by regimes, the total returns from 1959 to 1977 ranged from 1.9 million to 13.0 million (Table1) and averaged 6.3 million. Average total returns increased from 1979 to 1989 to 15.2 million with a range of

7.2 million to 19.0 million. From 1991 to 1999, the average return was 12.8 million with a range of 3.6 million to 22.2 million. If 1991 is grouped in the 1977 to 1989 regime, the 1993 to 1999 return averages 10.4 million and the 1979 to 1991 return averages 16.2 million. In 2001, the recorded total return was estimated to be 20 million. However, it appears that this estimate is still being assessed. Some reports indicate that the total return could be substantially larger.

Stock and Recruitment Relationships

The relationship between the number of spawning fish (escapement) and the subsequent total return of maturing and mature fish (recruitment) for the years from 1959 to 2001 is weakly dome shaped (Fig. 3) if extrapolations are not made beyond the last data point. According to the calculated equation a maximum number of recruits of approximately 15 million occurs at an escapement of about 7.5 million. Both a Ricker type curve (Fig.3) and a Beverton-Holt type curve (not shown) fit the data equally poorly.

The stock and recruitment relationships convey a very different interpretation about the population dynamics and the effects of fishing when the relationships are separated by regimes. The regime from 1959 to 1976 includes all brood years that went to sea from 1958 to 1976 and returned from 1959 to 1977. The relationship is steeply vertical within a narrow range of escapements and a wide range of returns (Fig. 4A). The regime from 1977 to 1988 is represented by fish that entered the ocean from 1978 to 1988 and returned from

1979 to 1989. The observations fit well on either a straight line or an ascending side of a curvilinear relationship, except for 1985 (Fig. 4B). It is known that the 1998 regime shift probably started mid-year (Fig.1B) thus the Pink salmon entering the ocean in 1998 would experience climate and ocean conditions characteristic of the existing regime. Thus, the regime from 1989 to 1998 would be represented by Pink salmon that went to sea in 1990 through to 1998 and returned from 1991 to 1999. The stock and recruitment relationship is linear (r^2=0.28) with no indication of being curvilinear at the higher spawning abundances (Fig. 4D). The slope of the line (slope=1.5) is considerably lower than observed in the previous regime (slope=3.2) indicating that there was a reduction in productivity in the 1990s. If the fish that went to sea in 1990 did not experience new ocean conditions, they should be grouped in the previous regime. When this is done (Fig. 4C, 4E) the relationship improves in both regimes, as the variability is reduced.

The recruitment per spawner index of 5.84 for Pink salmon that entered the ocean in 2000 and returned in 2001 was higher than any year for the return years 1991 to 1999. There was a significant difference between the mean recruit per spawner index from 1991 to 1999 of 1.60 and 4.17 from 1979 to 1989 (t test, $P<0.01$). If the 1991 estimate is included in the 1979 to 1989 regime, the differences in the recruits per spawner of 1.23 for 1993 to 1999 and 4.02 for 1978 to 1991 is significant at $P<0.001$ (t test). The period from 1961 to 1977 was characterized by wide variations in the annual recruit per spawner with a mean value of 4.77 which is not different from the 1979 to 1989 value (t test $P>0.05$).

However the mean recruitment per spawner for the period 1961 to 1977 was significantly larger than for the period 1991 to 1999 (t test, $P<0.05$).

Discussion

Ricker (1958) first described a standard approach for assessing the impacts of fishing on Pink salmon stocks from the Fraser River. At that time, there were unreliable estimates of catch and escapement as well as an absence of evidence of regimes and regime shifts. Forty-four years later, it is possible to compare the catch and escapement data using a Ricker curve for the total time series with the data grouped according to persistent states in the climate/ocean environment. The fit of a Ricker curve to the total time series conveys a relationship about the population that differs from the information conveyed when the data are grouped into regimes. The major differences between the two approaches occurred before and after the 1989 regime shift. The regime in the 1990s was characterized by reduced marine survival or reduced yield per spawner. In fact, the relationship between stock and recruitment was strongly linear for abundances that represented much of the historic range observed after 1913. With hindsight, and with an acceptance that the regimes represent real and persistent influences on the number of recruits per spawner, the relationships within each regime would provide a clearer interpretation of response to fishing than the Ricker curve fit. For example, in the 1990s, the slope of the line fitted to the escapement and resulting stock is approximately 1, indicating that the stock size will be approximately equivalent to the escapement (Fig. 4E). Fortunately, another change occurred in 1998 that affected the fry going to sea in 2000. The return in 2001 was large, indicating that the new regime appears to be very productive for Pink salmon. The significant differences in the recruit per spawner index between the 1989 to 1998 regime and the earlier regimes is additional evidence of the changes in the response of Pink salmon to the changes in the ocean.

The regime up to the 1977 regime shift was characterized by a narrow range of low escapements, but a wide range in total returns. This clearly is a different response to ocean conditions than observed in the 1990s. A possible explanation is that in the 1947 to 1977 regime, the variable response in total returns resulted from greater variation in the annual weather within the regime. If this interpretation is correct, the response of Pink salmon population dynamics would be characterized by being in a regime of extreme variability in marine survival. The regime from 1977 to 1989 (or 1990) would be characterized by higher marine survival and less interannual variability. The larger returns in this regime may have occurred when the marine survival in 1978 and 1980 improved and a management decision allowed the future escapements to remain higher than in the 1960s. This is only speculation as it is difficult to reconstruct the reasons for the management decisions. However, the recruit per spawner for the pink salmon that went to sea in 1976, 1978, and 1980 (6.0, 6.0 and 5.3 respectively) were approximately twice the average for the entire time series. The high value in 1976, appears to be inconsistent with a regime shift in 1977, however, the exact timing of the 1977 shift is less clear than the shifts in 1989 and 1998. It is also possible that the natural variability in weather that characterized the 1947 to 1977 regime resulted in a more productive ocean in 1976.

It might be argued that these rather short-term assessments are not informative for the establishment of long-term strategic fishing plans. For example, how would the relationship observed from 1959 to 1977 help managers plan for sustainability? The answer is that the relationship between stock and recruitment naturally may be highly variable. Theoretically, if escapements were larger, perhaps double, it would still be expected that the resulting stock size would be highly variable. It would also be expected that the productivity might change at the next regime shift. Thus the time frame for theoretical sustainability is decadal. Certainly, the Ricker curve fit conveys very different information about the dynamics of the population during the 1990s than the relationship seen from a regime perspective. However, a target escapement from the regime relationship in the 1990s might be in the eye of the beholder as the more fish that spawn, the more that return with the range of returns within the approximate range since 1913. It is understandable that the regime relationships could be unsettling for managers who are used to having target reference levels calculated from a Ricker curve. One interpretation and potential solution would be to consider that a Ricker curve defines a very long-term relationship between stock and recruitment. The regime relationship is the actual time frame required for management. According to this approach, long-term targets could be estimated from Ricker curves, but the annual (bi-annual in the case of the Fraser River Pink Salmon) management would be based on the productivity of the population during a regime. Regime changes would be detected using indicators such as in Fig. 1, which hopefully will become more understandable. In fact, the existence of regimes and their impacts would indicate that for practical purposes, fishing strategies need to be adapted to the productivities that are characteristic of the regime scale of variability.

The catch and escapement data for Pink salmon stocks are generally considered to be reliable beginning with the brood year 1959 and the subsequent return in 1961. The estimated stock and recruitment relationship from 1961 through to 1999 using the “Ricker” curve is weakly dome shaped and possibly asymptotic at an escapement of approximately 7.5 million fish. If the Ricker curve is extrapolated beyond the 40-year data series, an escapement of about 20 million Pink salmon in 2001 would produce a return of approximately 10 million fish. However, we know that returns before 1913 were considerably larger than 10 million. The escapement in 2001 was estimated to be about 20 million fish, although other unpublished estimates range from 22 to 30 million fish. The returns in 2003 may produce a remarkable opportunity to study the consequences of an escapement that is higher than anything believed to have occurred in the last 95 years.

In an earlier publication (Beamish et al. 1997), it was shown that the population dynamics of sockeye salmon (*O. nerka*) from the Fraser River also were affected by regimes. An intervention analysis of the catch from 1958 to the

1989 brood years indicated that there was a significant step up in the time series in 1977. The abundance changes of the combined sockeye salmon stocks could be separated into productivity regimes that corresponded to changes in trends in climate. It was noted that future regime shifts should be expected to occur quickly and that effective management would require an understanding of the resulting productivity in a new regime.

It appears that the management information for stock and recruitment relationships for Pink salmon from the Fraser River is more relevant when the relationships are portioned by climate and ocean regimes. It is possible that the Ricker curve describes a longer-term relationship that represents a mean response over a number of regimes. However, the improved understanding of fishing effects, should encourage analysts to assess the population dynamics of pink salmon within regimes. Regime grouping is important because there is now solid evidence for the existence of regimes. This is evidence that was not available to Bill Ricker (1958) when he considered the ocean's effect to be random over the entire time series.

References

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

Beamish, R. J., C. M. 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.

Beamish, R. J., D. J. Noakes, G.A. McFarlane, L. Klyashtorin, V.V. Ivanov, V. Kurashov. 1999. The regime concept and natural trends in the production of Pacific salmon. Can. J. Fish. Aquat. Sci. 56:516-526.

Beamish, R. J., G. A. McFarlane, and J. R. King. 2000. Fisheries Climatology: understanding decadal scale processes that naturally regulate British Columbia fish populations. pp. 94-145. In: P. J. Harrison and T. R. Parsons (eds.) Fisheries Oceanography: An Integrative Approach to Fisheries Ecology and Management. Blackwell Science, Oxford.

Benson, A.J. and A. W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fish and Fisheries 3:95-113.

Hare, S. R. and N. J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanography 47:103-145.

Hurrell, J. W. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science 269:676-679.

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. Meteorol. Soc. 78:1069-1079.

McFarlane, G.A., J. R. King, and R. J. Beamish. 2000. Have there been recent changes in climate? Ask the fish. Prog. Oceanography 47:147-169.

Neave, F. 1958. The origin and speciation of *Oncorhynchus*. Proc. Trans. R. Soc. Can. Ser. 3 52(5):25-39.

Neave, F. 1962. The observed fluctuations of pink salmon in British Columbia. pp. 3-14. In: N. J. Wilimovsky (ed.). Symposium on Pink Salmon. H. R. MacMillan Lectures in Fisheries. Institute of Fisheries, University of British Columbia, Vancouver, B.C.

Pacific Salmon Commission (PSC). 1988. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1987 Fraser River sockeye and pink salmon fishing season. Pacific Salmon Commission. Vancouver BC. 48pp

Pacific Salmon Commission (PSC). 1990. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1989 Fraser River sockeye and pink salmon fishing season. Pacific Salmon Commission. Vancouver BC. 51pp

Pacific Salmon Commission (PSC). 1996. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1993 Fraser River sockeye and pink salmon fishing season. Pacific Salmon Commission. Vancouver BC. 58pp

Pacific Salmon Commission (PSC). 1999. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1997 Fraser River sockeye and pink salmon fishing season. Pacific Salmon Commission. Vancouver BC. 47pp.

Pacific Salmon Commission (PSC). 2001. Report of the Fraser River Panel to the Pacific Salmon Commission on the 1999 Fraser River sockeye and pink salmon fishing season. Pacific Salmon Commission. Vancouver BC. 47pp.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can. Bull. 119: 300pp.

Ricker, W. E. 1962. Regulation of the abundance of pink salmon populations. pp. 155-201. In: N. J. Wilimovsky (ed.) Symposium on Pink salmon, H.R. MacMillan Lectures in Fisheries. Institute of Fisheries, University of British Columbia, Vancouver, B.C. (FRB Studies No. 713).

Ricker, W. E. 1989. History and present state of the odd-year pink salmon runs of the Fraser River region. Can. Tech. Rep. Fish. Aquat. Sci 1702: 37p.

Thompson, D.W.J. and J.M. Wallace. 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophys. Res. Lett. 25(9):1297-1300.

Vernon, E. H. 1958. An examination of factors affecting the abundance of Pink salmon in the Fraser River. Prog. Report, Int. Pac. Salmon Fisheries Commission. 49p.

Table 1A. Catch, escapement and total returns of Pink salmon used in this report (data from Pacific Salmon Commission).

Catch Year	Catch	Escapement	Total Return
1959	5,382,055	1,078,000	6,460,055
1961	796,685	1,092,561	1,889,246
1963	3,528,312	1,954,038	5,482,350
1965	1,125,788	1,194,099	2,319,887
1967	11,131,572	1,831,219	12,962,791
1969	2,400,548	1,530,913	3,931,461
1971	7,958,376	1,804,952	9,763,328
1973	5,049,723	1,751,261	6,800,984
1975	3,526,866	1,367,089	4,893,955
1977	5,821,674	2,387,811	8,209,485
1979	10,843,466	3,560,655	14,404,121
1981	14,196,353	4,488,335	18,684,688
1983	10,714,376	4,631,620	15,345,996
1985	12,577,074	6,460,614	19,037,688
1987	3,948,252	3,223,521	7,171,773
1989	9,295,074	7,189,186	16,884,260
1991	9,230,804	12,942,535	22,173,339
1993	6,215,163	10,768,335	16,983,498
1995	5,729,124	7,174,584	12,903,708
1997	5,333,586	2,842,108	8,175,964
1999	163,796	3,422,194	3,585,990
2001	low	20,000,000[1]	20,000,000[1]

[1]Preliminary

Table 1B. Total number of Pink salmon returning to the Fraser River, estimated from Ricker (1989).

Catch year	Total Return	Catch year	Total Return
1907	34,500,000	1933	8,230,000
1909	59,900,000	1935	6,730,000
1911	48,200,000	1937	5,910,000
1913	48,200,000	1939	5,280,000
1915	8,500,000	1941	3,580,000
1917	15,000,000	1943	1,290,000
1919	10,700,000	1945	6,740,000
1921	9,500,000	1947	12,290,000
1923	14,700,000	1949	9,430,000
1925	8,750,000	1951	7,970,000
1927	10,040,000	1953	9,090,000
1929	12,800,000	1955	8,820,000
1931	12,180,000	1957	8,390,000

Figure Captions

Figure 1 (A). Climate indices showing changes in trends that correspond to the regime shifts of 1925, 1947, 1977, 1989, and 1998 (solid vertical lines). AFI is the atmospheric forcing index (McFarlane et al. 2000), PDO is the Pacific decadal oscillation (Mantua et al. 1997), ALPI is the Aleutian Low pressure index (Beamish et al. 1997), PCI is the Pacific circulation index (McFarlane et al. 2000) and AO is the Arctic oscillation (Thompson and Wallace, 1998).

(B). Changing trends in the length-of-day (LOD) and sea level height occurred approximately at the same time in May of 1998, indicating that the 1998 regime shift was associated with other large-scale climate, ocean, and physical changes. The increased velocity of the spinning of the solid Earth (LOD) is an indication that the regime shift of 1998 was associated with large-scale energy transfers (Beamish et al. 1999). The increase in sea level height is shown as the first EOF of Topex/Poseidon altimeter data (Lagerloef and Cummins, personal communications).

Figure 2 (A). The total return of Pink salmon to the Fraser River. The estimates up to 1957 were calculated from Ricker (1989) and should be considered to be approximate. The values from 1959 to 1999 are from the Pacific Salmon Commission (Table 1). The estimate for 2001 is preliminary. Note that the returns occur only in odd-numbered years.

(B). Escapements for the same period as (A). The estimates up to 1957 were made assuming an average exploitation rate of 70% (Ricker 1989). Note that the 2001 estimate is the largest since 1907.

Figure 3. The relationship between stock (escapement) and recruitment (total return) using a Ricker curve for the return years from 1959 to 2001.

Figure 4. The relationship between stock and recruitment grouped by regimes. The years represent the return years. The return in 1991 is from the 1989 brood year that went to sea in 1990. It is possible that the pink fry that went to sea early in 1990 experienced the ocean conditions characteristic of 1977 to 1989, thus the 1991 return is also shown in the 1977 to 1989 regime (Fig. 4C) and removed from the 1989 to 1998 regime (Fig. 4E).

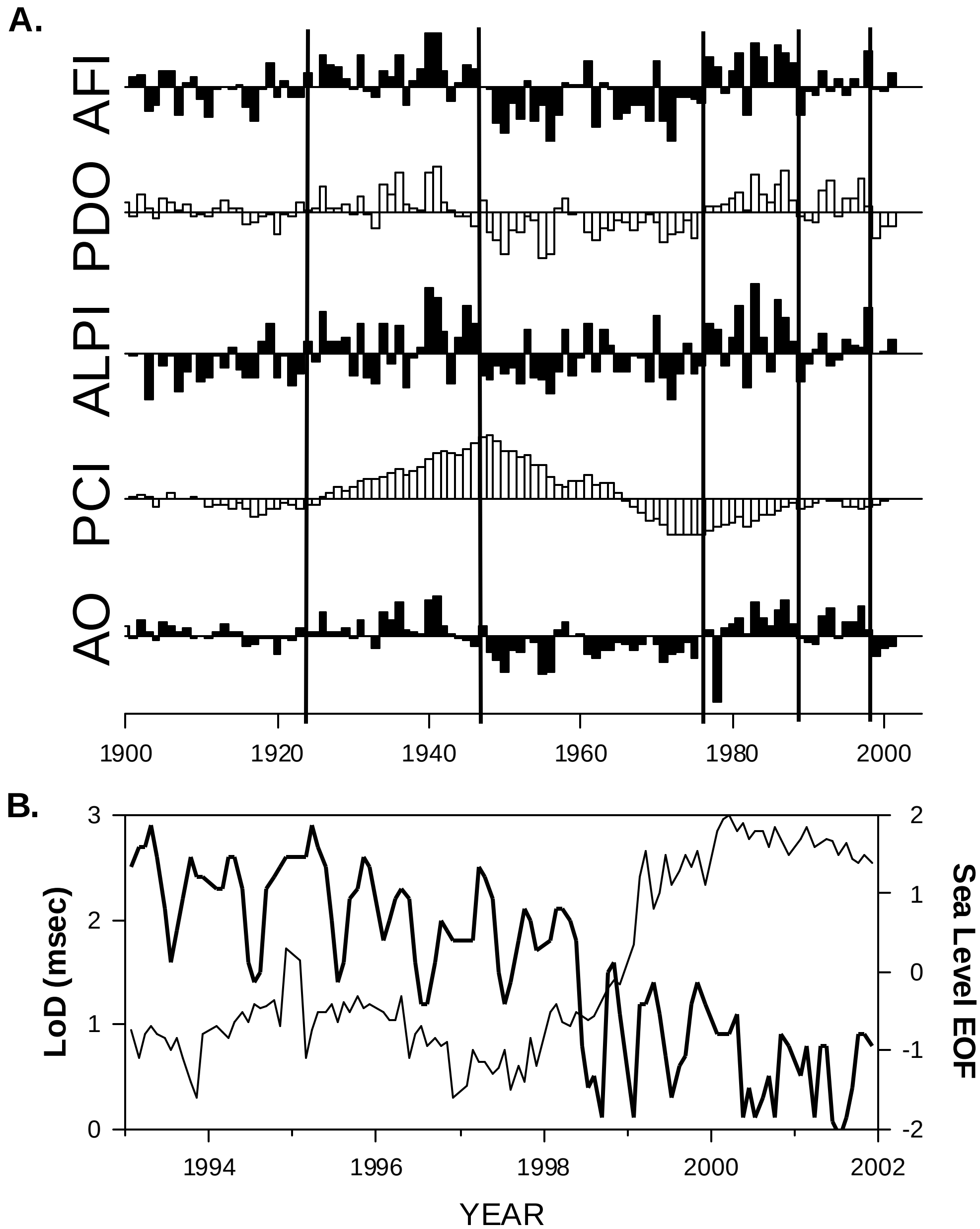
A.
AFI
PDO
ALPI
PCI
AO
1900
1920
1940
1960
1980
2000
B.
LoD (msec)
Sea Level EOF
1994
1996
1998
2000
2002
YEAR

Figure 1.

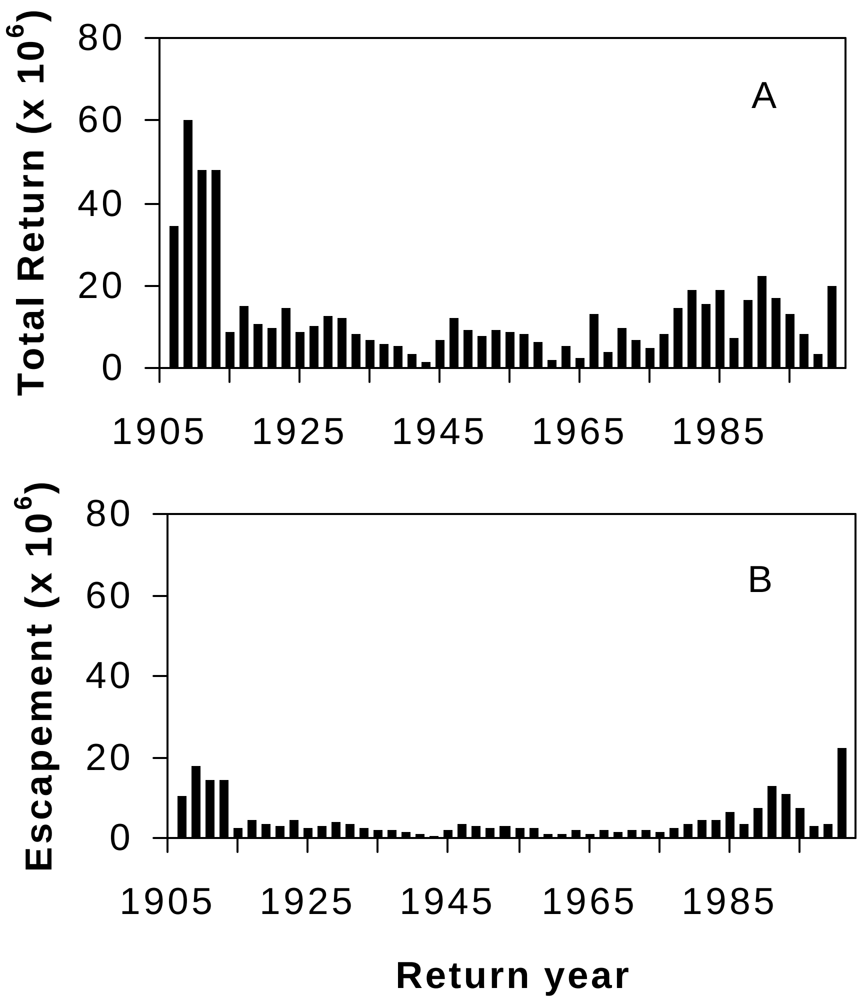
Total Return (x 10^6)
80
60
40
20
0
A
1905 1925 1945 1965 1985
Escapement (x 10^6)
80
60
40
20
0
B
1905 1925 1945 1965 1985
Return year

Figure 2.

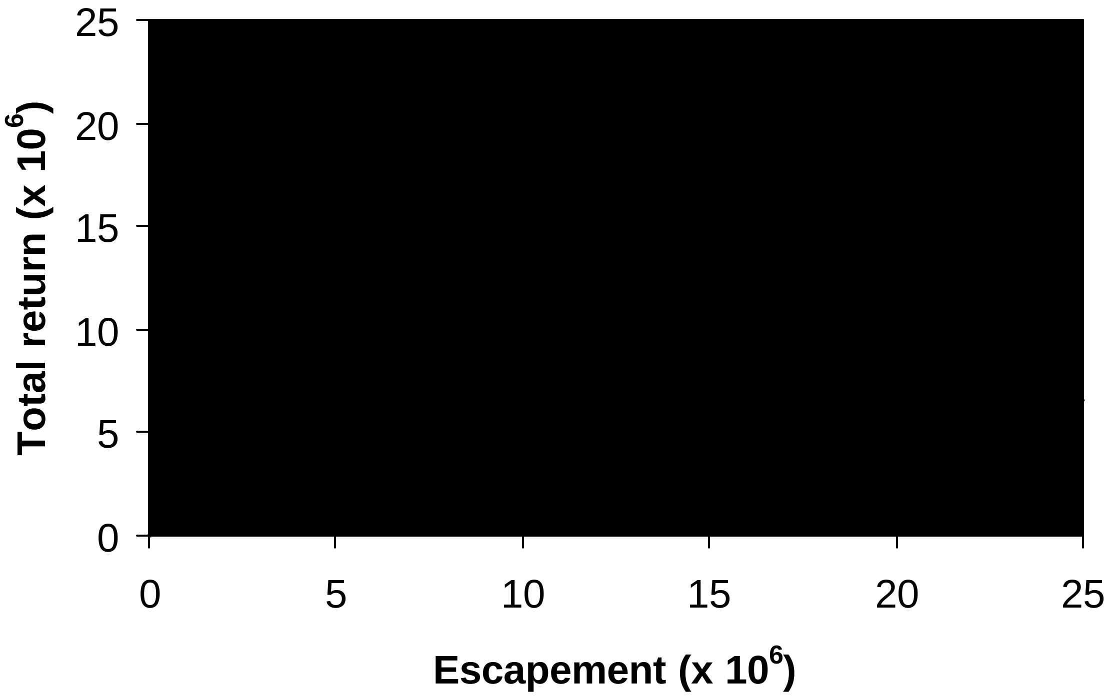

Figure 3.

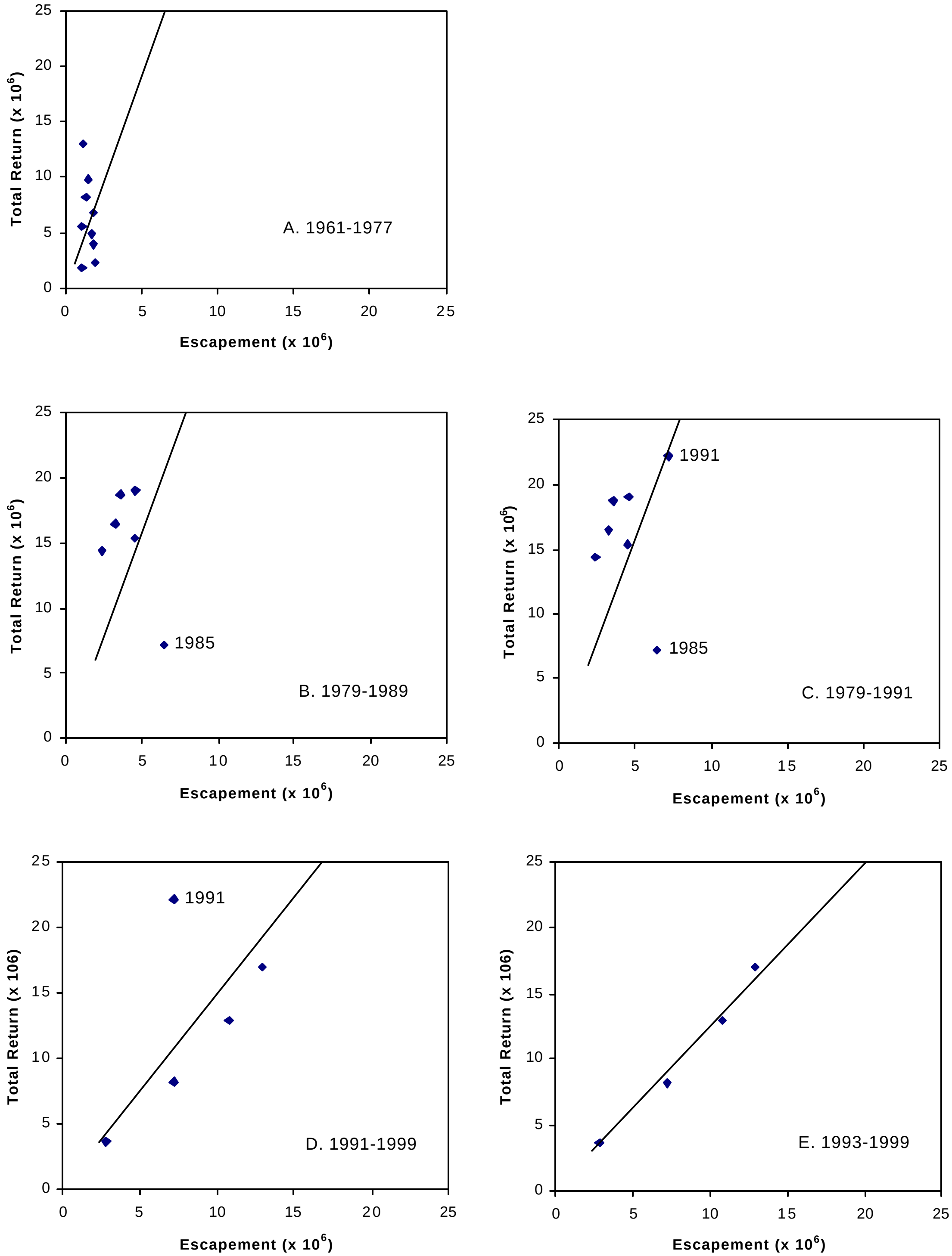
Total Return (x 10^6)
Escapement (x 10^6)
A. 1961-1977
B. 1979-1989
1985
C. 1979-1991
1991
1985
Total Return (x 106)
D. 1991-1999
1991
E. 1993-1999

Figure 4.