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Trends in Abundance and Biological Characteristics for 1RUWK3DFL¿F6RFNH\H6DOPRQ

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salmon. N. Pac. Anadr. Fish Comm. Bull. 4: 53–75.

Abstract: Trends in abundance, productivity, and average size were reviewed for sockeye salmon populations from Washington, British Columbia, southeast Alaska, central Alaska, western Alaska, and Russia. Aggregate catch estimates were reasonable indicators of overall stock status, but in areas toward the southern extent of WKHLUUDQHRDWLRQVHFLFUHWUDQGHVFDHPHQWHVWLPDWHVDUHDVRQHHGHGEVKHUPDQDHUV6RFNHH abundance in Russia and western and central Alaska declined coincident with a regime shift in 1949. Declines DVRRFFUUHGLQWKHHDVWHUQ1RUWK3DFLFDWKRKWKHZHUHHVVHYHUHEQGDQFHLQFUHDVHVZHUHELTLWRV DURQGWKHWLPHRIWKHUHLPHVKLIWLQ6KRUWWHUPUHGFWLRQVLQDEQGDQFHLQZHVWHUQDVNDDQGDUWVRI FHQWUDDVNDIRRZHGWKHVKLIWEWZHUHQRWHYLGHQWLQ5VVLDRUWKHHDVWHUQ1RUWK3DFLF7KHVWDWVRI many North American stocks recently declined, with severest declines in southernmost areas. Trends in survival rate indices were similar to trends in catch and abundance. Average body size was inversely related to aggregate abundance, implying that growth was density-dependent. The coherence in trends in abundance, catch, and average weight among stocks suggests that large-scale environmental processes are major factors controlling VRFNHHVDPRQVUYLYDDQGURGFWLRQDURQGWKH1RUWK3DFLF5LPDQGUREDEUHVWULFWWKHWRWDURGFWLRQ from particular ocean zones. However, local-scale environmental processes can result in regional differences in productivity.

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INTRODUCTION

Trends in salmon abundance indices, including catch, as well as various biological characteristics, including body size and survival, have been used as indicators of climate change (Beamish and Bouillon 1993; Francis and Hare 1994; Hare and Francis 1995). These trends suggest that decadal-scale shifts in abundance of sockeye salmon (*Oncorhynchus nerka*) and other species of salmon have occurred over broad areas of the North Pacific Rim (Beamish and Bouillon 1993; Francis and Hare 1994; Hare and Francis 1995). Periods or regimes of intense winter-time Aleutian lows correlate with increased zooplankton abundance in the Subarctic Gyre (Francis and Hare 1994; Brodeur and Ware 1992). High productivity in the Subarctic Gyre during regimes of intense winter-time Aleutian lows appears to result from increased water column stability associated with reduced salinities and high precipitation that characterize these regimes (Gargett 1997).

Eleven of these regime shifts have occurred in the North Pacific Ocean since 1650 (Gedalof and Smith 2001), with recent shifts occurring in 1949, 1977, 1989 (Francis and Hare 1994; Hare and Mantua 2000; Beamish and Bouillon 1993), and possibly 1998 (Peterson and Schwing 2003). It is now widely accepted that these shifts are responsible for large changes in the abundance of many species of fish (Bakun and Broad 2002; Trites et al. 2007), including Pacific salmon.

Researchers (e.g. Beamish et al. 1999) have hypothesized that the North Pacific Ocean alternates between high and low salmon production regimes that are driven by decadal-scale changes. In 1949, there was a shift from a high to a low production regime (Francis and Hare 1994; Hare and Francis 1995; Beamish and Bouillon 1993); in 1977 conditions shifted back to a high production regime (Francis and Hare 1994; Hare and Francis 1995; Beamish and Bouillon 1993; Hare and Mantua 2000), and in 1989, back to a low production regime (Hare and Mantua 2000).

Catches of large aggregates of salmon vary in synchrony with oceanographic indices (Beamish and Bouillon 1993; Beamish et al. 1999; Beamish and Noakes 2002). In addition, decreases in salmon body size coincident with increases in salmon abundance and climatic changes have been widely observed (Bigler et al 1994; Helle and Hoffman 1998;

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Walker et al. 1998; Pyper and Peterman 1999). The spatial and temporal scale for these patterns of salmon abundance suggests climate forcing and bottom-up control of salmon abundance.

However, some researchers argue that local processes are more important than large-scale climate processes in determining the survival of salmon at sea (Pyper et al. 2001; Mueter et al. 2002a). Patterns of covariation in survival (i.e. from stock-recruit analysis) between Bristol Bay and Fraser River sockeye salmon stocks (Peterman et al. 1998) and among Washington, British Columbia and Alaska pink (*O. gorbuscha*), chum (*O. keta*), and sockeye salmon stocks (Pyper et al. 2005) are correlated on both local and regional spatial scales. Catches of northern and southern populations of salmon can be out of phase with each other (Hare et al. 1999).

In this review we examine trends and patterns of covariation of abundance (catch and escapement), survival, and body size for sockeye salmon stocks in the North Pacific. We consider the two competing hypotheses of salmon population regulation: 1, ocean basin-scale environmental processes control sockeye salmon production, and 2, local- and regional-scale environmental processes control sockeye salmon production. While others (e.g. Peterman et al 1998; Mueter et al 2002) have carried out similar analyses, our data set is much larger, both in terms of number of populations and the area covered.

METHODS

Data Sources

We examined spatial abundance patterns and biological characteristics for sockeye salmon populations in the following areas: Russia, Bristol Bay, Alaska Peninsula, south Alaska Peninsula, Chignik, Kodiak, Cook Inlet, Prince William Sound, southeast Alaska – northern British Columbia (BC), and southern BC – Washington (Fig. 1). Southeast Alaska and northern BC were combined because of the significant contribution of northern BC stocks to fisheries in southeast Alaska. Similarly, the southern BC and Washington areas were combined because sockeye salmon catches in Washington are primarily of Fraser River (southern BC) origin.

We evaluated two abundance estimates: retained commercial catch, and total run sizes (catch plus spawning escapement). We also examined trends in survival based on stock-recruit analysis of recruits from parental escapements when these data were available.

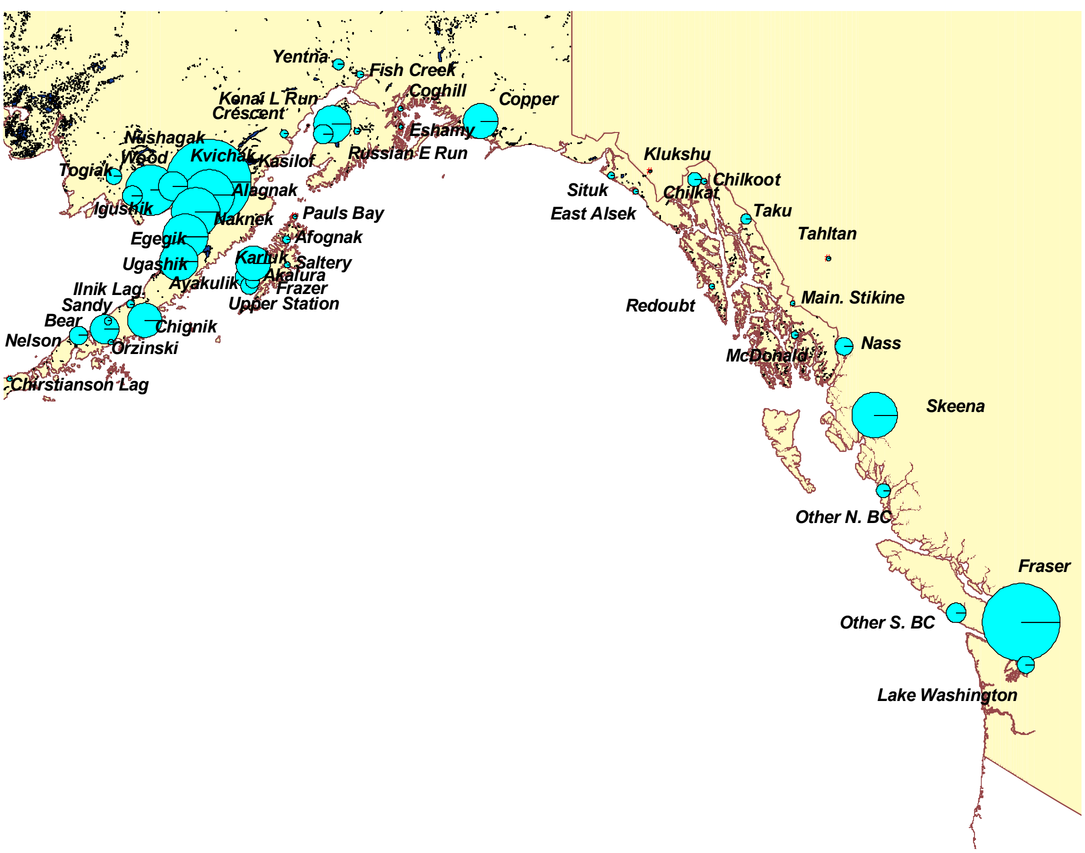


Fig. 1. Major stocks of sockeye salmon assessed in Alaska, B.C., and Washington. The size of the pie scaled to average escapement, 1996–2005.

Commercial Catch Data

Commercial catch of sockeye salmon by area were from Eggers et al. (2005), Alaska Department of Fish and Game catch records, and Fisheries and Oceans Canada (DFO) catch records (e.g. Irvine et al. 2006). Canadian data were partitioned into fish retained in commercial fisheries taking place north and south of the north end of Vancouver Island.

Escapement Data

Escapement data were assembled for each area, except that estimates were not available for Russia. In Bristol Bay, escapement has been assessed for essentially all of the sockeye-producing river systems since 1956 (Fair et al. 2004). In the Alaska Peninsula area, escapements have been estimated for most of the sockeye-producing river systems since the early 1970s (Nelson et al. 2005). In the Chignik area, escapements have been assessed annually since 1922 (Dahlberg 1968; Witteveen et al. 2005). In the Kodiak area, escapements have been estimated for three of the major systems since the 1920s, and in virtually all of the other sockeye-producing river systems since the late 1970s (Nelson et al. 2004). In the Cook Inlet area, assessment of sockeye escapement has been fairly complete since the late 1970s (Hasbrouck and Edmundson 2005). Only a portion of Susitna River (i.e., Yentna River) sockeye escapement is assessed. In Prince William Sound, the assessment of sockeye escapement is fairly complete with the exception of the Copper River Delta river systems that are incompletely assessed with aerial survey counts (Evenson et al 2005). Geiger et al. (2005) describe escapement programs in southeast Alaska.

Escapements are estimated annually for many British Columbia sockeye populations although methods vary, as do the numbers of systems evaluated annually. We obtained data from DFO's escapement database (nuSEDs) and aggregated estimates for systems north of the northern tip of Vancouver Island separately from data for systems to the south that included the Fraser River. From 1950–2004, 75–195 sockeye systems were assessed annually in northern BC (excluding transboundary rivers), and 48–290 systems in southern BC.

Run Sizes

Run sizes for each area were estimated as the sum of escapements and commercial catches in the area. Run size estimates will be biased low when non-commercial (i.e. recreational and aboriginal) fisheries occur.

Stock Recruit Data

Stock-recruit data from brood tables based on age-specific total runs (catch plus escapement) were assembled for 32 sockeye salmon stocks (Appendix 1). Fewer stocks had stock-recruit data than escapement data because stock and age-specific catch estimates are not available for many stocks. We restricted our analysis to those stocks that had a time series of spawner numbers that we judged had been estimated with reasonable precision. Except for Russia, there were at least two stocks with stock-recruit data from each area. To avoid errors in catch allocations implicit in the individual river system (population) brood tables, we pooled these data for those populations common to major commercial fisheries. For instance, in Bristol Bay we analyzed data for 3 stocks (Togiak; Nushagak District (pooled brood tables for Wood, Igushik, and Nushagak); and Eastside Districts (pooled brood tables of Kvichak, Alagnak, Naknek, Egegik, and Ugashik (Appendix 1; Fair et al. 2004). We analyzed data for 2 stocks in the Alaska Peninsula area (Bear River late-run, and Nelson Lagoon (Nelson et al. 2005)), 2 stocks in the Chignik area (Chignik early-run, Chignik late-run (Witteveen et al. 2005)), 4 stocks in the Kodiak area (Ayakulik, Upper Station early-run, Upper Station late-run, Karluk combined-run, and Frazer (Nelson et al. 2004)), 4 stocks in the Cook Inlet area (Kenai late-run, Russian R early-run, Kasilof, and Crescent (Hasbrouck and Edmondson 2005)), 3 stocks in the Prince William Sound area (Eshamy, Coghill, Copper (Evenson 2002; Evenson et al. 2005)), 9 stocks in southeast Alaska – northern British Columbia (Situk, Italio, Klukshu, East Alsek, Chilkat, Chilkoot, Redoubt, Nass, Skeena (Geiger et al. 2005; DFO, Nanaimo, BC, unpublished data)) and 5 stocks in the Fraser River watershed (Birkenhead, early Stuart, early Summers, Summers, and late Summers (Schubert 1998)).

As previously mentioned, methods to estimate escapements vary (Appendix 1). Visual surveys from towers are the predominant method in Bristol Bay; weirs are commonly used in the Alaska Peninsula, Chignik, and Kodiak. Weirs and sonar are the most common techniques in Cook Inlet and Prince William Sound while aerial visual surveys, mark-recapture, and weirs are common in southeast Alaska.

Within Canada, in the Nass fishwheel (formerly gillnet) test fishery catches are calibrated with sockeye counts at a fishway below Meziadin Lake (Link and Peterman 1998). In smaller Nass tributaries, visual survey estimates are expanded using the area-under-the-curve method (Levy 2006). In the Skeena, a test fishery in the lower river is calibrated with fence counts at Babine Lake (DFO 1999). Visual surveys are carried out in various Skeena tributaries and a weir is maintained on the Sustut. In the Fraser, the method used depends on the anticipated size of the run, and since populations can have strong and weaker cycle lines, methods for some systems vary among years. For most of the time series, when anticipated escapements were less than 25,000, estimates were usually generated by visual surveys and when anticipated escapements exceeded 25,000, estimates were made using counting fences (weirs) and mark-recapture (Schubert 1998). Appendix 1 lists the Fraser escapement estimation methods used in 2004 (K. Benner, Fisheries and Oceans Canada, 985 McGill Place, Kamloops BC V2C 6X2, pers. comm.). Fraser stock groups (Birkenhead, early Stuart, early Summers, Summers, and late Summers) are separated primarily based on run timing. Fraser visual survey estimates usually are indexed peak live counts plus cumulative dead and carcass counts and are generally complete.

Catch Weight Data

Average weight of sockeye salmon in the catch by area was based on the reported catch in weight divided by the reported catch in numbers of fish. Data for the Alaskan areas, 1960 to 1966 were from INPFC (1979), 1977–2004 data were from Alaska Department of Fish and Game catch records. Data for northern and southern British Columbia, 1960–2004 were the reported catch in weight from purse seine gear divided by the reported catch in numbers from purse seine gear from DFO catch records.

Statistical Analyses

Using methods in Peterman et al. (1998), we calculated indices of survival for the 32 stocks with stock recruit data after normalizing the data and removing possible within-stock density dependence. We fit the Ricker stock recruit model (Ricker 1975) to each data set by maximum likelihood with lognormal process error (Microsoft Excel Solver). The index of survival was the time series of brood-year residuals (i.e., ln(observed recruits/predicted recruits)) with predicted recruits based on the fitted Ricker stock-recruit model.

We tested for trends in catch time series by area, abundance (commercial catch plus escapement) by area, survival rate index by stock, and catch weights by area. To evaluate spatial coherence, we computed correlations among areas and stocks for the time series.

Many of these time series were highly auto-correlated. Here the test of significance of the correlation coefficient would have a type one error rate greater than the assumed alpha. To correct for the tendency of two auto-correlated time series to appear correlated, we used the method outlined in Peterman et al. (1998) (who cited results of Pyper and Peterman (1998)) to adjust the degrees of freedom in all our tests of significance for correlation coefficients.

To improve the ease of visually interpreting time series plots, we computed running averages over the average lifespan of the fish (4 years for southern BC and 5 years for the rest). This procedure reduces year-to-year fluctuations in abundance that may have little influence on overall population status.

RESULTS

Catch

Sockeye salmon occur throughout the North Pacific Rim, from west Kamchatka on the west to the Columbia River in the southeast (Fig. 1). The largest runs are in the Bristol Bay area (Appendix 1), with the recent 10-year average Bristol Bay catch of 21 million, which is roughly 40% of the North Pacific total. The recent 10-year average catch and proportion of the North Pacific is 5.8 million and 11% for Russia, 3.8 million and 7.1% for the Alaska Peninsula, 1.5 million and 2.8% for Chignik, 3.5 million and 6.8% for Kodiak, 3.3 million and 4.4% for Cook Inlet, 2.3 million and 4.4% for Prince William Sound, 3.7 million and 7% for southeast Alaska – northern BC, and 2.2 million and 4.1% for southern BC - Washington.

Catches in western Alaska (Bristol Bay and Alaska Peninsula) from the 1920s to the late 1940s fluctuated with no discernible trend, then remained relatively low until the early 1970s (Fig. 2). Catches increased rapidly following the 1977 regime shift and subsequently declined in the late 1990s. The pattern of sockeye catch in Russia was similar, except the increase from the early 1970s lows was moderate and delayed relative to catches in western Alaska, and there was no indication of reduced Russian catches in the 1990s.

The pattern of catch in all central Alaska areas was similar to that of western Alaska. For the Chignik, Kodiak, and Cook Inlet areas, declines in catch occurred during the 1990s, similar to those observed in western Alaska (Fig. 2). No decline in catch in the 1990s occurred in Prince William Sound.

Sockeye salmon catches in the eastern North Pacific Alaska, 1925–1950, were compiled for southeast Alaska and combined BC and Washington State areas. Thereafter, catches were compiled for combined southeast Alaska and northern BC and for the combined southern BC and Washington State. Southeast Alaska catches declined around the time of the 1949 regime shift while BC and Washington catches were relatively constant until the late 1970s (Fig. 2). Catches subsequently increased until the mid-1990s after which they declined precipitously.

We examined patterns of co-variation of salmon catches among the 9 areas using correlation analysis. There was strong positive correlation in sockeye salmon catch among the areas (mean correlation = .433) with 35 of 36 possible 2-way correlations being positive and 15 being significant ($\alpha = 0.10$) (Table 1). Correlations were generally the highest for adjacent areas, and decreased with increasing distance, indicating substantial spatial coherence in catches.

Body Size

Trends in body size (average weight) were similar in many areas (Fig. 3). Size increases were common from the 1960s through the late 1970s, followed by decreases during the early 1990s, and increases during the last decade (Fig. 3). Exceptions to this general pattern included sockeye from southern BC that exhibited little discernible temporal pattern other than a short-lived decrease in size in the early 1990s, and sockeye from Bristol Bay, the Alaska Peninsula, south-

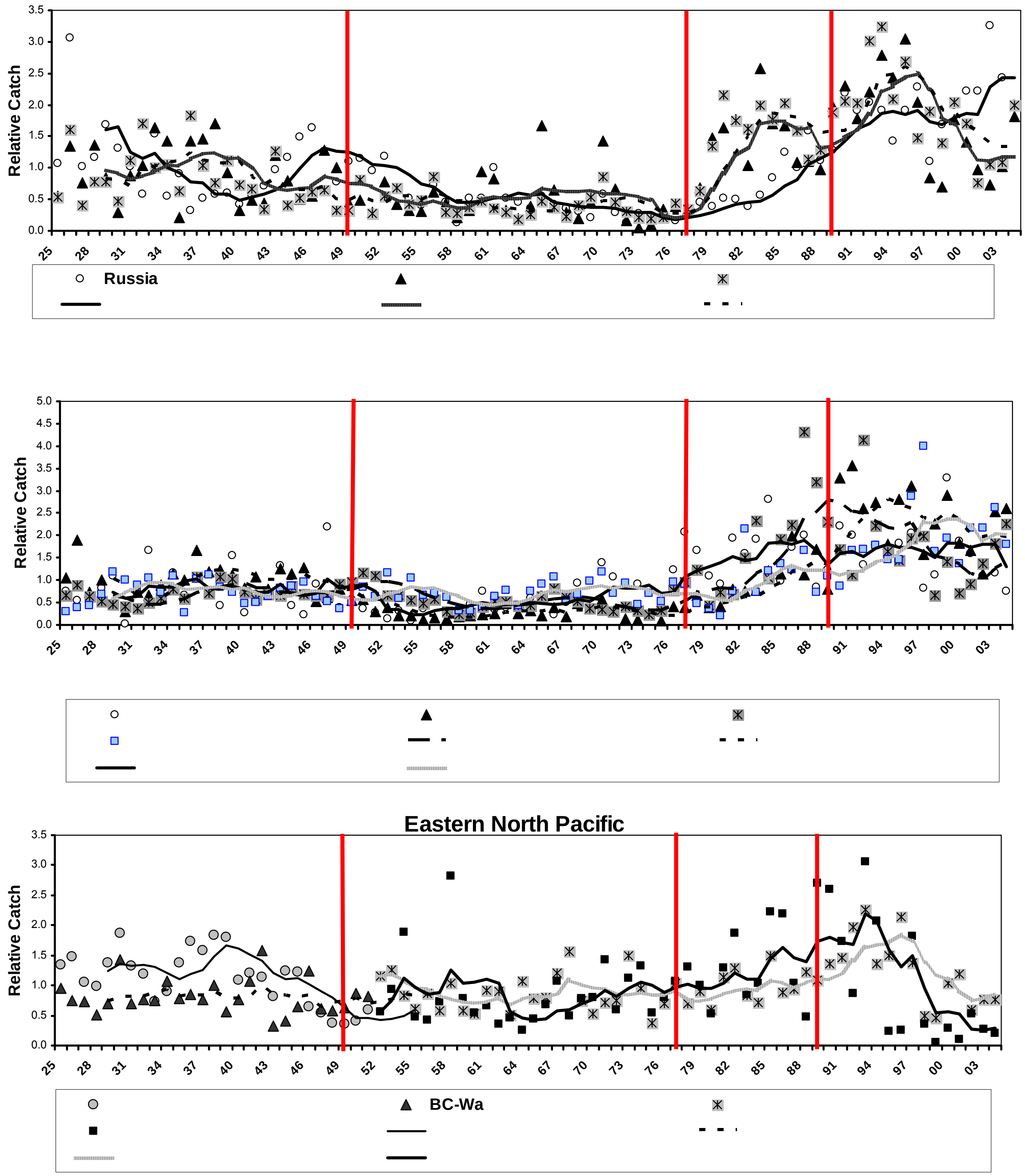


Fig. 2. Historical trends in sockeye salmon catch by area. Catches are in numbers scaled to historical averages. Vertical lines at 1949, 1977, and 1989 separate the regimes.

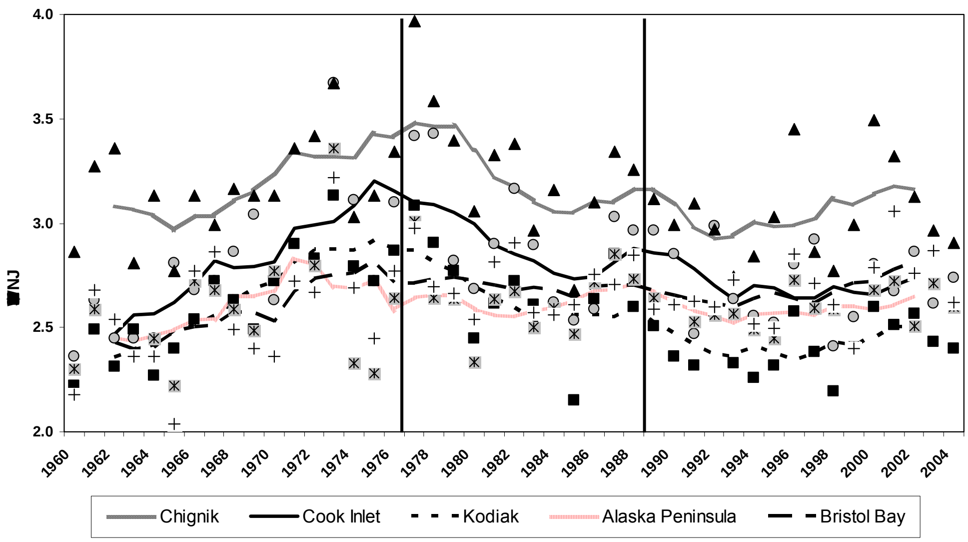
east Alaska and northern British Columbia where sizes have been relatively constant since the late 1970s.

In Bristol Bay and the Alaska Peninsula, significant stock-specific variations in age-at-maturity occur. In Bristol Bay, Kvichak River salmon are the dominant population that returns primarily at ocean age 2 (.2). Because of the cyclic nature of Bristol Bay runs, this masks trends in average size. Estimates of the mean length of the major ages-classes in the Bristol Bay total run are available (West and Fair 2006). There appeared to be minor length increases for each age-class from the mid 1950s through the late 1970s, then decreases through the early 1990s, followed by increases commencing in the early 1990s (Fig. 4). These patterns appeared most pronounced for ocean age-two classes (Fig. 4).

We examined the patterns of co-variation in body size among the nine areas. There was a strong positive correlation in sockeye salmon body size among the areas (mean correlation = .433) with 36 of 36 possible 2-way correlations

Table 1. [illegible] α α α α α ≤ 0.10 are lightly shaded.

	Russia	Bristol Bay	Alaska Peninsula	Chignik	Kodiak	Cook Inlet	Prince William Sound	SE Alaska - N. British Columbia	S. British Columbia - Washington
Russia	1								
Bristol Bay	0.459	1							
Alaska Peninsula	0.498	0.848	1						
Chignik	0.331	0.603	0.614	1					
Kodiak	0.714	0.667	0.738	0.565	1				
Cook Inlet	0.444	0.603	0.622	0.413	0.563	1			
Prince William Sound	0.516	0.356	0.492	0.391	0.586	0.498	1		
SE Alaska N. British Columbia	0.325	0.428	0.486	0.235	0.461	0.430	0.358	1	
S. British Columbia Washington	-0.057	0.224	0.307	0.138	0.106	0.205	0.026	0.379	1



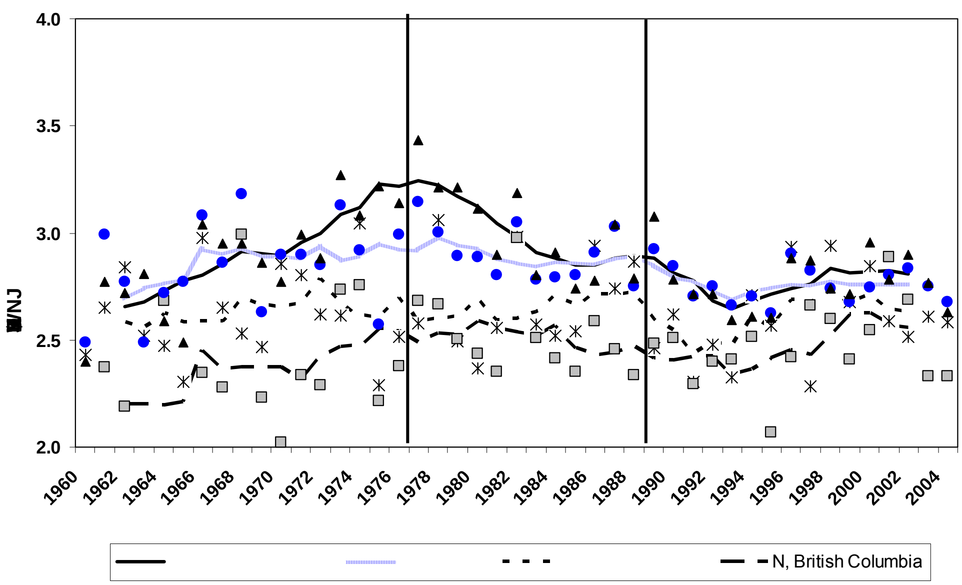


Fig. 3. Average body size and trend of sockeye salmon in the commercial catch, 1960–2004. Upper panel shows trends for Chignik, Cook Inlet, Kodiak, Alaska Peninsula and Bristol Bay areas. Lower panel shows trends for Prince William Sound, southeast Alaska, southern British Columbia, and northern British Columbia areas. Vertical lines at 1949, 1977, and 1989 separate the regimes.

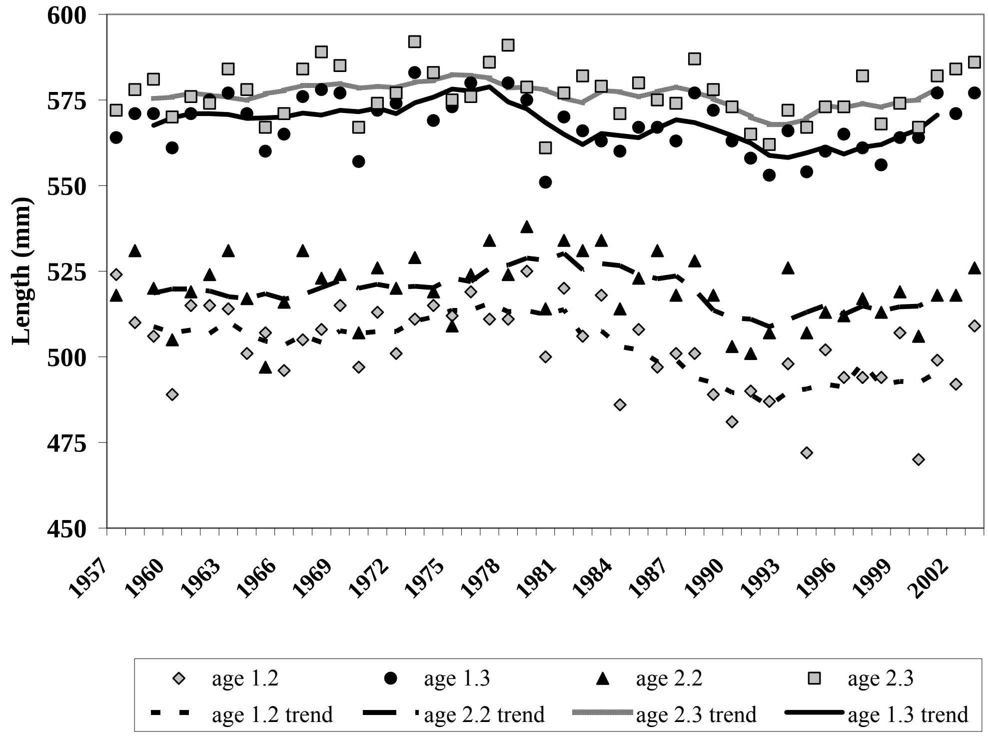


Fig. 4. Average body length and trend for returning Bristol Bay sockeye salmon, 1957– 2003.

Table 2.3[illegible] α α α α α
at α = 0.10 are lightly shaded.

	Year	6RWKHUQ BC	Northern BC	6(Alaska	Prince William 6RQG	Cook Inlet	Kodiak	Chignik	Alaska Peninsula	Bristol Bay
Year	1.000									
6RWKHUQ%&	0.005	1.000								
Northern BC	0.304	0.256	1.000							
6(DVND	-0.165	0.381	0.599	1.000						
3ULQFH:LOOLDP6RQG	-0.124	0.205	0.436	0.658	1.000					
Cook Inlet	-0.032	0.161	0.462	0.625	0.711	1.000				
Kodiak	-0.238	0.277	0.280	0.637	0.798	0.773	1.000			
Chignik	-0.150	0.327	0.360	0.600	0.693	0.621	0.762	1.000		
Alaska Peninsula	0.094	0.328	0.366	0.631	0.472	0.559	0.623	0.667	1.000	
Bristol Bay	0.332	0.333	0.566	0.536	0.542	0.516	0.515	0.565	0.771	1.000

being positive and 34 being signi f cant (α = 0.10) (Table 2). The highest correlations were among adjacent areas, with correlations decreasing with increasing distance. Body size in southern British Columbia showed the least coherence with other areas (Table 2).

Abundance

In Bristol Bay escapements generally co-varied with total runs until the early 1980s (Fig. 5). Since then, escapements have been relatively constant, a result of the constant escapement harvest policy under which the f sheries have been managed. Total runs for Bristol Bay sockeye salmon increased after the 1977 regime shift (Fig. 4) but not to the extent that catch increased. This is due to the relatively greater exploitation of large runs that have occurred in Bristol Bay since the late 1970s. Total runs declined in the late 1990s but are still large relative to those prior to the late 1970s (Fig. 5).

Trends in total runs and escapements of sockeye salmon in the northern Alaska Peninsula area are similar to that of Bristol Bay. Escapements co-varied with total runs before

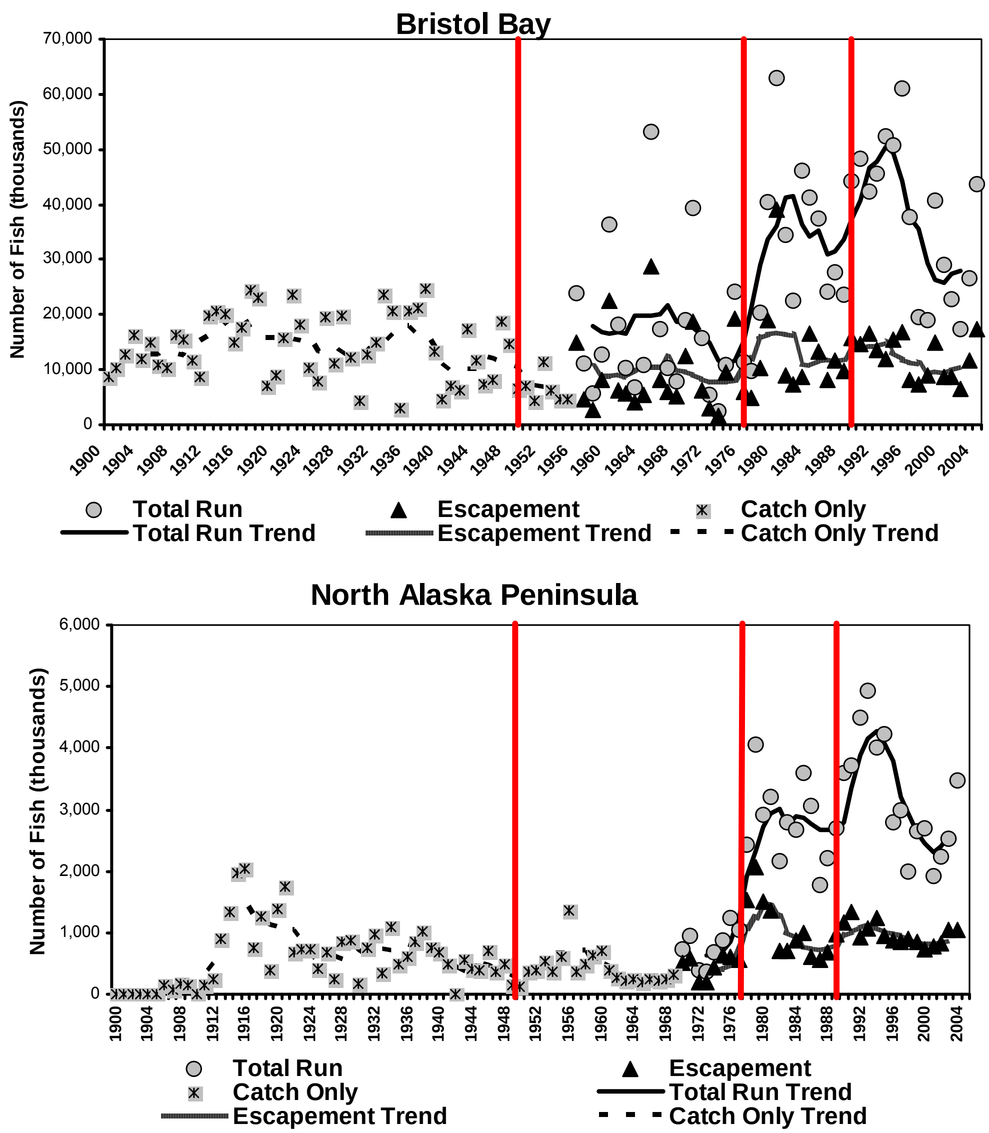


Fig. 5. Trends in total run (catch + escapement), escapement, and catch (prior to 1956) of sockeye salmon in Bristol Bay (upper panel). Trends in total run (catch + escapement), escapement, and catch (prior to 1970) of sockeye salmon in the northern Alaska Peninsula (lower panel). Vertical lines at 1949, 1977, and 1989 separate the regimes.

the early 1980s and have been relatively constant since (Fig. 5). The relative increase in north Alaska Peninsula sockeye salmon runs appears to be greater than that of Bristol Bay; however, escapements were not monitored prior to 1970.

Chignik River escapements also fuctuated with catch until the early 1980s, and have been relatively constant since (Fig. 5). Escapements were much more variable during the period of federal management before the State of Alaska took over management in 1960. With state management, and timely escapement with the Chignik weir close to the fshery, managers have been able to effectively control fshing and to consistently achieve escapement targets in the Chignik fshery. After 1960, escapements were more stable, and generally increased with the increasing runs through the 1970s. With the larger runs since the late 1970s, escapements have been maintained at maximum sustained yield levels. Total runs of sockeye salmon to the Chignik areas decreased after the 1949 regime shift, and increased after the 1977 regime shift. Total runs were consistently high after 1977 (Fig. 6).

Escapements of sockeye salmon in the Kodiak area have been partially monitored since the 1920s, with the establishment of counting weirs on the Karluk, Akalura, and Ayakulik river systems. In the 1960s counting weirs were also established on the Upper Station and Frazer River systems. In the late 1970s, counting weirs were established on several minor river systems. Sockeye salmon escapement monitoring has been complete since the late 1970s; however a large portion of the escapement is from river systems which have been monitored since the 1920s. As with the other areas in western and central Alaska, escapements fuctuated with

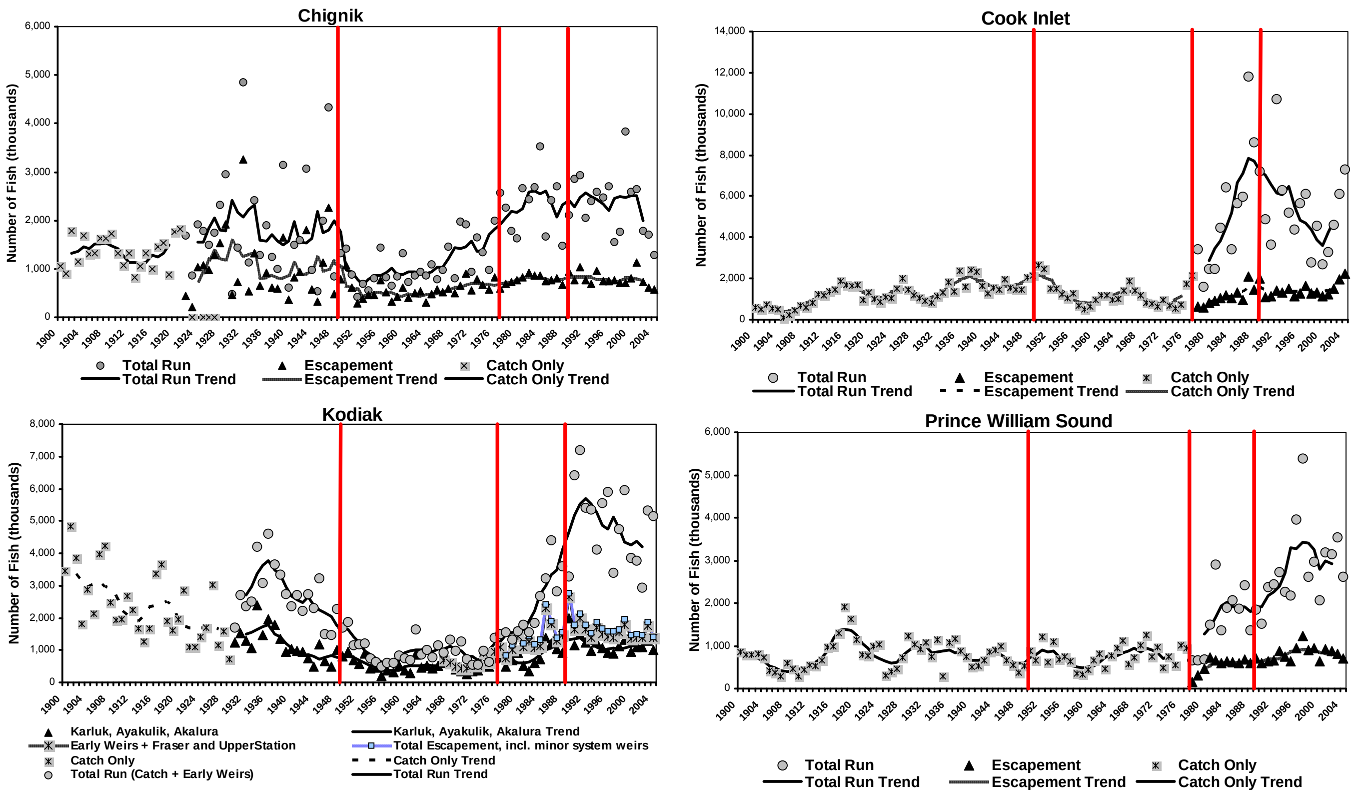


Fig. 6. Trends in total run (catch + escapement), escapement, and catch only (prior to 1922) of sockeye salmon in the Chignik Area (upper left panel). Trends in total run (catch + escapements), escapement, and catch only (prior to 1930) of sockeye salmon in the Kodiak Area (lower left panel). Trends in total run (catch + escapements), escapement, and catch only (prior to 1930) of sockeye salmon in the Cook Inlet Area (upper ULKWDQHDQG3ULQFH:LLDP6RQGUHDRZHUULKWDQH9HUWLFDLQHVDWDQGVHDUDWHWKHUHLPHV

catch until the early 1980s, and since have been relatively stable. Total runs of sockeye salmon to the Kokiak area decreased after the 1949 regime shift, and increased after the 1977 regime shift. Total runs to the Kodiak area increased coincident with the 1989 regime shift (Fig. 6).

Sockeye salmon escapements in Cook Inlet have been monitored since the late 1970s with establishment of sonar counting on the Kenai, Kasilof, Crescent, and Yentna river systems. Escapement monitoring is relatively complete, except that some sockeye salmon stocks in the Susitna River system are unmonitored. Sockeye salmon escapements in Cook Inlet have been relatively stable (Fig. 6). Total runs of sockeye salmon to Cook Inlet increased coincident with the 1977 regime shift and have continued at high levels since the mid 1980s.

Sockeye salmon escapements in Prince William Sound (except for small stocks in the Copper River delta) area have been monitored since the late 1980s with the establishment of sonar counting on the Copper River, and counting weirs on the Eshamy and Coghill rivers. Escapements have been relatively stable during this period (Fig. 6). Total runs of sockeye salmon to the Prince William Sound area increased coincident with the 1977 regime shift and have remained high since the mid 1980s.

Aggregate sockeye salmon escapements in northern BC, since 1950, are shown in Fig. 7. Most of the sockeye salmon in northern British Columbia are from the Nass and Skeena river systems (Appendix 1). Escapements trended upwards slightly from the 1950s to the mid 1980s, and subsequently declined. Sockeye salmon escapements from southeast Alaska, including transboundary rivers (i.e., Alsek, Taku, and Stikine) have been available since early 1980s. The combined escapement from the northern British Columbia and southeast Alaska areas has been decreasing since the mid 1980s. Total combined runs to southeastern Alaska/northern BC were relatively stable from the 1950s through the late 1970s, increased slightly through the mid 1990s, and have since decreased.

Aggregate sockeye salmon escapements in southern BC (Fig. 7) consist largely of Fraser River fsh (Appendix 1). Escapements were relatively stable from the 1950s to the early 1980s. Escapements increased through the early 1990s as did total run sizes. Aggregate escapements in southern BC remained relatively high during the most recent decade in spite of reduced catches (Fig. 5) and consequently total run sizes (Fig. 7). Escapement estimates were signifcantly positively correlated with the numbers of streams surveyed in both northern and southern BC.

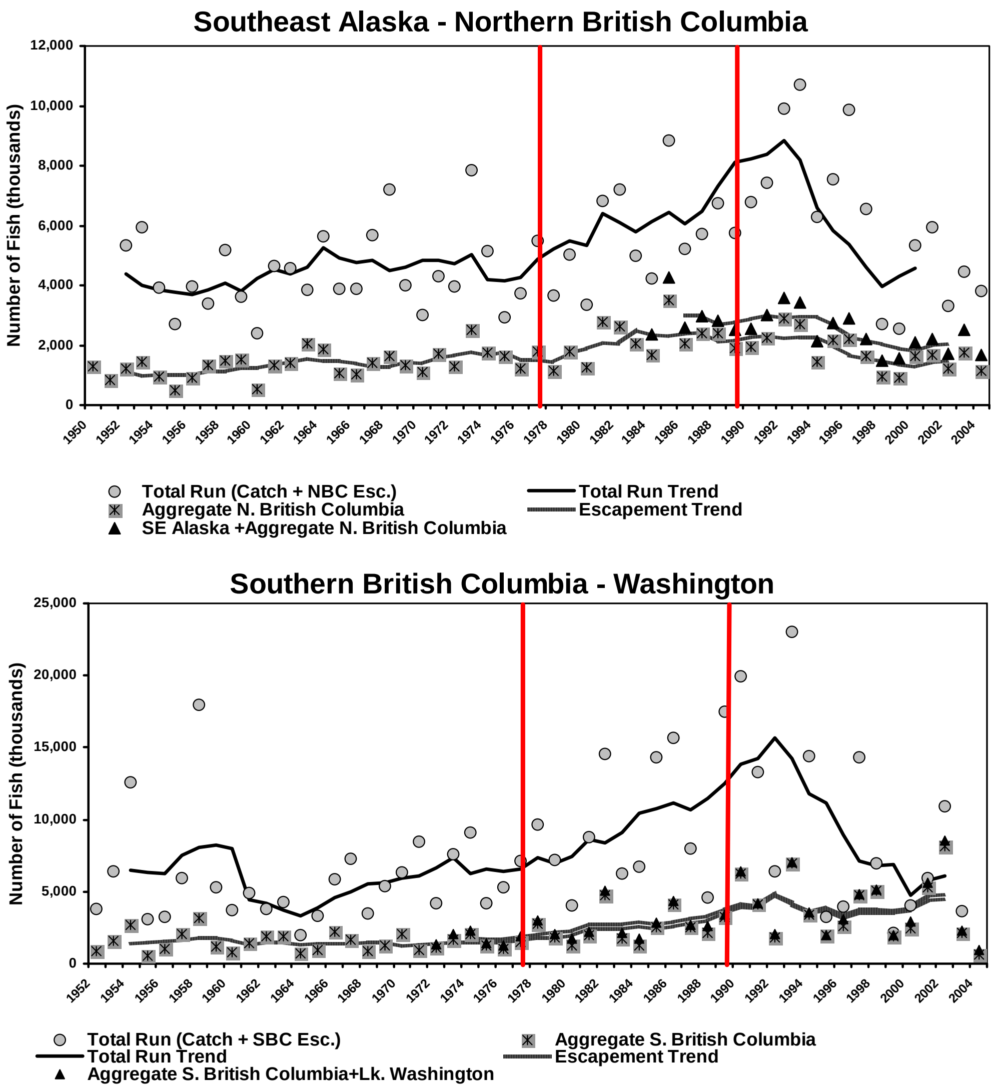


Fig. 7. Trends in total run (catch + northern British Columbia escapement) and escapement of sockeye salmon in the southeast Alaska – northern British Columbia area (upper panel). Trends in total run (catch + southern British Columbia escapement) and escapement of sockeye salmon in the southern British Columbia – Washington area (lower panel). Vertical lines at 1949, 1977, and 1989 separate the regimes.

Although the period of escapement monitoring varies by areas, monitoring has been continuous once the escapement assessment programs were implemented. Correlations of catch and escapement as well as catch abundance were examined to test whether or not catch is a good surrogate for abundance for these areas. Catch and total run were highly correlated in all areas. Catch and escapement were also highly correlated, less so than catch and total run (Table 3). Sockeye catch appears to be a reasonable surrogate for abundance, at least at the level of population aggregation we looked at here.

We also examined patterns of co-variation of salmon abundance (i.e. total run) among the 8 areas using correlation analysis. There was generally positive correlation in sockeye salmon abundance among the areas (mean correlation = .24) with 22 of 28 possible 2-way correlations being positive and 13 being signifcant (α = 0.10) (Table 4). Correlations were highest for adjacent areas, and decreased with increasing distance. This indicated substantial spatial coherence in sockeye salmon total runs. Note that the high auto-correlation in the catch time series contributed to the high correlations.

Survival Indices

Trends in survival indices were examined for 34 stocks of sockeye salmon relative to the 1949, 1977, and 1989 regime shifts (Table 5). If the ocean basin-scale hypothesis is true, survival indices should be highly correlated among stocks, consistently high during the pre-1949 regime (regime 1), consistently low during the 1949 to 1977 regime (regime 2), consistently high during the 1977 to 1989 regime (regime

Table 3. Correlation of catch to escapement, and catch to total run, for areas from Bristol Bay to southern British Columbia/Washington. Cor-UHDWLRQ FRHIILFLHQWV WKDW DUH VWDWLVWLFDOO\ VLJQLILFDQW DW α α α α = 0.10 are lightly shaded.

	Years	Catch - Escapement	Catch - Total Run
Bristol Bay	56–04	0.497	0.927
North Alaska Peninsula	70–04	0.481	0.962
Chignik	22–04	0.384	0.888
Kodiak	30–04	0.524	0.974
Cook Inlet	78–04	0.578	0.991
3ULQFH :LOOLDP 6RXQG	78–04	0.844	0.994
6RXWKHDVW $ODVND 1 %ULWLVK &ROXPELD	85–04	0.722	0.979
6 %ULWLVK &ROXPELD :DVKLQJWRQ	72–03	0.388	0.950

Table 4. [illegible] α α α α = 0.10 are lightly shaded.

	Bristol Bay	Alaska Peninsula	Chignik	Kodiak	Cook Inlet	Prince William 6RXQG	6(DVND - N. British Columbia	6%ULWLVK Columbia - Washington
Bristol Bay	1							
Alaska Peninsula	0.775	1						
Chignik	0.513	0.340	1					
Kodiak	0.554	0.677	0.457	1				
Cook Inlet	-0.014	0.024	-0.163	0.210	1			
3ULQFH :LOOLDP 6RXQG	-0.347	-0.129	-0.031	0.403	0.223	1		
6(DVND 1 %ULWLVK &ROXPELD	0.460	0.653	-0.048	0.260	0.313	0.017	1	
6 %ULWLVK &ROXPELD :DVKLQJWRQ	0.177	0.402	0.091	0.210	0.211	0.147	0.330	1

3), and consistently low during the post-1989 regime (regime 4).

Trends in survival rate indices were highly consistent with the 1949 and 1977 regime shifts, and marginally consistent with the 1989 regime shift (Table 5). Although stock-recruit data transcending the 1949 regime shift were limited, there was a significant decrease in average survival after the 1949 regime shift for the three stocks where data were available. There also were significant increases in mean survival following the 1977 shift. Of 20 stocks with stock-recruit data transcending the 1977 regime shift, 19 of these showed an increase in survival with 14 showing a significant increase (Table 5). There were 34 stocks with stock recruit data transcending the 1989 regime shift; here 22 stocks showed a decrease in survival with 12 showing a significant decrease. Decreases in survivals were greatest for stocks in the eastern north Pacific areas.

For western Alaska stocks, survival indices increased significantly with the 1977 regime shift for 3 out of 3 stocks; however there was little change in survival with the 1989 regime shift (Fig. 8, Table 5). A significant decline in survival index was observed only for 1 (the eastside Bristol Bay river systems) out of 5 stocks.

For the Chignik and Kodiak areas there was a significant decrease in survival index following the 1949 regime shift for 3 of 3 stocks (Fig. 9, Table 5); a significant increase in survival following the 1977 regime shift for 5 of 7 stocks (Fig. 8, Table 5); and little change in survival following the 1989 regime shift with a decline in survival observed for 1 (Upper Station late-run) of 7 stocks.

For the Cook Inlet and Prince William Sound areas there were limited survival indices for the period preceding the 1977 regime shift. Survival indices increased with the 1977 regime shift for 4 of 4 stocks (Fig. 10, Table 5), however these were not statistically significant. Survival rates generally decreased for Cook Inlet and Prince William Sound sockeye stocks following the 1989 regime shift (Table 4) with 3 of 6 stocks showing significant decreases in survival.

For southeast Alaska sockeye stocks, there were no survival indices for the pre-1977 regime; however survival rates decreased for all but one southeast Alaska sockeye stock with 3 stocks showing a significant decrease following the 1989 regime shift (Table 5).

For northern British Columbia and Fraser River sockeye stocks, survival generally increased following the 1977 regime shift with 3 of 5 stocks showing significant increases (Fig. 11). Survival rates decreased following the 1989 regime shift for all British Columbia stocks, with 3 of 6 stocks

Table 5. Changes in mean survival index at various regimes at the 1949 regime shift (47 brood year (BY)), at the 1977 regime shift (74 BY), and 1989 (88 BY) for various stocks of sockeye salmon. Differences in mean survival rate indices (based on 2 sample mean difference tests) that DUHVWDWLVWLFDOO\VLJQLILFDQWDW α α α α = 0.10 are lightly shaded. α α

		1949 (47 BY) 5HLPH6KLIW		%5HLPH6KLIW		1989 (88 BY) 5HLPH6KLIW	
6WRFN	Area	Change in 0HDQ6XUYLYD Rate Index	*p*-value	Change in 0HDQ6XUYLYD Rate Index	*p*-value	Change in 0HDQ6XUYLYD Rate Index	*p*-value
Togiak. R.	Bristol Bay			0.380	**0.037**	0.001	0.998
Nushagak Districts.	Bristol Bay			0.602	**0.002**	0.077	0.846
Eastside Districts	Bristol Bay			0.748	**0.000**	-0.394	**0.017**
Bear R. Late	N. Ak. Pen.					-0.012	0.483
Nelson R.	N. Ak. Pen.					0.118	0.758
Chignik R. Early	Chignik	-0.599	**0.008**	0.634	**0.003**	0.094	0.821
Chignik R. Late	Chignik	-0.356	**0.003**	0.463	**0.000**	-0.100	0.239
Ayakulik R.	Kodiak			0.406	**0.073**	-0.408	**0.081**
86WDWR5QD	Kodiak			0.903	**0.002**	-0.042	0.434
8HU6WDWLRQ5/DWH	Kodiak			0.762	**0.003**	-0.727	**0.002**
Frazer R.	Kodiak			0.507	**0.089**	0.157	0.852
Karluk R.	Kodiak	-0.448	**0.002**	0.401	**0.061**	0.069	0.894
Kenai Late	Cook Inlet			0.138	0.271	-0.377	**0.042**
Russian R. Early	Cook Inlet			0.314	0.227	0.046	0.934
Kasilof R.	Cook Inlet					-0.239	**0.027**
Crescent R.	Cook Inlet					-0.450	**0.025**
Copper R.	3ULQFH:LLDP6RQG			0.391	**0.058**	0.235	0.596
Cognill R.	3ULQFH:LLDP6RQG			0.443	0.145	-0.611	0.105
6LWN5	6(Nt1%					0.005	0.987
Italio R.	6(Nt1%					-0.427	0.131
Klukshu R.	6(Nt1%					-0.386	**0.028**
East Alsek R.	6(Nt1%					-0.602	**0.022**
Chilkat R.	6(Nt1%					0.457	0.528
Chilkoot R.	6(Nt1%					-1.467	**0.002**
Redoubt L.	6(Nt1%					-0.698	0.126
Nass R.	6(Nt1%					-0.087	0.308
6NHHQD5	6(Nt1%			0.162	0.229	-0.170	0.334
Birkenhead	6%			0.392	**0.036**	-1.090	**0.005**
6WDW	**6%**			-0.465	0.515	-0.665	**0.015**
6RPH	**6%**			0.063	0.338	-0.228	0.107
)UDVHU/DWH6PPHU	6%			0.275	**0.068**	-0.143	0.307
)UDVHU6PPHU	6%			0.358	**0.020**	-0.504	**0.020**

showing a significant decrease (Table 5)

Our examination of patterns of co-variation in survival rate indices among the 34 stocks of sockeye salmon was similar to and used methods of Peterman et al (1998); however, we examined more sockeye salmon stocks distributed throughout Alaska and British Columbia. We found strong positive correlations in survival rate indices among Bristol Bay stocks (mean correlation = 0.584) with 3 of 3 possible 2-way correlations for the 3 stocks within Bristol Bay being significantly (α = 0.10) positive (Table 6). There were also strong positive correlations in survival rate indices among Fraser River stocks (mean correlation = 0.391) with 10 of 10 possible 2-way correlations for the 5 stocks within the Fraser being significantly positive. There was strong significant positive correlation (correlation = 0.410) in survival rate index for the two stocks in the Chignik area (Table 6).

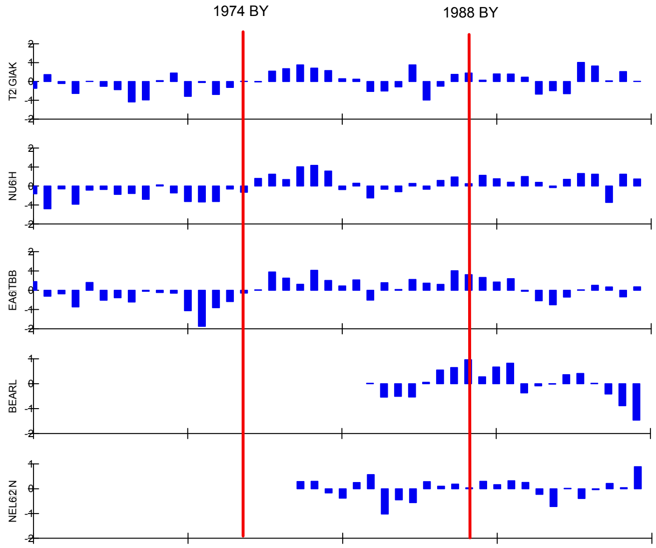


Fig. 8. Time series of standardized survival index for stocks in western Alaska, including Togiak R., Nushagak District, Eastside Bristol Bay Districts, Bear R., and Nelson R. Vertical lines separate the brood years affected by the 1977 and 1989 regime shifts. BY = brood year.

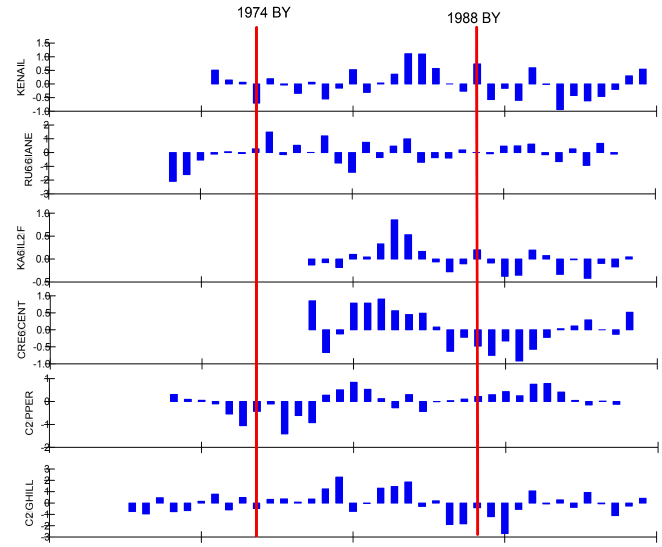


Fig. 10. Time series of standardized survival index to stocks in the RRN,QHWDQG3ULQFH:LOOLDP6RXQGDUHDVLQFOXGLQJ.HQDL5ODWH run, Russian R. early-run, Kasilof R., Crescent R., Copper R., and Coghill R. Vertical lines separate the brood years (BY) affected by the 1977 and 1989 regime shifts.

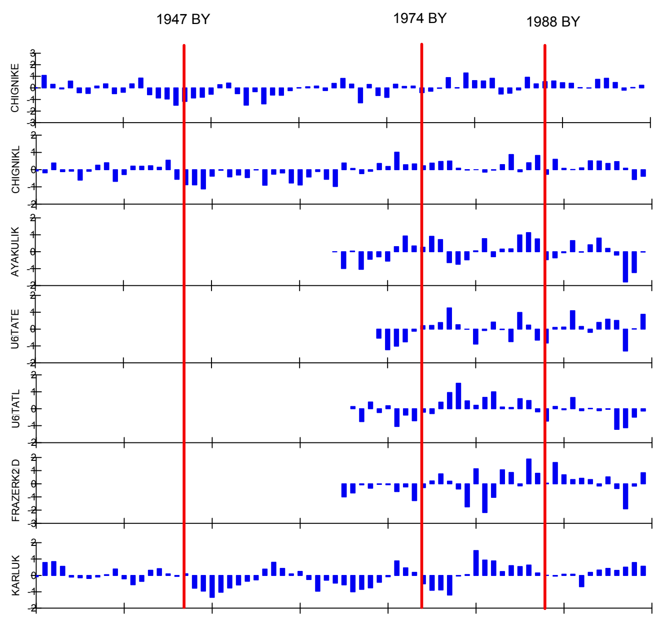


Fig. 9. Time series of standardized survival index to stocks in the Chignik and Kodiak areas, including Chignik early-run, Chignik late-UQDNN5&8HU6WDWLRQHDUUQ8HU6WDWLRQDWHUQ Frazer R., and Karluk R. Vertical lines separate the brood years affected by the 1977 and 1989 regime shifts. BY = brood year.

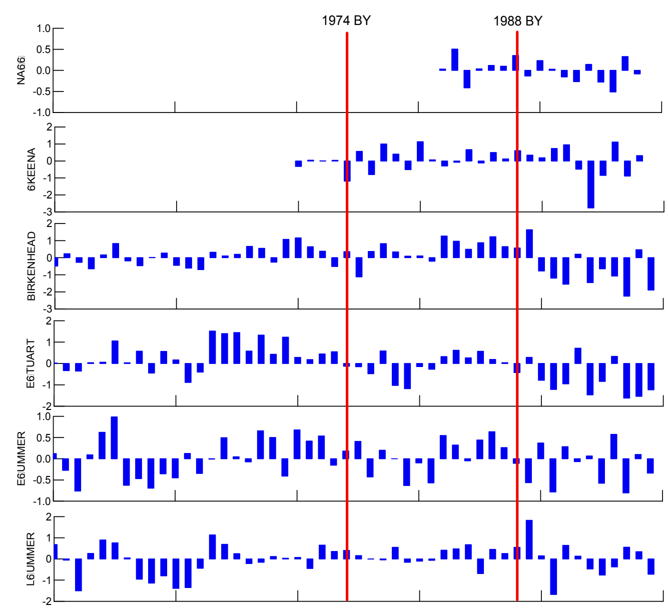


Fig. 11. Time series of standardized survival index to stocks in the %ULWLVKRPELDDUHDLQFOXGLQ1DVV56NHHQD5%LUNHQKHDG HDU6WDUW)UDVHU5LYHUHDUVXPPHUUQDQG)UDVHU5DWHVXP mer-run. Vertical lines separate the brood years (BY) affected by the 1977 and 1989 regime shifts.

For the other areas, patterns of co-variation in survival among sockeye salmon stocks within the area were generally positive; however considerably weaker than for stocks within the Bristol Bay, Fraser River, and Chignik areas (Table 6). For stocks within the Alaska Peninsula there was positive correlation (mean correlation = 0.19) with 3 of 3 possible 2-way correlations being positive with no significant correlations. For Kodiak stocks there was positive correlation (mean correlation = 0.13) in survival rate index, with 6 of 10 possible 2-way correlations being positive, 2 being significant. For stocks within the Cook Inlet area there was positive correlation (mean correlation = 0.22) in survival rate

Table 6. 3HDUVRQ FRUUHODWLRQ [illegible]
FRHIILFLHQWV [illegible] α α α α αα α α α α α
α = 0.05 are in bold type.

	Bristol Bay			North Alaska Peninsula		Chignik		Kodiak					Cook Inlet			
	Togiak	Nushagak Dist.	Eastside Dist.	Bear Late	Nelson R.	Chignik Early	Chignik Late	Ayakulik	Upper 6WDWLRQ Early	Upper 6WDWLRQ Late	Frazer R.	Karluk R.	Kenai Late	Russian R Early	Kasilof R.	Crescent R.
Togiak	1.000															
NushagakD.	**0.607**	1.000														
EastsideD.	**0.534**	**0.611**	1.000													
BearLate	0.106	0.161	0.354	1.000												
NelsonR.	0.055	0.169	0.191	0.024	1.000											
ChignikEarly	0.244	**0.372**	0.252	0.289	0.010	1.000										
ChignikLate	**0.340**	**0.393**	0.247	**0.595**	-0.120	**0.410**	1.000									
Ayakulik	0.080	**0.402**	**0.324**	0.382	-0.061	0.126	**0.303**	1.000								
8HU6WDWLRQ(DU	0.349	**0.591**	0.219	-0.129	-0.063	**0.336**	-0.196	0.244	1.000							
8HU6WDWLRQ/DWH	-0.070	0.029	0.070	0.027	-0.295	0.284	-0.122	0.179	**0.469**	1.000						
FrazerR.	0.135	0.290	0.109	0.367	**0.359**	-0.082	0.256	**0.320**	0.164	0.106	1.000					
KarlukR.	-0.061	-0.105	0.156	-0.287	-0.015	0.186	0.185	0.160	-0.300	-0.074	-0.012	1.000				
KenaiLate	-0.122	-0.256	-0.082	-0.454	-0.102	-0.204	-0.239	-0.045	0.067	**0.393**	-0.001	0.136	1.000			
RussianR.Early	0.021	0.246	0.221	-0.065	0.276	0.089	0.022	**0.364**	-0.027	-0.145	0.003	0.256	-0.059	1.000		
KasilofR.	-0.333	**-0.374**	-0.063	**-0.531**	**-0.352**	0.117	-0.322	0.104	-0.137	0.323	**-0.410**	**0.386**	**0.651**	0.245	1.000	
CrescentR.	-0.061	-0.279	-0.348	**-0.603**	-0.298	0.043	-0.159	-0.163	-0.125	0.194	-0.312	0.288	0.321	-0.268	**0.423**	1.000
CopperR.	-0.146	0.016	-0.014	0.154	0.039	**0.424**	-0.138	-0.159	**0.359**	**0.434**	0.192	-0.060	-0.001	-0.082	-0.023	-0.303
Cognill	0.011	0.069	-0.115	**-0.492**	-0.220	0.098	-0.051	0.070	0.201	0.266	-0.184	-0.008	0.215	0.160	**0.459**	0.327
6LWN	0.151	0.241	0.326	0.292	0.236	0.313	0.080	0.272	0.201	0.040	0.078	0.098	0.042	0.218	0.016	**-0.392**
ItalioR.	0.304	0.118	0.254	-0.097	0.133	0.124	-0.170	-0.162	-0.095	0.113	-0.178	-0.231	0.029	0.254	0.226	0.281
KlukshuR	-0.056	-0.030	0.500	0.378	0.204	0.003	-0.134	-0.135	-0.023	0.338	-0.125	-0.238	0.042	0.039	0.048	-0.298
EastAlsekR.	-0.098	-0.006	0.369	0.242	0.018	0.208	-0.256	0.098	-0.136	0.360	0.018	0.094	0.222	0.113	0.212	0.147
ChilkatR.	-0.245	0.113	-0.160	0.291	0.374	0.027	0.297	-0.023	-0.176	-0.337	0.264	-0.250	-0.343	0.053	-0.364	-0.370
ChilkootR.	0.196	-0.113	0.264	-0.249	-0.240	-0.009	0.001	-0.075	0.088	**0.490**	-0.187	0.181	**0.503**	-0.327	0.323	**0.575**
RedoubtR.	**-0.640**	**-0.565**	-0.118	-0.220	0.102	-0.317	**-0.469**	-0.068	-0.137	0.429	-0.290	0.010	0.263	0.116	0.286	-0.205
NassR.	0.119	0.223	-0.101	0.036	0.139	0.166	-0.257	-0.293	-0.274	-0.277	0.024	**-0.488**	-0.195	0.108	-0.017	-0.362
6NHHQD5	0.060	0.053	0.061	-0.064	0.163	0.034	-0.080	-0.104	0.020	0.062	0.278	-0.008	0.240	-0.156	0.111	-0.006
Birkenhead	-0.025	-0.040	0.076	0.336	-0.237	0.005	0.218	0.030	-0.155	**0.322**	0.223	0.043	0.141	-0.066	0.060	-0.005
(DU6WDUW	-0.253	**-0.329**	-0.206	0.330	-0.309	**-0.266**	-0.040	0.062	-0.135	-0.030	0.062	-0.223	0.083	**-0.282**	-0.046	-0.071
(DU6PPHU	-0.018	0.105	-0.120	0.271	-0.093	-0.093	0.179	0.120	-0.043	-0.080	0.186	-0.088	0.104	0.007	-0.028	-0.020
/DWH6PPHU	-0.058	0.093	0.180	0.217	-0.120	-0.070	0.219	-0.250	**-0.412**	-0.051	0.130	-0.097	0.071	0.025	-0.091	0.052
6PPHU	-0.040	-0.009	0.114	**0.416**	-0.318	0.024	0.167	0.161	-0.107	0.236	0.093	-0.039	-0.028	-0.059	0.132	0.058

7DEHERQWLQHG

	Copper	Cognill	6LWN	Italio	Klukshu R	East Alsek R.	Chilkat R.	Chilkoot R.	Redoubt R.	Nass R.	6NHHQD R.	Birkenhead	Early 6WDUW	Early 6PPHU	Late 6PPHU	6PPHU
Togiak																
NushagakD.																
EastsideD.																
BearLate																
NelsonR.																
ChignikEarly																
ChignikLate																
Ayakulik																
8HU6WDWLRQ(DU																
8HU6WDWLRQ/DWH																
FrazerR.																
KarlukR.																
KenaiLate																
RussianR.Early																
KasilofR.																
CrescentR.																
CopperR.	1.000															
Cognill	-0.064	1.000														
6LWN	-0.070	-0.106	1.000													
ItalioR.	-0.216	0.238	-0.098	1.000												
KlukshuR	0.267	-0.067	0.161	0.206	1.000											
EastAlsekR.	0.018	-0.290	-0.108	0.385	0.524	1.000										
ChilkatR.	0.474	-0.314	0.101	-0.033	0.009	-0.102	1.000									
ChilkootR.	-0.267	0.167	0.087	-0.060	0.001	0.196	**-0.644**	1.000								
RedoubtR.	0.210	-0.033	-0.157	0.151	0.386	0.441	0.141	-0.325	1.000							
NassR.	0.574	-0.222	0.145	0.565	0.064	0.118	0.565	-0.070	0.496	1.000						
6NHHQD5	0.209	0.051	-0.073	0.006	0.386	0.277	0.028	0.091	-0.147	0.168	1.000					
Birkenhead	-0.018	-0.152	0.130	0.145	0.380	0.594	-0.109	0.374	0.202	-0.002	0.162	1.000				
(DU6WDUW	-0.295	-0.037	0.024	-0.032	0.210	0.269	-0.077	0.148	0.010	-0.313	0.290	0.527	1.000			
(DU6PPHU	-0.197	0.013	0.011	-0.260	0.253	0.163	-0.071	0.018	0.162	**-0.410**	0.178	0.323	0.375	1.000		
/DWH6PPHU	-0.021	**-0.358**	-0.229	0.266	0.222	0.488	0.079	-0.001	0.162	0.194	0.124	0.361	0.255	0.397	1.000	
6PPHU	-0.025	-0.219	0.136	0.139	0.477	0.605	-0.036	0.010	0.293	0.099	0.162	0.493	0.277	0.441	0.462	1

index, with 6 of 6 possible 2-way correlations being positive, and 2 being significant. For stocks within the Prince William Sound area there was a negative correlation (mean correlation = -0.08) in survival rate index. For stocks within the southeast Alaska and northern British Columbia area there was positive correlation (mean correlation = 0.11) in survival rate index, with 22 of the 36 possible 2-way correlations being positive, 6 of which being significant.

Patterns of co-variation in survival rate indices among stocks from different areas were very weak (mean correlation = 0.04) with 223 of 394 possible 2-way correlations being positive and 27 being significantly positive (Table 6).

DISCUSSION

Estimates of commercial catch of sockeye salmon were reasonable surrogates for estimates of total sockeye abundance (i.e. catch plus spawning escapement). This finding is not new - trends in sockeye salmon catches in various management areas have previously been shown to generally mirror abundance time series (e.g. Beamish and Bouillon 1993; Francis and Hare 1994; Hare and Francis 1995). Aggregate sockeye catches are often significant components of abundance time series and therefore the two will be highly correlated.

What is surprising is the similarity in trends of sockeye catches and abundance throughout the North Pacific. Sockeye abundance in Russia and western and central Alaska declined coincident with the 1949 regime shift. Declines also occurred in the eastern North Pacific although they were less severe. Increases in sockeye abundance coincident with the 1977 regime shift were ubiquitous. Other species also benefited from changing ocean conditions after 1977, for example Canadian pink and chum salmon (Irvine and Chen 2004).

Regional abundance patterns associated with the 1989 shift varied. Short-term reductions in sockeye abundance occurred in western and parts of central Alaska but were not evident in Russia or the eastern North Pacific. A lack of a consistent response to the 1989 regime shift for salmon abundance was also reported by Irvine and Chen (2004) and is consistent with Hare and Mantua's (2000) observation that the 1989 regime shift was neither as persuasive as the 1977 regime shift nor a simple return to preceding conditions. Many North American stocks declined in the late 1990s, around the time of the proposed (Peterson and Schwing 2003) 1998 shift, with the most severe declines occurring in southernmost areas.

Body size trends, available for a shorter period (1960–2004) than abundance data, were also consistent among the eight areas in Alaska and British Columbia where these data were available. There were positive 2-way correlations in body sizes among all areas, with a high degree of spatial coherence in the patterns with correlations decreasing with increasing distance. Trends in body size reflected the 1977 and 1989 regime shifts. Body sizes generally increased during regimes of low salmon abundance (1960 – late 1970s, and from the mid 1990s) and decreased during regimes of high salmon abundance (i.e., late 1970s to late 1980s). Ultimate sizes of sockeye salmon are determined during their final period of ocean residence and growth is density-dependent (Rogers 1984). Because many stocks of sockeye salmon have similar marine distributions (Harris 1988; French et al. 1976; Fredin et al. 1977; Habicht et al. 2005), and share their environments with populations of chum and pink salmon (Urawa et al. 2005), temporal patterns in body size probably reflect density-dependent effects caused by the aggregate abundance of salmon in the North Pacific Ocean.

Trends in survival rate indices were similar to trends in catch and abundance. Survival rate changes generally coincided with regime shifts. Survival rate indices prior to the 1949 regime shift (< 1947 BY) averaged much lower than survival indices for the 1949 – 1973 BY. With the exception of the early Stuart, survival rate indices increased for all populations following the 1977 regime shift. Survival rates generally decreased after the 1989 regime shift for stocks in the eastern North Pacific, however many stocks in western and central Alaska showed little change in survival with the 1989 regime shift.

Patterns of co-variation in survival rate indices among the 34 sockeye salmon stocks indicated some coherence at regional scales. Correlations were particularly strong for populations within the Bristol Bay, Chignik, and Fraser river areas. Within-area positive correlations in survivals were much weaker for other areas. There was little positive correlation in survival indices among areas, consistent with the findings of Peterman et al (1998).

We aggregated our data over relatively large areas, appropriate for agencies such as the North Pacific Anadromous Fish Commission and the North Pacific Marine Science Organization. Correlations were generally highest for data from adjacent areas, and decreased with increasing distance. While this illustrated a surprising degree of spatial coherence in sockeye abundances among areas, it also demonstrated that local factors play a role determining regional patterns in salmon survival and abundance.

In Canada, salmon stock assessment and management is becoming increasingly focused on Conservation Units (DFO 2005; Irvine and Riddell 2007), rather than large stock aggregates. Canadian fishery managers need to understand regional differences in productivity; the poor status of some sockeye populations has major effects on the prosecution of fisheries (Irvine et al. 2005). Assessments and forecasts for Canadian sockeye are therefore made for component populations or Conservation Units within major stock groups (e.g. Cass et al. 2006). Because of cyclical abundance patterns, populations that are abundant within an aggregate one year may be uncommon the next year. Population-specific return and escapement estimates are better indices of population status than aggregate catches -- provided they can be contrasted with a benchmark. Survival indices allow one to better understand mechanisms responsible for regime shift and climate change effects than abundance, particularly when marine and freshwater mortality can be partitioned.

In contrast, sockeye management and assessment in Alaska and Russia focuses to a greater extent on population aggregations. In these areas, there may be less variability in productivity within aggregates compared to British Columbia. Aggregate catch statistics continue to provide a good indication of stock status in these areas, and presumably will continue to do so provided that exploitation rates do not change dramatically.

It appears that ocean basin-scale environmental processes control the overall production of sockeye salmon, and probably restrict the total production from particular ocean zones. However, local-scale environmental processes can result in regional differences in productivity. Aggregate catch statistics are appropriate indicators of oceanographic conditions over large areas and enable an understanding of the effects of major fisheries, but are not necessarily appropriate indicators of the health of individual populations.

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Appendix 1. Major sockeye salmon stocks for which escapement data (range of years) and escapement-return (brood years) are available. Included are the primary escapement estimation methodology, average catch (thousands, 1995–2004) by area, and average escapement (thousands, 1995–2004), and returns (thousands, 1989–1999 brood years) by stock. E = early; L = late.

Management area	Average catch (thousands) 1995–2004 (percent of North 3DFLF□	6WRFNVDQGFRPRQHQW□ populations	Escapement data			Escapement - return data		
			Escapement method	Years of escapement (range)	Average escapement (thousands) 1995–2004	Brood years (BY) of returns	Average escapement (thousands) BY 89–99	Average returns (thousands) BY 89–99
Russia	5,786 (11%)							
Bristol Bay	20,807 (40%)	Togiak District	Tower	56–04	212	56–99	184	626
		Nushagak District	Tower	56–04	2,380	56–99	2,366	7,108
		Wood	Tower	56–04	1,494			
		Nushagak	7RZHU6RQDU	56–04	585			
		Igushik	Tower	56–04	305			
		Eastside Districts	Tower	56–04	8,333	56–99	10,557	24,830
		Kvichak	Tower	56–04	3,696			
		Alagnak	Tower	56–04	1,488			
		Naknek	Tower	56–04	1,389			
		Egegik	Tower	56–04	1,177			
		Ugashik	Tower	56–04	927			
Alaska Peninsula	3,761 (7.1%)	Bear R. E. Run	Weir	64–04	337			
		Bear R. L. Run	Weir	64–04	122	80–99	176	580
		Nelson R.	Weir	70–04	265	75–99	241	591
		Ilnik L.	weir	70–04	66			
		6DQG5LYHU	Weir	70–04	58			
		Chirstianson L	Aerial	71–04	37			
		2ULQVNL/DNH	Weir	70–04	38			
Chignik	1,477 (2.8%)	Chignik Combined	Weir		754			
		Chignik E. Run	Weir	22–04	447	22–99	461	1,391
		Chignik L. Run	Weir	22–04	307	22–99	345	1,113
Kodiak	3,526 (6.8%)	Pauls Bay	Weir	78–04	27			
		Afognak Lake	Weir	78–04	64			
		Akalura Lake	Weir	23–04	17			
		6DWHU/DNH	Weir	76–04	43			
		Ayakulik R.	Weir	29–04	282	65–99	384	674
		8HU6WDWLRQ(5Q	Weir	69–04	53	69–99	43	127
		8HU6WDWLRQ/5Q	Weir	66–04	183	70–99	211	469
		Frazer L.	Weir	66–04	177	66–99	218	543
		Karluk Combined	6RQDU	22–04	777	22–99	796	1,449
		Karluk E. Run	Weir	22–04	332	80–99		
		Karluk L. Run	Weir	22–04	445	80–99		

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Management area	Average catch (thousands) 1995–2004 (percent of North 3DFLF)	6WRFNVDQGFRPRQHQW populations	Escapement data			Escapement - return data		
			Escapement method	Years of escapement (range)	Average escapement (thousands) 1995–2004	Brood years (BY) of returns	Average escapement (thousands) BY 89–99	Average returns (thousands) BY 89–99
Cook Inlet	3,271 (6.2%)	Kenai R. L. Run	6RQDU	78–04	886	68–99	688	2,910
		Russian R. E. Run	Weir	65–04	47	65–97	35	87
		Kasilof R.	6RQDU	75–04	303	75–98	197	761
		Yentna R	6RQDU	81–04	114			
		Fish Cr.	Weir	38–04	55			
		Crescent R.	6RQDU	75–04	70	75–98	63	93
Prince William 6RQG	2,302 (4.4%)	Eshamy R.	Weir	61–04	29	65–00		
		Cognill R.	Weir	62–04	39	69–00	26	112
		Copper R.	6RQDU	78–04	798	65–97	706	2,213
6RWKHDVWDODVND N. British Columbia	3,671 (7%)	6LWN5	Weir	76–04	54	76–97	64	118
		Lost R.	Aerial	72–04	3			
		Italio R.	Aerial	73–04	3	72–97	4	4
		Klukshu R.	Weir	76–04	15	76–96	17	17
		East Alsek R.	Aerial	72–04	36	72–97	55	89
		Chilkat R.	Weir	76–04	171	76–95	128	296
		Chilkoot R.	Weir	76–04	50	76–95	55	43
		Redoubt L.	Weir	82–04	37	82–96	35	33
		Taku R.	Mark/Recap	84–04	103			
		Tahltan L.	Weir	79–04	25			
		0DLQVWHP6WLNLQH5	Visual	79–04	32			
		McDonald Lake	Aerial	82–04	58			
		Aggregate N. BC Q6(V		48–04	1,522			
		Nass River	Mark/Recap	82–04	247	82–98	304	967
		6NHHQD5LYHU	Mark/Recap	70–02	1,271	70–00	1,179	3,158
		2WKHU1% Q6(V	Various	50–04	186			
6%ULWLVKRPELD - Washington	2,175 (4.1)	UHDWH6% Q6(V		48–04	3,493			
		Fraser R aggregate Q6(V	Various	48–04	3,134			
		Birkenhead	Visual	48–04	100	48–99	134	299
		Birkenhead	Visual	48–04				
		%L6LYHU	Visual	73–04				
		(DU6WDUW7DND Middle R., Trembleur)	Visual/Carcass census	48–04	84	48–99	176	387

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Management area	Average catch (thousands) 1995–2004 (percent of North 3DFLF)	6WRFNVDQGFRPRQHQW populations	Escapement data			Escapement - return data		
			Escapement method	Years of escapement (range)	Average escapement (thousands) 1995–2004	Brood years (BY) of returns	Average escapement (thousands) BY 89–99	Average returns (thousands) BY 89–99
		(DU6PPHUV		48–04	262	48–99	193	574
		Chilliwack	Visual	74–04				
		Nahatlatch	Visual	72–04				
		Upper Pitt	Mark/Recap	48–04				
		Gates	CarcassCensus	48–04				
		Upper Adams	Visual	74-04				
		Anstey	Visual	74–04				
		Cayenne	Visual	73–04 (not continuous)				
		Eagle	Visual	73–04				
		6FRWFK	CarcassCensus	48–04				
		6HPRU	Visual	48–04				
		Fennell	Visual	54–04				
		Raft	Visual	48–04				
		Taseko	Visual	75–04				
		Nadina	Visual/Carcass Weir	48–04				
		Bowron	Visual	48–04				
		6PPHUV	Various	48–02	1,917	48–99	1,981	6,425
		Chilko	Mark/Recap	48–04				
		Mitchell		49–04				
		+RUVH	CarcassCensus	48–04				
		McKinley	Visual	53–04				
		Quesnel	Visual	61–04 (not continuous)				
		6WHDNR	Weir	48–04				
		/DWH6WDUW	Visual/Carcass Census	48–04				
		/DWH6PPHUV (lates)	Various	48–04	374	48–99	860	2,390
		Cultus	Weir	24–04				
		Widgeon	Visual	95–04				
		Harrison	Visual	48–04				
		Weaver	Visual/Carcass Census	48–04				
		Portage	Visual	49–04				574

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Management area	Average catch (thousands) 1995–2004 (percent of North 3DFLF	6WRFNVERGDQG component populations	Escapement data			Escapement - return data		
			Escapement method	Years of escapement (range)	Average escapement (thousands) 1995–2004	Brood years (BY) of returns	Average escapement (thousands) BY 89–99	Average returns (thousands) BY 89–99
		/ZU6KVZD	Weir	49–04				
		0LG6KVZD	Visual	74–04				
		67KRPVRQ	Visual	72–04				
		2WKHU6% Q6(V	Various	48–04	303		303	
		L. Washington	Lock Count	72–04	430		247	