Salmon-omics: Effect of Pacific Decadal Oscillation on Alaskan Chinook Harvests and Market Price

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Introduction

Found only in North Pacific waters from Alaska to Oregon and California, Alaskan Chinook (King) salmon are the most sought-after of all salmon species due to their size and rich flavor. Over the last three years, significant rises in annual harvests of Alaskan Chinook have been accompanied by a 35% price increase. This paper examines the effect of the Pacific Decadal Oscillation (PDO) on Alaskan Chinook prices by studying: i) the impact of PDO on the size, population, and annual harvests of Alaskan Chinook; ii) the market effect of harvests on Chinook prices.

Life History of Alaskan Chinook Salmon

Chinook salmon are anadromous, i.e. they migrate upstream from the ocean to breed in freshwater. Ideal temperatures for breeding are between 5.8°C and 14.2°C (ADF&G 1985), and hatch in about 12 weeks (USFWS 2004), depending on the time of spawning and water temperatures.

The juveniles (fry) then remain in their ponds for between three months and a year, depending on the water temperature (salmon fry in colder ponds tend to remain longer). In Alaska, most fry remain in their ponds until the following spring. During this period, fry feed on plankton, aquatic insect larvae, terrestrial insects, salmon eggs and spiders (Scott and Crossman 1973).

Following the fry stage, Chinooks begin to make the transition from freshwater to saltwater in a process known as smolting. Now called “smolts”, their parr marks, the pattern of vertical bars and spots useful for freshwater camouflage, are replaced with dark-back and white-belly coloration useful for open ocean camouflage. Their gills and kidneys change to process saltwater as smolts gradually move downstream, where salinity increases (USFWS 2004).

While at sea, Chinooks are considered opportunistic drift and benthic feeders (Beauchamp et al. 1983). The spatial extent of Chinooks ranges from 45^{o}N to the North Alaskan arctic waters. Young Chinooks feed on crab larvae, amphipods, copepods, euphasiids, cladocerans, barnacles and a variety of small fish (Hart 1973), whereas adult Chinooks eat fish, squid, euphasiids, shrimps and crab larvae (Major 1978). The young adult stage is a period of high mortality, and believed to be the period when the class size is established (Pearcy 1992). Chinooks remain in the ocean for one to seven years (ADF&G 1985) until they reach sexual maturity.

Chinooks typically return to freshwater to spawn between the ages of three and seven, though usually at age six (USFWS 2004). Thus, the size of Chinooks in any spawning run may vary significantly. Each female deposits between 3,000 and 14,000 eggs (ADF&G 1994) into gravel nests on the riverbed (redds), which are then fertilized by males externally. However, up to 85% of the eggs may be lost before hatching (USFWS 2004). All Chinooks die after spawning.

Pacific Decadal Oscillation

The Pacific Ocean experiences significant climate variability. Much of this is caused by the El Niño Southern Oscillation (ENSO). However, scientists have found that predictions for climate response to ENSO in the North Pacific often fail. In particular, the North Pacific climate has exhibited continuous “El Niño conditions” from 1976-77 onwards, despite the absence of an El Niño event in that year and infrequent El Niño events thereafter (Hare and Mantua 2001).

Miller et al. (1994) declared this 1976-77 North Pacific climate shift a regime change, and presented descriptions of the changes. Ebbesmeyer et al. (1991) also discovered a significant shift in 40 climatic and biological variables in 1976. The regime shift has since been identified as periodic in nature on the decadal time scale, and named the Pacific Decadal Oscillation (PDO). In the positive phase of the PDO, Northeast Pacific waters become anomalously warm while Northwest Pacific waters become anomalously cool. Aleutian Low will also become more pronounced. Actual anomaly values may be found in **Figure 1**.

Intricacies of the PDO are a subject of active research. There are suggestions that the PDO is a product of two discrete oscillations – a 20-year cycle and a 50-70 year cycle (Minobe 1997). Tree-ring analysis has revealed 11 regime changes since 1650, with an average regime duration of 23 years (Gedalof and Smith 2001), suggesting that the next regime shift is due.

PDO Effect on Alaskan Chinook

This author suggests the following model governing the PDO-Alaskan Chinook interaction:

- Positive PDO is accompanied by a pronounced Aleutian Low. This strengthens cyclonic wind around the North Pacific gyre.
- The strengthened wind produces increased Ekman pumping, drawing up deeper water from the center of the gyre. This deep water is then advected around the gyre by the cyclonic surface currents. The result is increased vertical and horizontal mixing throughout the gyre and especially along the periphery of the gyre.
- The increased mixing promotes phytoplankton (primary) growth, particularly along the peripheral surface currents. This in turn promotes zooplankton (secondary) growth, including amphipods, copepods and cladocerans, all of which are prey of young Chinooks. Increased zooplankton growth is also beneficial for euphasiids, another common prey of young Chinooks. Increased secondary growth also promotes growth of adult Chinook prey such as shrimps and squids.
- The migration route (**Figure 2**) of Alaskan Chinooks runs along the same gyre periphery currents. Thus, the increased biotic production occurs directly along their migration paths.
- Fish metabolism is directly related to the temperature of their surroundings. Higher water temperatures along the migration path associated with positive PDO promote Chinook metabolism.
- With greater abundance of food and increased metabolism, young Chinooks grow and develop more rapidly, reducing susceptibility to environment and predators. Thus, the usually-high young Chinook mortality rate is reduced. Moreover, reduced vulnerability allows Chinooks to grow larger, and average Chinook size increases.

The proposed model is in agreement with the PDO-Alaska salmon model of Hare (1996), although Hare further mentions the effects of density-dependent growth in salmons' final year at sea, as well as the effects of water temperature on predator-prey distribution and salmon feeding ranges.

Thus, this author believes positive PDO phases are beneficial to Chinook survival and growth, leading to increased Chinook population and size, which in turn results in larger Chinook harvests. This is evidenced in **Figure 3**, which shows the annual Alaskan Chinook harvests for 1970-2004, and compares it to the PDO index. Notice the sharp rise in annual catch beginning in 1976 corresponding to the PDO regime shift to positive phase, as well as local minimums of both catch and PDO index in 1975 and 2000. These reflect a strong relationship between annual catch and PDO phase, suggesting that Chinook recruitment is significantly affected by PDO cycles.

Alaskan Chinook Market Prices

Nominal prices of Alaskan Chinook over the last 20 years have exhibited high variability, from the current $1.92/lb to the peak price of $2.69/lb in 1988, but falling as low as $1.28/lb in 1998 (ADF&G 2005). Real prices filter away some of the variability, but still results in a price range of $0.72 in 2002 to $2.27 in 1988 (in 1982-84 dollars). **Figure 4** shows a plot of Alaskan Chinook catch and prices from 1984-2004.

Ordinary Least-Squares regression of real prices against yearly catch (setting intercept = 0) produced a slope of $0.002/1000-catch. The regression results (**Figure 5**) were mixed: the slope result was significantly non-zero at the 99% significance level, with a negligible P-value of $2.967*10^{-11}$. However, R^2 was –16%, with the negative sign occurring due to the condition on the intercept. Moreover, despite the significantly positive slope, the slope was very small (multiple orders of magnitude) compared to the prices (~$0.72-$2.27) and yearly catch (353-804 thousands), suggesting low price sensitivity to yearly catch.

The regression results imply that Alaskan Chinook prices are not driven so much by supply-side factors, and lead this author to believe that Alaskan Chinook prices must be driven largely by demand-side factors, such as Chinook consumption or availability and demand for substitutes (such as other salmon, e.g. Sockeye, Pink).

Conclusion

Since Alaskan Chinooks spend a large portion of their lives in the North Pacific waters, the PDO has a very large impact on Chinook survival and size, which relates directly to yearly harvests of Alaskan Chinook. Positive PDO phases result in increased food production along Chinooks' migration path (due to increased vertical and horizontal mixing of North Pacific waters) and higher growth rates (due to increased water temperature) for Chinooks. These lead to increased class population and size, resulting in larger harvests.

A regression of Alaskan Chinook prices and yearly harvests has revealed a significantly non-zero slope indicating a positive relationship between real Chinook prices and annual catch. However, this slope is orders of magnitude smaller than the regression variables, indicating low price sensitivity to yearly harvest.

Thus, while the PDO has significant impact on the Alaskan Chinook population, it should not be considered a critical factor affecting Chinook market prices.

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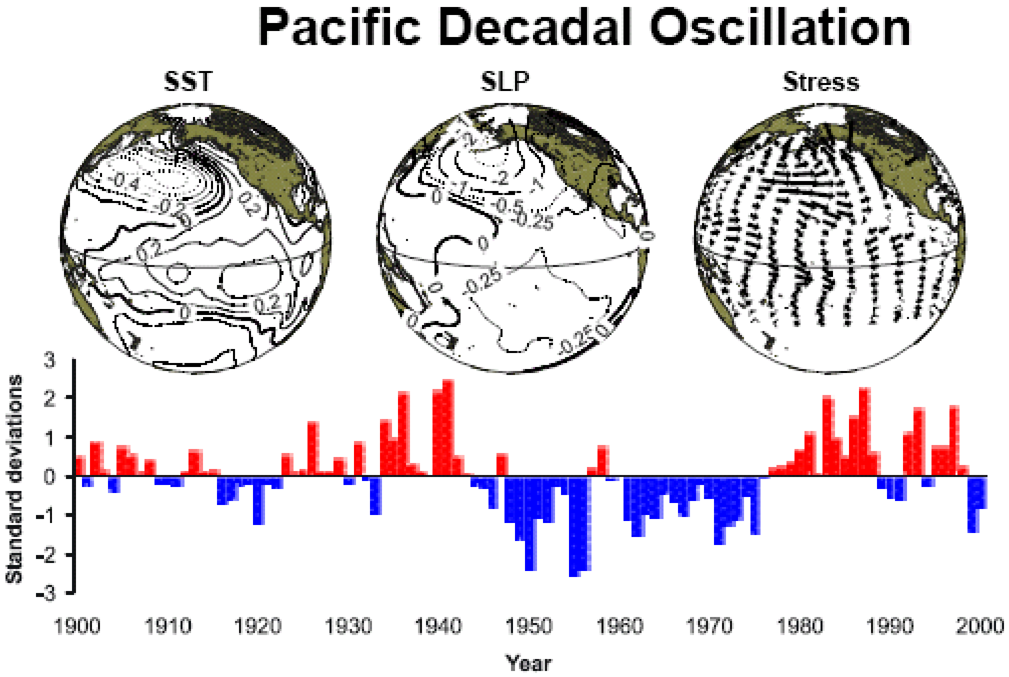
Figure 1:
Anomalous climate conditions associated with the positive phases of the Pacific Decadal Oscillation (PDO) and El Niño-Southern Oscillation (ENSO), the PDO and ENSO temporal indices. Values shown are °C for sea surface temperature (SST), millibars for sea level pressure (SLP) and direction and intensity of surface wind stress. The longest wind vectors represent a stress of 10 m²/s². Actual anomaly values for a given year at a given location are obtained by multiply the climate anomaly by the associated index value. Adapted from Hare (2001)


Pacific Decadal Oscillation

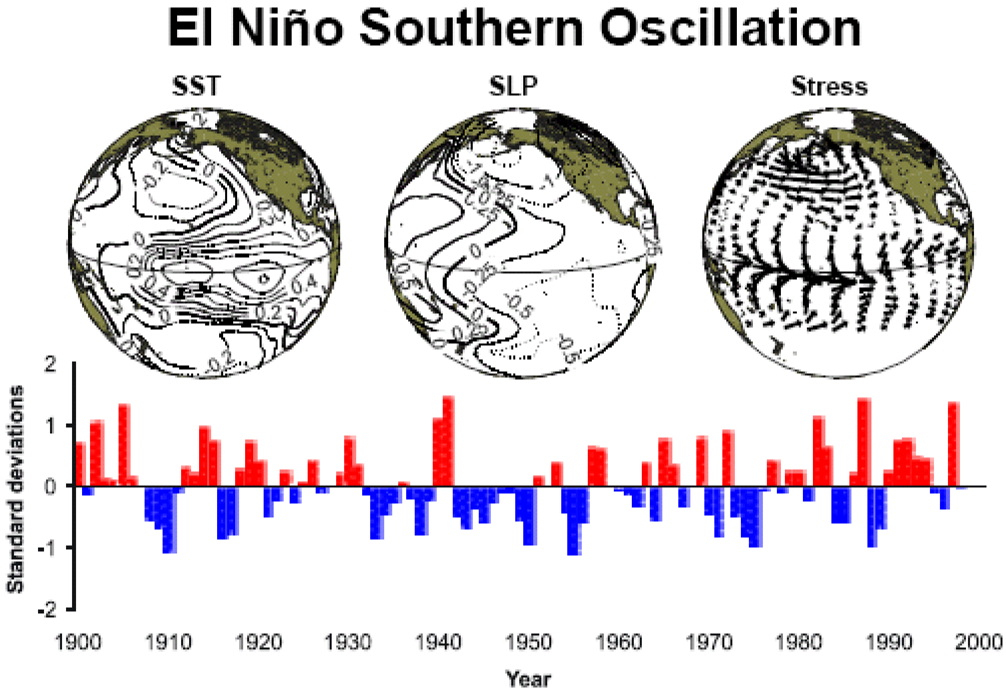
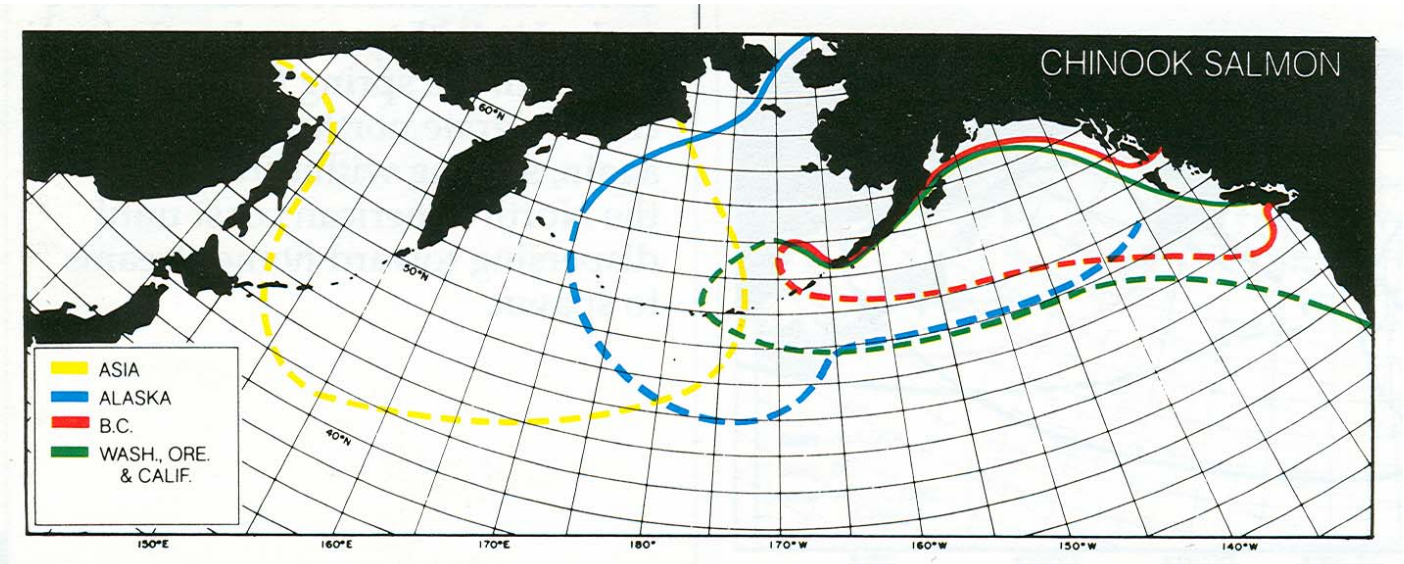

El Niño Southern Oscillation

Figure 2:
Top: Chinook salmon migration routes. Alaskan Chinook in blue. Adapted from DFO (2005).
Bottom: North Pacific ocean surface currents. Adapted from US Navy (1976).



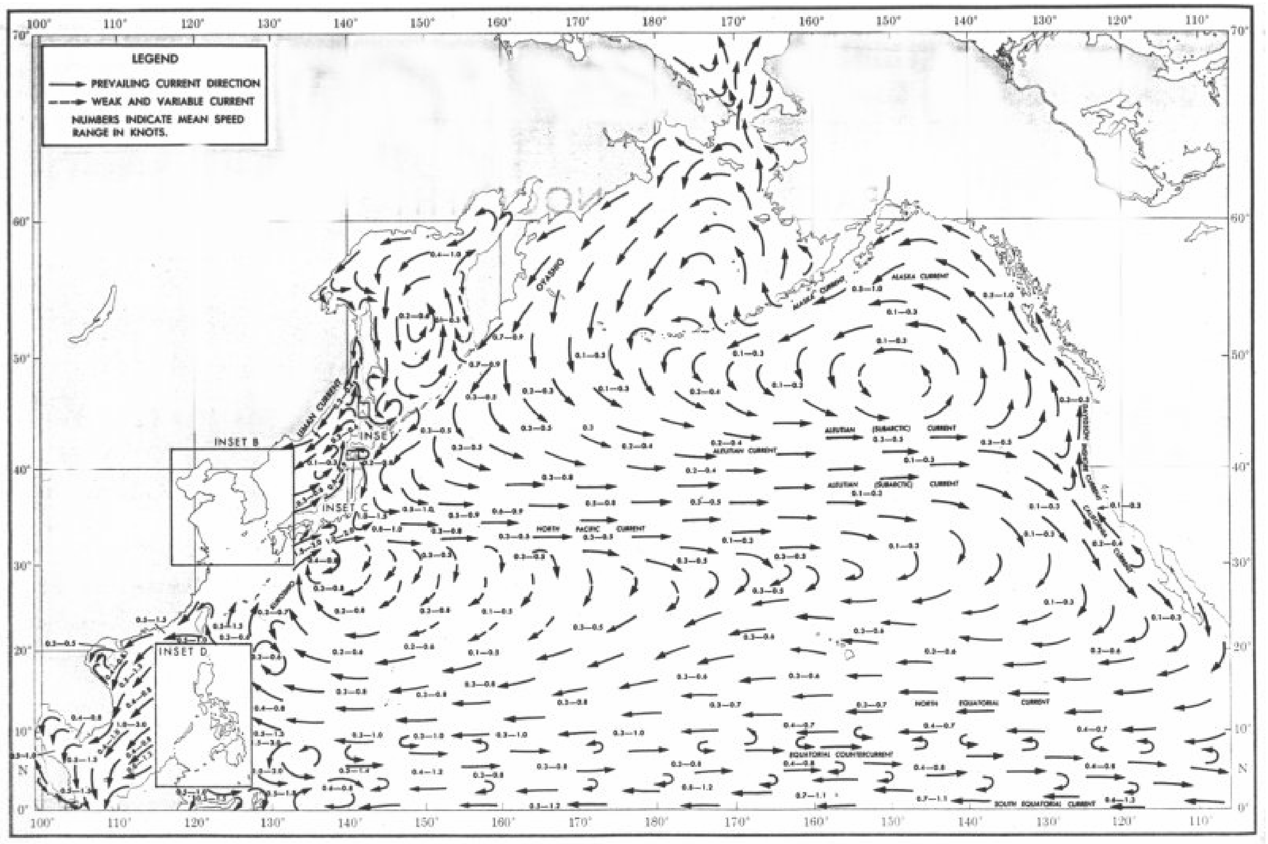


Figure 3:
Upper: Time series plot of Catch (‘000s) and Average Weight (lb) of Alaskan Chinook salmon.
Lower: PDO index for 1970-2005 and 1900-2005. Adapted from Mantua (2005).

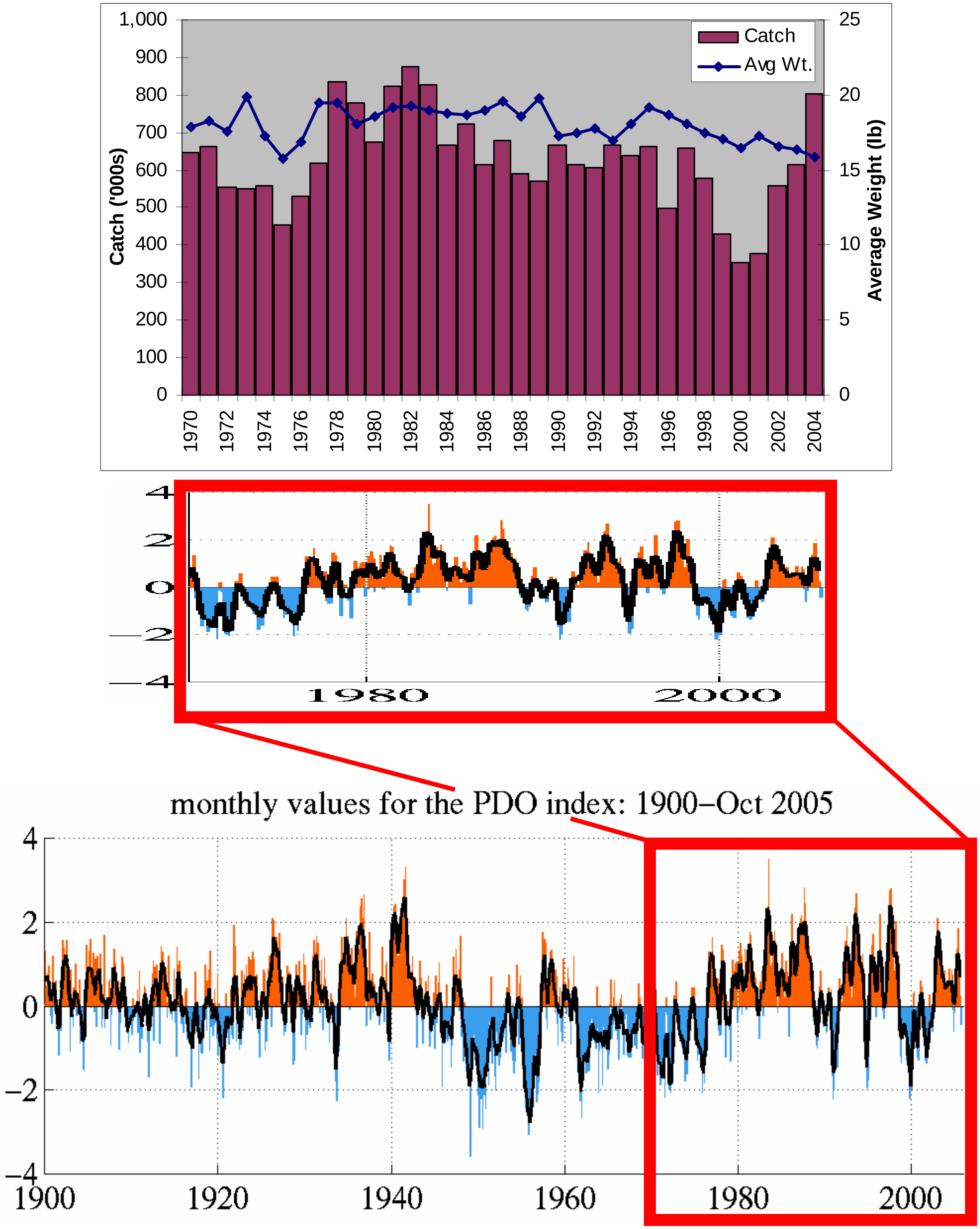


Figure 4:
Time series plot of Catch (bars, left axis) and Real Price (line, right axis). Data from ADF&G (2005).

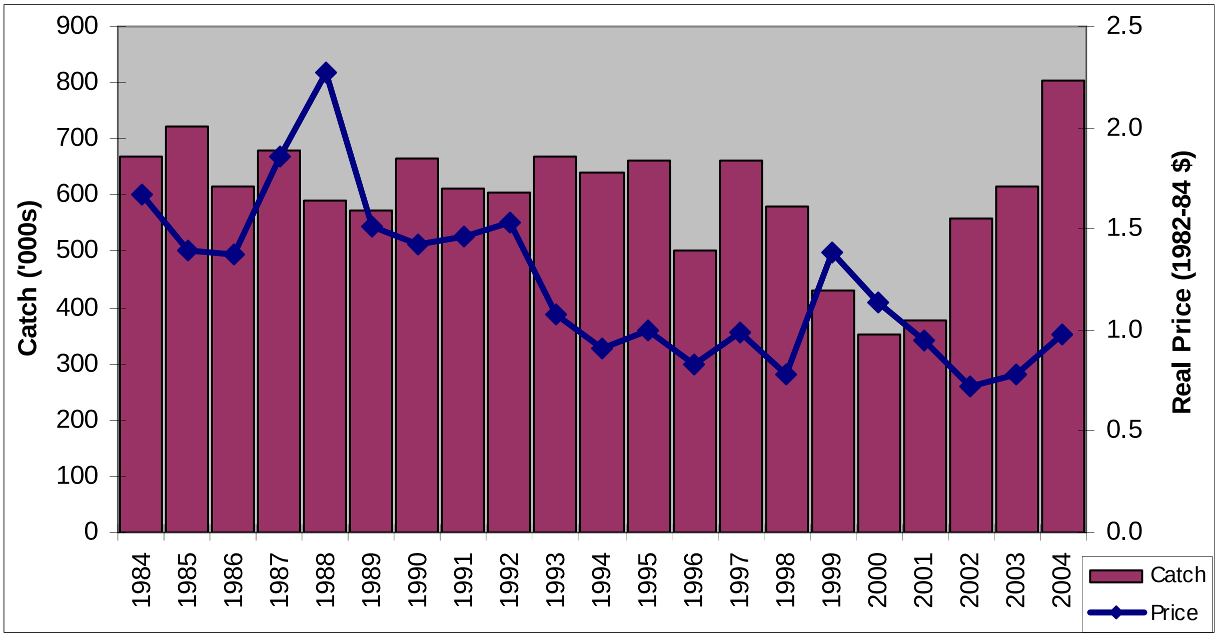
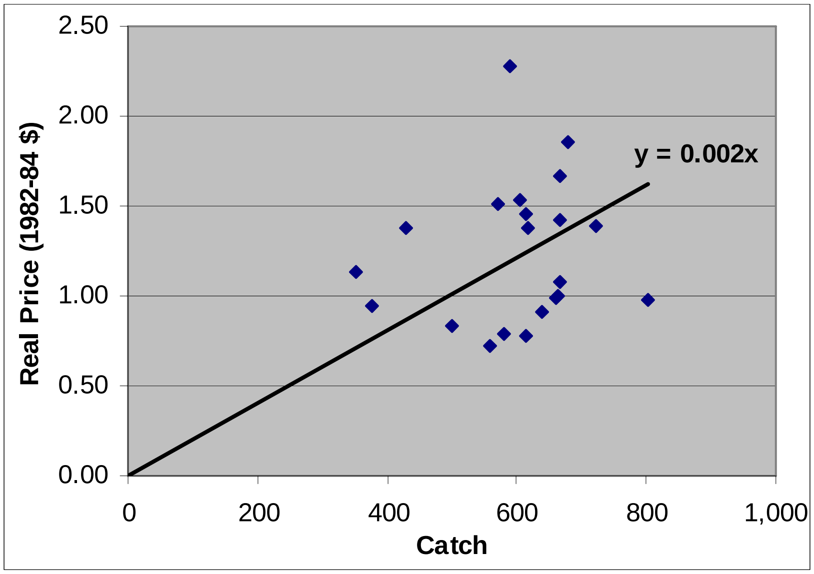


Figure 5:
Regression results – Real Price ordinary-least-squares regressed against annual Catch (‘000s). Data from ADF&G (2005).



Statewide Price of Chinook Salmon

Year	Price (1982-4 $)	Catch ('000s)
1984	1.67	667.0
1985	1.39	721.0
1986	1.38	616.0
1987	1.86	680.0
1988	2.27	589.0
1989	1.52	572.0
1990	1.42	666.0
1991	1.46	613.0
1992	1.53	606.0
1993	1.07	667.0
1994	0.91	640.0
1995	1.00	663.0
1996	0.83	500.0
1997	0.99	660.0
1998	0.79	580.0
1999	1.38	430.0
2000	1.13	352.6
2001	0.95	376.591
2002	0.72	557.305
2003	0.78	615.1
2004	0.98	803.782

SUMMARY OUTPUT

Regression Statistics	
Multiple R	65535
R Square	-0.15584
Adjusted R Square	-0.20584
Standard Error	0.43119
Observations	21

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	-0.50135	-0.50135	-2.69657	-
Residual	20	3.71843	0.18592		
Total	21	3.21708			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 99.0%*	*Upper 99.0%*
Intercept	0	-	-	-	-	-
X Variable 1	0.00202	0.00015	13.06921	0.00000	0.00158	0.00246