

NPAFC
Doc. 1404
Rev. _____

**Concordant Distribution, Abundance and Growth of Juvenile Pink,
Chum and Sockeye Salmon in Eastern Pacific Coastal Waters**

by

Strahan Tucker¹, Mary Thiess¹, John Morris¹, Asit Mazumder² and Marc Trudel^{1,2}

¹Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC, Canada
V9T 6N7

²Department of Biology
University of Victoria
Victoria, British BC, Canada
V8W 3N5

Submitted to the
NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

CANADA

SEPTEMBER 2012

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:

Tucker, S., M.E. Thiess, J.F.T. Morris, A. Mazumder, and M. Trudel. 2012. Concordant distribution, abundance, growth of juvenile pink, chum and sockeye salmon in Eastern Pacific coastal waters. NPAFC Doc. 1404. 13 pp. Fisheries and Oceans Canada, Science Branch, Pacific Region, Pacific Biological Station. Department of Biology, University of Victoria. (Available at <http://www.npafc.org>).

ABSTRACT

Competition is thought to be an important factor affecting growth of Pacific salmon (*Oncorhynchus* spp.) in marine waters. Pink salmon (*O. gorbuscha*) are the most abundant species of the five Pacific salmon. As such, we hypothesized that high abundances of juvenile pink salmon might result in decreased abundances and/or growth of other planktivorous juvenile salmon species during the first growing season (summer-fall) at sea through direct competition for food. We evaluated spatial and temporal changes in growth rates and the seasonal catches between 1998 and 2011 of juvenile salmon and pelagic fishes, and the effects of oceanographic variables. Results suggest that, at least during the first marine growing season, interspecific competition is not manifested among salmon going to sea in the same year in northeastern Pacific stocks. Abundance of all salmon species were positively correlated and more likely driven by oceanographic features and processes at the base of the food chain.

INTRODUCTION

Competition is thought to be an important factor affecting growth of Pacific salmon (*Oncorhynchus* spp.) in marine waters (Ruggerone and Nielsen 2004). Pink salmon (*O. gorbuscha*) are the most abundant species of the five Pacific salmon, representing approximately 60% of all salmon (Rogers 2001). In North America, large pink salmon populations dominated by odd-year adults are located primarily at the northern and southern range of pink salmon, such as the Strait of Georgia/Puget Sound. Regions in the central portion of the pink salmon range in North America (central and southeast Alaska and northern British Columbia) produce large pink runs in both odd- and even-numbered years. Given their abundance, pink salmon may be the dominant salmonid in interspecific competitive interactions (Orsi et al. 2007).

Juvenile pink, chum and sockeye salmon enter coastal marine waters in early spring then disperse counter-clockwise along the coast and into the North Pacific Ocean or Bering Sea (Heard 1991; Salo 1991; Tucker et al. 2009). Pink and chum salmon in particular have similar life histories during early marine life and both species can be highly abundant. Chum salmon tend to enter coastal waters after pink salmon, but both species rear in near shore waters for weeks to months before moving offshore. In the Pacific Northwest schools of chum and pink salmon have been observed (Heard 1991). Sockeye salmon rear for 1-2 years in freshwater before quickly migrating north (Tucker et al. 2009). All three species have similar diets at this stage in coastal waters (Kaczynski et al. 1973; Beacham and Starr 1982; Duffy 2003) as they are primarily planktivorous. Therefore given the high dietary niche overlap, there is the strong possibility for direct competition for food if resources are limiting.

A variety of studies from the North Pacific Ocean, Bering Sea, and adjoining coastal waters indicates that the abundance of pink salmon influences growth and survival of all other species of salmon (Ruggerone and Nielsen 2004). Reduced growth is believed to lead to greater predation risk (Parker 1971) and to greater mortality during winter (Nasagawa 2000; Beamish and Mahnken 2001). The primary mechanism is thought to be through competitive reduction of available prey given the high abundance of

pink salmon. For example, in years of high pink salmon abundance, diet shifts (Tadokoro et al. 1996) and changes in the distribution on the high seas (Azumaya and Ishida 2000) of chum salmon have been noted, as well as reduced survival (Salo 1991; Beacham 1993; Fresh 1997). Similar reductions in growth and marine survival have been documented for sockeye salmon (Ruggerone et al. 2003; Connors et al. 2012).

While these studies provide evidence that competition may be an important process in offshore marine waters overall, many deal with survival and growth over the entire marine residence period rather than during a specific time period of their life cycle. These studies span all age classes and in fact, reductions in chum and sockeye growth have been observed in the second and third years at sea if pink salmon are abundant at that time (Ruggerone and Nielsen 2004). However, the first year of marine life is thought to be a critical period for survival as it is postulated that fish must grow fast enough and large enough to escape both predation-based and starvation-based mortality, both of which are size-dependent processes (Beamish and Mahnken 2001). Therefore, this life stage may actually be the most susceptible to competitive effects through reduced food availability and growth although predation might still be of greater consequence in early marine survival.

We hypothesized that high abundances of juvenile pink salmon might result in decreased abundances and/or growth of other planktivorous juvenile salmon species migrating on the continental shelf of the west coast of North America through direct competition for food. Furthermore, we evaluated the effects of potential environmental drivers and food web process on salmonid abundance and growth. Other planktivorous fish species could also be direct competitors for food or mitigate the impact of predation on juvenile salmon by providing predators an abundant alternative prey (Emmett and Sampson 2007). Pacific herring and Pacific sardines are the primary pelagic planktivorous fish species in this region (Orsi et al. 2007). Therefore we also sought to evaluate the potential effects of herring and sardines on salmon abundance and growth.

METHODS

Fish collection and oceanographic sampling

Our surveys involved both repeated cross-shelf transects and opportunistic sampling in June-July and Oct-Nov, from southern British Columbia to southeast Alaska between 1998 and 2011. A hexagonal mesh mid-water rope trawl (ca. 90 m long X 30 m wide X 18 m deep; cod-end mesh 0.6 cm; Cantrawl Pacific Ltd., Richmond, BC) was towed at the surface (0–20 m) for 30 minutes at 5 knots using primarily the *CCGS W.E. Ricker*, or a chartered fishing vessel when it was unavailable (i.e. *Ocean Selector* June 2002; *Frosti* June 2005, October 2005; *Viking Storm* October 2007, June 2008-2011). Sampling was conducted between 06:00 and 20:00 (Pacific Time). Trawl catches were sorted by species. A maximum of 15 juvenile salmon pink and chum salmon and 30 sockeye were randomly selected from each net tow and fork length (mm) and weight (g) were measured onboard the research vessel. Additional biological samples were taken (chlorophyll-a, zooplankton (8mm, 1.7mm, 1.0mm 0.25mm size fractions) and physical oceanographic observations (sea surface temperature, salinity, nitrate concentration) were made

at each sampling station (specific sampling and processing details and how they vary inter-annually and seasonally is reported in Trudel et al. 2010).

Data Analysis

To evaluate spatial and temporal changes in the catches of juvenile salmon and pelagic fishes, and the effects of oceanographic variables, we divided sampling locations into 3 catch regions (Figure 1): west coast of Vancouver Island (WCVI), central coast including Central and Northern British Columbia (CC), and southeast Alaska (SEAK). Samples were also pooled by season: June-July and October-November. We used catch-per-unit-effort (CPUE) as a measure of relative abundance. Species-specific catch-per-unit-effort (CPUE) was calculated separately for each fishing event (Fisher et al. 2007) as the number of fish caught per tow length of 1.5 nautical miles (2.8 km) where:

$$CPUE = [(\# \text{ fish}) / \text{tow duration (h)} / \text{tow speed (nautical miles/h)}] \times 1.5 \text{ nautical miles}$$

In order to reduce the influence of large catches from individual tows, we \log_{10} transformed the CPUE estimate for each haul (Fisher et al. 2007). CPUEs were subsequently pooled for each region and season in each year.

Mean seasonal growth rates of juvenile salmon were calculated for each region in each year, over the summer-fall growing season where:

$$G = \ln(W_t/W_i) / t$$

where G is growth rate ($\text{g} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$); W_t is mean body mass (g) in Oct-Nov; W_i is mean body mass (g) in June-July; t was the mean annual sampling interval between June-July and Oct-Nov (d). This assumes that we are resampling cohorts, and that migration is not linked to size and growth. That is, we assume that the larger fish did not leave earlier.

We examined the correlation (Pearson's correlation coefficient) between CPUEs of all fish species and growth rates of salmon. To more easily visualize covariation in abundance and growth, we calculated CPUE and growth rate anomalies ($(\text{observed} - \text{mean}) / \text{standard deviation}$) for each year, season and region grouping. We used Kendall's W coefficient of concordance, together with permutation tests to identify concordance in species abundances in our CPUE abundance data (Borcard et al. 2011). The method aims at finding the smallest number of groups containing the largest number of positively and significantly associated species. First, the method carries out an overall test of independence of all species. If the null hypothesis is rejected, the analysis looks for groups of correlated species and tests for the contribution of each species to the test statistic using a permutation test.

We tested for regional, seasonal and annual differences in salmon catch composition and abundance (pink, chum and sockeye CPUEs) through an R-based (R® version 2.12.2; R Development Core Team 2011) permutation procedure (analysis of variance using distance matrices, *adonis* function, Vegan Community Ecology Package Version 1.17-8; Oksanen et al. 2011) which does not require data to be normally distributed. The effects of biological and large-scale physical oceanographic conditions on salmon abundance were incorporated in the model through inclusion of herring and sardine abundance terms, in addition to a term for Pacific Decadal Oscillation (PDO) status during the year (NOAA 2011). In so far as it partitions the sums of squares of a multivariate data set, this nonparametric statistical approach is directly analogous to MANOVA (McArdle and Anderson 2001) and is a robust alternative to both parametric MANOVA and to ordination methods for describing how variation is attributed to different predictors or covariates. The function *adonis* can handle both continuous and factor predictors and uses permutation tests with pseudo-F ratios to inspect the significances of those partitions; we used 10,000 permutations. Similarly, we used Generalized Linear Models (GLM) to test for differences and effects of all predictor variables on growth rates of each salmon species including CPUEs of other species. All analyses were run using R.

RESULTS AND DISCUSSION

Between 1998-2011, we captured 47,982 juvenile pink, 46,988 chum, 19,208 sockeye salmon, 490,801 herring and 511,701 sardines from 2,604 tows (Figure 1). Salmon CPUEs (Figure 2) varied significantly between seasons ($P < 0.01$; higher in the summer period), regions ($P < 0.01$; generally higher in more northern regions), and years ($P < 0.01$). CPUE of all salmon species were positively correlated (Table 1) demonstrating very similar trends in the direction and magnitude of anomalies in each year, region and season (Figures 2-3). Therefore, high pink salmon abundance is not associated with decreased abundance of other salmonids as they covary positively. CPUEs of juvenile salmon were slightly, but significantly negatively correlated with herring CPUE and in the case of pink salmon, slightly negatively correlated with sardine CPUE (Table 1). The lack of a strong relationship with herring and sardines could be due to the greater patchiness and schooling behaviour of these pelagic fish such that any interaction between them is spatially and temporally limited. However, given that in most cases (20/30), salmon and herring demonstrated similar patterns in anomalies (Figure 3) a negative competitive association seems unlikely. Sardines are actually only abundant off the west coast of Vancouver Island (Figures 1-2; Orsi et al. 2007) where juvenile pink salmon are rare.

Kendall's W coefficient of concordance search for species associations is done without reference to typology or the sites known *a priori*. The approach seeks to identify species assemblages in abundance data by finding the most encompassing assemblages (i.e., the smallest number of groups containing the largest number of positively associated species). Here, "sites" are the individual tows. Pink, chum and sockeye formed a single group and were all positively associated with one another; herring and sardines were not positively associated to any other species (Table 2). The permutation procedure we

employed is a multivariate approach looking at effects and differences between the salmonid community composition and abundance as a whole, rather than one species at a time. There were significant biological and physical oceanographic effects on salmon CPUE; sea surface temperature ($P < 0.001$), nutrient - nitrate concentration ($P < 0.001$), chlorophyll a ($P = 0.03$) and the 1.7mm zooplankton fraction ($P = 0.02$) which would include such dietary species as copepods and euphausiids (Trudel et al. 2010). There was no effect of herring ($P = 0.16$) or sardine ($P = 0.11$) abundance on juvenile salmon CPUE. This suggests that abundance of these juvenile planktivorous salmon are more closely linked to production and food web processes.

Growth rates varied seasonally, regionally and annually for all species. Growth rates were positively correlated between pink and chum salmon (Table 3); there were no significant relationships with sockeye salmon. This suggests that chum salmon growth rates track pink salmon in a similar manner (Figure 4). There appeared to be no impact on sockeye salmon. We found no effects of biological or physical oceanographic variables on growth rate. In addition, there appears to be no significant effect of abundances of herring or sardine on juvenile salmon growth.

CONCLUSIONS

Results of this study suggest that, at least during the first marine growing season, interspecific competition is not manifested among salmon going to sea in the same year in northeastern Pacific stocks. Although competition may occur later in the marine phase, either as a result of interaction with abundant Northern Alaskan and Asian stocks in overlapping feeding grounds, or as older year classes of salmon (reviewed in Ruggerone and Nielsen 2004), our study suggests that the abundance of juvenile salmon in coastal waters is more likely driven by physical oceanographic features and processes at the base of the food chain. It is unclear however, why we did not find direct effects of these same factors on growth. Perhaps this can be attributed to pooling and bracketing of fish and variables across broad regional scales. It is likely these fish migrate quickly through each of these zones depending on their origin. Hence, we may not be adequately defining growth rates and perhaps oversimplifying the conditions experienced by these fish. Future analyses will need to consider smaller scale processes (Trudel et al. 2011).

REFERENCES

- Azumaya T, Ishida, Y. 2000. Density interactions between pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) and their possible effects on distribution and growth in the North Pacific Ocean and Bering Sea. N. Pac. Anadr. Fish. Comm. Bull 2: 165-174.
- Beacham TD, Starr, P. 1982. Population biology of chum salmon, *Oncorhynchus keta*, from the Fraser River, British Columbia. Fish. Bull 80: 813-825.
- Beacham TD. 1993. Competition between juvenile pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) and its effect on growth and survival. Can. J. Zool 71: 1270-1274.

Beamish RJ, Mahnken C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and linkage to climate and climate change. *Progr. Oceanogr* 49: 423-437.

Connors BM, Braun DC, Peterman RM, Cooper AB, Reynolds JD, Dill LM, Ruggerone GT, Krkošek M. 2012. Migration links ocean-scale competition and local ocean conditions with exposure to farmed salmon to shape wild salmon dynamics. *Conservation Letters* 5: 304–312.

Duffy EJ. 2003. Early marine distribution and trophic interactions of juvenile salmon in Puget Sound, University of Washington, Seattle, WA: M.S. Thesis

Emmett RL. and Sampson DB. 2007. The relationships between predatory fish, forage fishes, and juvenile salmonid marine survival off the Columbia River: a simple trophic model analysis. *CalCOFI Rep.*, Vol. 48.

Fisher J, Trudel M, Ammann A, Orsi JA, Piccolo J, Bucher C, Casillas E, Harding JA, MacFarlane RB, Brodeur RD, Morris JFT, and Welch DW. 2007. Comparison of the coastal distributions and abundances of juvenile Pacific salmon from Central California to the Northern Gulf of Alaska. In CB Grimes, RD Brodeur, LJ Haldorson, and SM McKinnell (eds). *The ecology of juvenile salmon in northeast Pacific Ocean: regional comparisons*. American Fisheries Society, Symposium 57, Bethesda Maryland. Pages 31-80.

Fresh KL. 1997. The role of competition and predation in the declines of anadromous salmonids in the Pacific Northwest *In: Stouder, DJ., Bison, PA., Naiman, RJ. eds. , Pacific Salmon and Their Ecosystems: Status and Future Options*, Chapman & Hall, New York, pp 245-276.

Heard WR. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*) *In: Groot, C, Margolis, L eds. , Pacific Salmon Life Histories*, University of British Columbia, Vancouver, BC, pp 121-232.

Kaczynski VW, Feller RJ, Clayton J, Gerke, RJ. 1973. Trophic analysis of juvenile pink and chum salmon (*Oncorhynchus gorbuscha* and *keta*) in Puget Sound. *J. Fish. Res. Bd. Can* 30: 1003-1008.

McArdle BH and Anderson MJ. 2001. Fitting multivariate models to community data: A comment on distance-based redundancy analysis. *Ecology* 82: 290–297.

Nagasawa K. 2000. Winter zooplankton biomass in the Subarctic North Pacific, with a discussion on overwintering survival strategy of Pacific salmon (*Oncorhynchus spp.*). *N. Pac. Anadr. Fish. Commun. Bull* 2: 21-32

NOAA, Climate Prediction Center Internet Team (2011; last updated Oct 4, 2011). National Weather Service Climate Prediction Center, Cold and Warm Episodes by Season (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

Oksanen J, Blanchet FG, Kindt R, Legendre P, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, and Wagner H (2011). *vegan: Community Ecology Package*. R package version 1.17-8. <http://CRAN.R-project.org/package=vegan>.

Orsi JA, Harding JA, Pool SS, Brodeur RD, Haldorson LJ, Murphy JM, Moss JH, Farley Jr EV, Sweeting RM, Morris JFT, Trudel M, Beamish RJ, Emmett RL, and Fergusson EA. 2007. Epipelagic fish assemblages associated with juvenile Pacific salmon in neritic waters of the California current and the Alaska current. In CB Grimes, RD Brodeur, LJ Haldorson, and SM McKinnell (eds). *The ecology of juvenile salmon in northeast Pacific Ocean: regional comparisons*. American Fisheries Society, Symposium 57, Bethesda Maryland. Pages 105-156

Parker RR. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28(10):1503-1510.

R Development Core Team (2011) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available: www.r-project.org.

Rogers DE. 2001. Estimates of annual salmon runs from the North Pacific, 1951-2001. University of Washington Rep. No. SAFS-UW-0115.

Ruggerone GT, Zimmermann M, Myers KW, Nielsen JL, Rogers DE. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fish Oceanogr 12: 209-219.

Ruggerone GT and Nielsen JL. 2004. Evidence for competitive dominance of Pink salmon (*Oncorhynchus gorbuscha*) over other Salmonids in the North Pacific Ocean. Reviews in Fish Biology and Fisheries 14: 371-390.

Salo EO. 1991. Life history of chum salmon (*Oncorhynchus keta*) In: Groot, C, Margolis, L eds. , Pacific Salmon Life Histories, University of British Columbia, Vancouver, BC, pp 231-309.

Tadokoro K, Ishida Y, Davis ND, Ueyanagi S, Sugimoto T. 1996. Change in chum salmon (*Oncorhynchus keta*) stomach contents associated with fluctuations of pink salmon (*O. gorbuscha*) abundance in the central subarctic Pacific and Bering Sea. Fish. Oceanogr 5: 89-99.

Trudel M, Thiess ME, Tucker S, Morris JFT, Zubkowski TB, and Mackas D. 2010. Canada-USA Salmon Shelf Survival Study. Annual Report submitted to the Bonneville Power Administration, BPA Project 2003-009-00, 115 p.

Trudel M, Moss JH, Tucker S, Candy JR and Beacham TD. 2011. Stock-Specific Distribution of Juvenile Sockeye Salmon in the Eastern Gulf of Alaska. NPAFC Doc. 1353, 11 p.

Tucker S, Trudel M, Welch DW, Candy JR, Morris JFT, Thiess ME, Wallace C, Teel DJ, Crawford W, Farley Jr EV, and Beacham TD. 2009. Seasonal stock-specific migrations of juvenile sockeye salmon along the west coast of North America: implications for growth. *Trans. Am. Fish. Soc.* 138: 1458-1480.

Table 1. Pearson's correlation coefficient between CPUE of all species. * denotes significant correlation.

	<i>chum</i>	<i>sockeye</i>	<i>herring</i>	<i>sardine</i>
pink	0.57* (0.001)	0.39* (0.001)	-0.096* (0.001)	-0.13* (0.001)
chum		0.52* (0.001)	-0.068* (0.014)	-.031 (0.26)
sockeye			-0.091* (0.001)	-0.029 (0.30)
herring				-0.051 (0.065)

Table 2: Results of (a) the overall and (b) the *a posteriori* tests of Kendall's coefficient of concordance (W) among fish species and partial Spearman correlation coefficients (r_j) and concordance statistic W_j for each species (j) . P = permutational probability, based upon 9,999 random permutations. Reject H_0 at $\alpha = 0.05$.

a) Overall test of the W statistic. H_0 : the 5 species are not concordant with one another

Kendall's W = 0.245 P < 0.001* Reject H_0
 Friedman's chi-square = 1.3

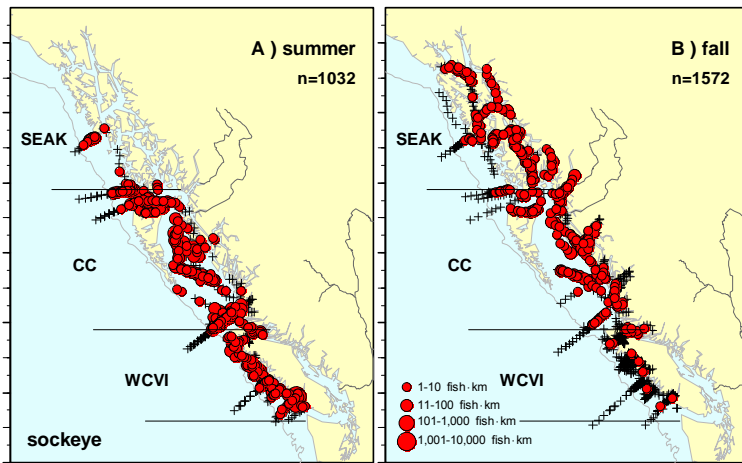
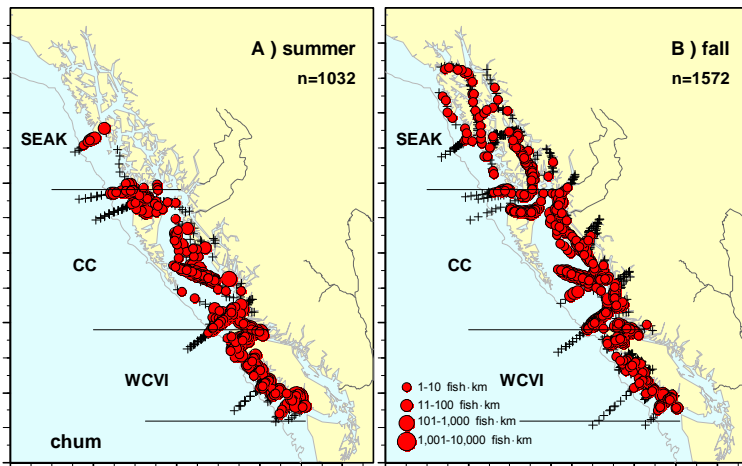
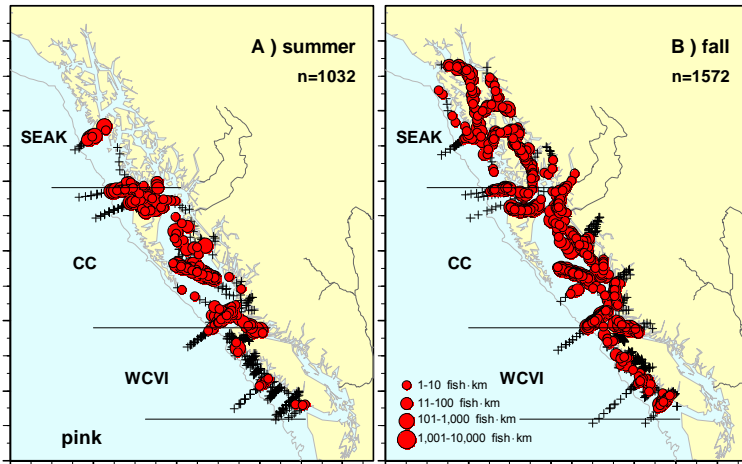
b) *A posteriori* tests

H_0 : this species is not concordant with the other

	r_j	W_j	P	
Pink	0.055	0.244	P<0.001*	Reject H_0
Chum	0.129	0.304	P<0.001*	Reject H_0
Sockeye	0.087	0.269	P<0.001*	Reject H_0
Herring	-0.06	0.149	P=1	Do not reject H_0
Sardines	-0.04	0.168	P=1	Do not reject H_0

Table 3. Pearson's correlation coefficient between growth rate of all species. * denotes significant correlation.

	<i>chum</i>	<i>sockeye</i>
pink	0.41* (0.03)	0.03 (0.89)
chum		-0.13 (0.49)



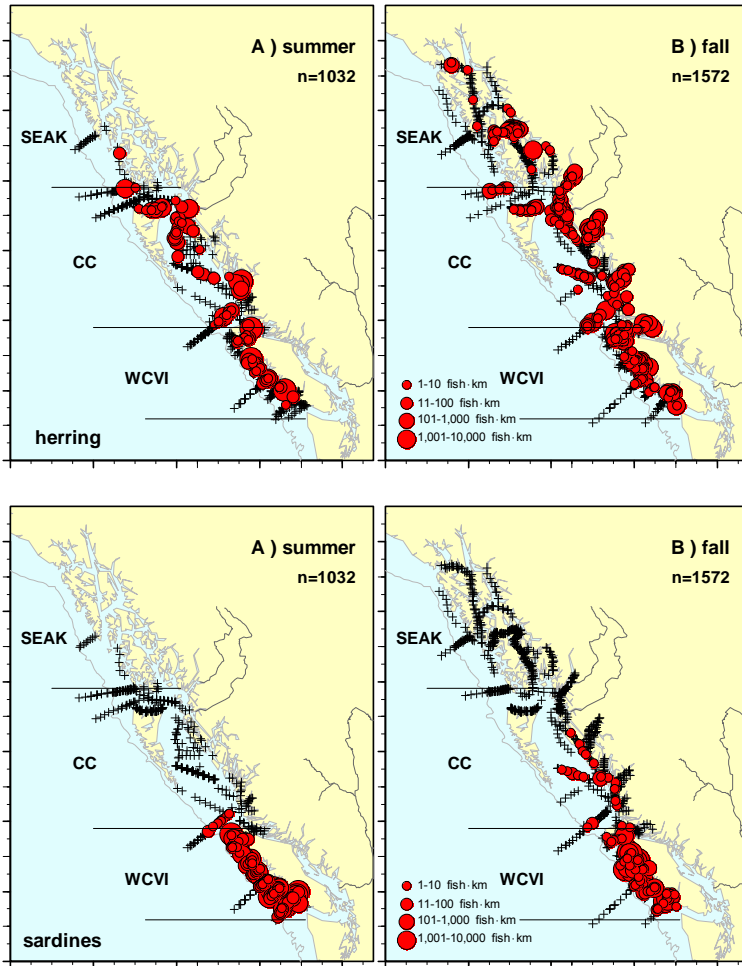


Figure 1: Locations of the trawl stations (+) and Catch-per-unit-effort (CPUE) of juvenile pink salmon, juvenile chum salmon, juvenile sockeye salmon, herring and sardines (red circles) caught from 1998-2011 during summer (Jun-Jul) and fall (Oct-Nov) in three catch regions: southeast Alaska (SEAK), the central coast (CC) and the west coast of Vancouver Island (WCVI). Sample sizes denote the number of tows. The solid line delineating the margin of the continental shelf is the 1000m depth contour.

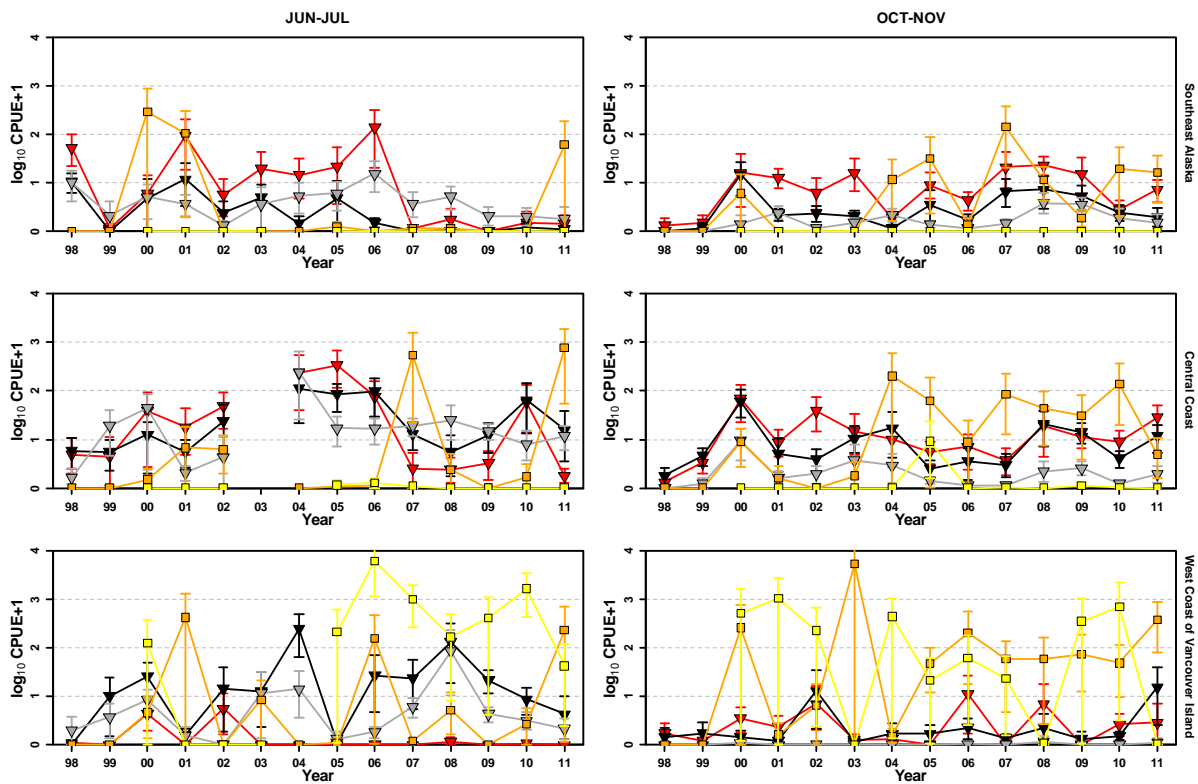


Figure 2. Annual average catch per unit effort ($\log_{10}(\text{CPUE}+1)$) of pink salmon (red), chum salmon (black), sockeye salmon (grey), herring (orange) and sardines (yellow) by region (rows) and seasons (columns). Average CPUE and 95% confidence intervals were obtained by bootstrap approximations.

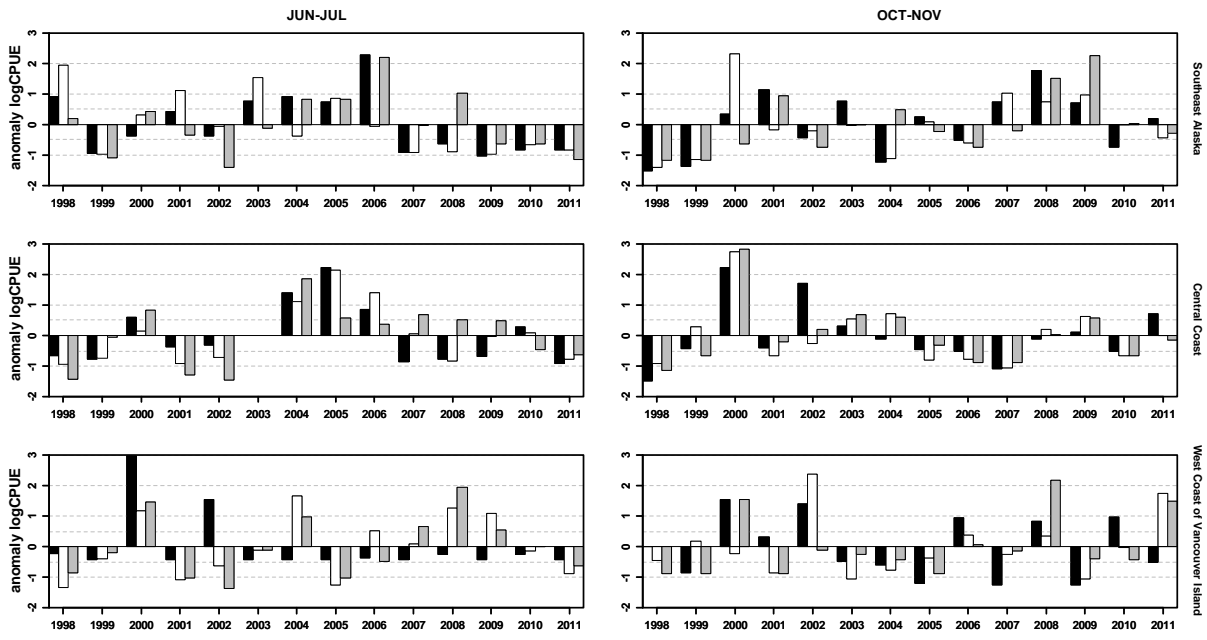


Figure 3. Anomalies in catch per unit effort ($\log_{10}(\text{CPUE}+1)$) by region (rows) and seasons (columns).

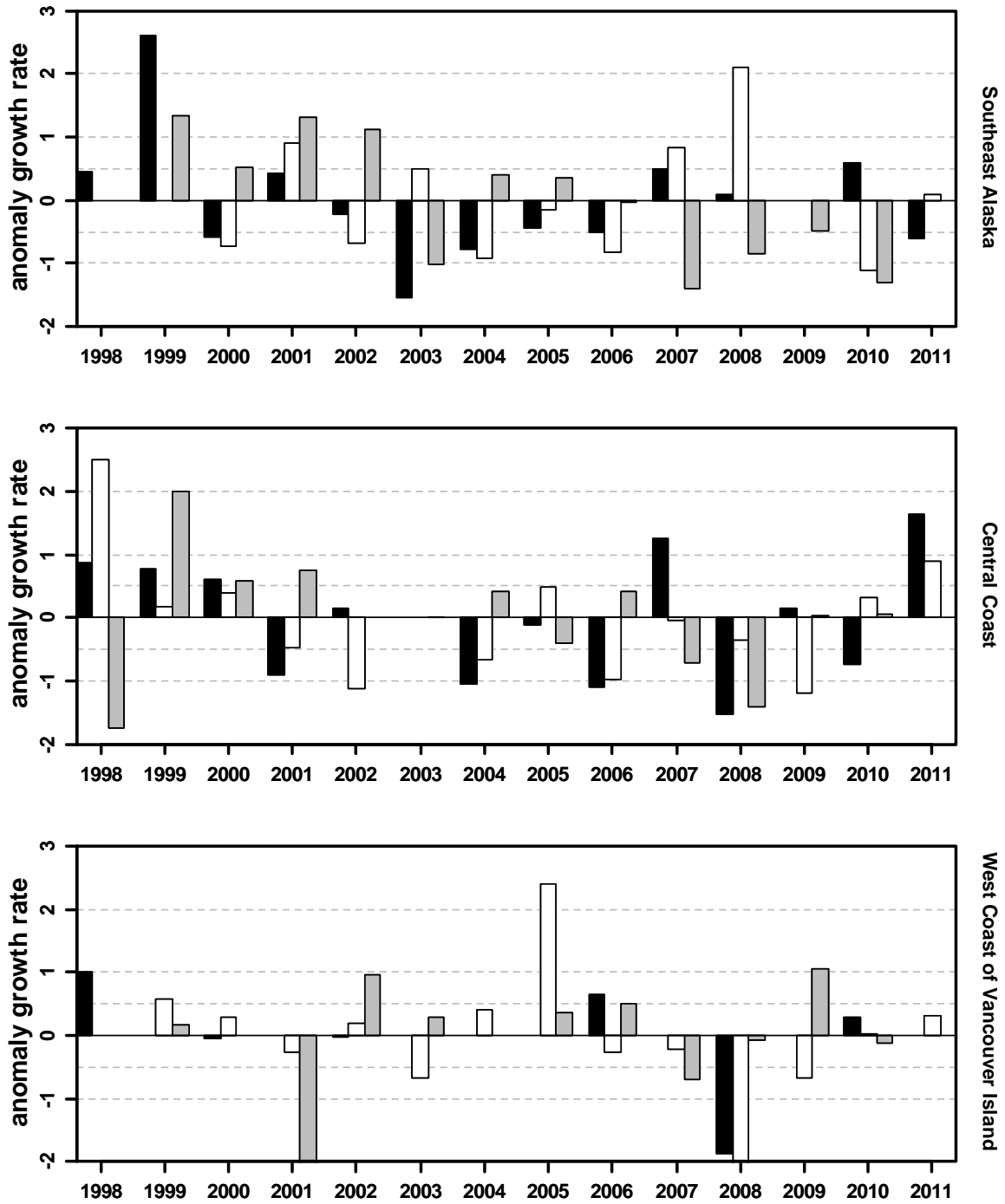


Figure 4. Anomalies in growth rate ($g \cdot g \cdot d^{-1}$) by region (rows).