

Does Predation by Returning Adult Pink Salmon Regulate Pink Salmon or Herring Abundance?

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Processes of early marine predation are poorly understood despite the acknowledged role of predation in regulating recruitment (Beamish and Neville 2001; Farley et al. 2007a). Marine predation on juvenile Pacific salmon (*Oncorhynchus* spp.) and Pacific herring (*Clupea pallasii*) by adult salmon and other fish species is often observed (e.g., Prakash 1962; Healey 1976; Livingston 1993; Orlov and Moiseev 2001; Duffy and Beauchamp 2008; Willette 2008; Beamish et al. 2012; Sturdevant et al. 2012); however, assessments of predation impact on survival are often ambiguous (Ware and McFarlane 1986; Beamish et al. 2001; Deriso et al. 2008; Emmett and Krutzikowsky 2008; Sturdevant et al. 2009). Cannibalism by adult pink salmon (*O. gorbuscha*) has long been proposed as a potential mechanism that causes oscillation of odd- and even-year abundance cycles (Ricker 1962; Barber 1979; Dudiak et al. 1984; Krkošek et al. 2011). Similarly, predation by salmon and other fish species has been linked to poor recruitment to herring fisheries (Beamish et al. 2001; Schweigert et al. 2010; Pearson et al. 2012). In Prince William Sound (PWS), a recent shift in pink salmon odd-even brood line dominance (Helle 1964; Heard and Wertheimer 2012) and the continued depression of herring populations (Deriso et al. 2008; Pearson et al. 2012) led to this investigation of pink salmon cannibalism and predation on herring by homing adult pink salmon as potential mechanisms that maintain these conditions.

Homebound adult pink salmon from the ocean often do overlap in space and time with out-migrating juvenile pink salmon and transient herring. Pink salmon are the most abundant salmon species in both PWS and Southeast Alaska (SEAK), where hatchery and wild stocks predominate, respectively (Heard and Wertheimer 2012). Adult pink salmon are usually described as planktivorous (Ishida 1966; Takagi et al. 1981; Davis 2005; Koval 2006; Karpenko et al. 2007), but juvenile pink salmon and herring have been among the prey fish reported in their diets (Beacham 1986; Karpenko and Maksimenkov 1991; Izergin et al. 2008; Sturdevant et al. 2012). In contrast, coho (*O. kisutch*) and Chinook (*O. tshawytscha*) salmon are considered to be the most piscivorous *Oncorhynchus* species, preying extensively on forage fish including both pink salmon and herring (Prakash 1962; Beacham 1986; Karpenko and Maksimenkov 1991; Beamish et al. 2012). Adult pink salmon cannibalism and predation on herring could vary depending on the extent of their spatial and temporal overlap. Climate could determine their overlap by shifting their abundance and behavior, leading to match-mismatched conditions in different years and locations (Cooney et al. 2001; Healey 2011; Beamish et al. 2012), and thus predation interactions may partially depend on migration patterns, distribution, and timing that are affected by climate (Willette et al. 1999; Durant et al. 2007; Willette 2008; Radchenko 2012). Monitoring potential predation events is important because climate and salmon production changes are altering migration patterns, distribution, and timing traits for many salmon species and stocks (Kaeriyama et al. 2004; Kaev and Rudnev 2007; Andrews et al. 2009; Chittenden et al. 2009; Moss et al. 2009; Ruggerone and Nielsen 2009; Beamish et al. 2010; Coyle et al. 2011; Fukuwaka et al. 2011; Beamish et al. 2012; Kaev 2012).

Our objectives in this report were to assess potential salmon predation impact on juvenile salmon and herring by: (1) comparing diets of adult pink salmon during their homing migrations using samples taken from surface trawls in SEAK straits and purse seines in SEAK and PWS; (2) contrasting predation incidence of these abundant pink salmon with the less abundant, more piscivorous adult coho and immature (age-1+) Chinook salmon in SEAK straits; and (3) examining potential climate mechanisms that could influence predator-prey match-mismatch by altering life history patterns of growth, migration timing, or stock-specific characteristics.

Salmon stomach samples were examined shipboard during NOAA surface trawling research in northern SEAK and in the laboratory from frozen samples collected during Alaska Department of Fish and Game (ADFG) purse seine test fisheries (TF) in SEAK and PWS (Fig. 1). Adult pink and coho salmon and immature (age-1+) Chinook salmon were sampled during Southeast Coastal Monitoring (SECM) project annual trawling at eight stations in the vicinity of Icy Strait, SEAK, from June-August or September, 1997-2012 (n ~ 20 trawl operations per month). Adult pink salmon stomachs were sampled more intensively during June and July TFs at alongshore locations in 2009-2011 in PWS and in 2011 in SEAK. In PWS, TFs typically sampled all early-returning adult pink salmon captured in June at eleven stations in the vicinity of Knight Island Passage (Fig. 1) using a small-mesh anchovy seine, whereas adult pink salmon were subsampled in July at three stations

fished with a commercial purse seine at the southwest entrance to PWS. However, in 2011, sampling gear and schedules were altered compared to the other years, and no adults were captured in June. In SEAK, TFs used a commercial purse seine during four weekly samplings beginning in mid-June (~ ADFG Statistical Week 26) at Hawk Inlet (four stations) in the northern region and at Point Gardner and Kingsmill Point in the central region (Fig. 1). Overall, monthly samples were collected approximately concurrently from each locality and gear.

During sample processing, fish were measured for length (mm FL or SL), weighed (kg; trawl samples only), and

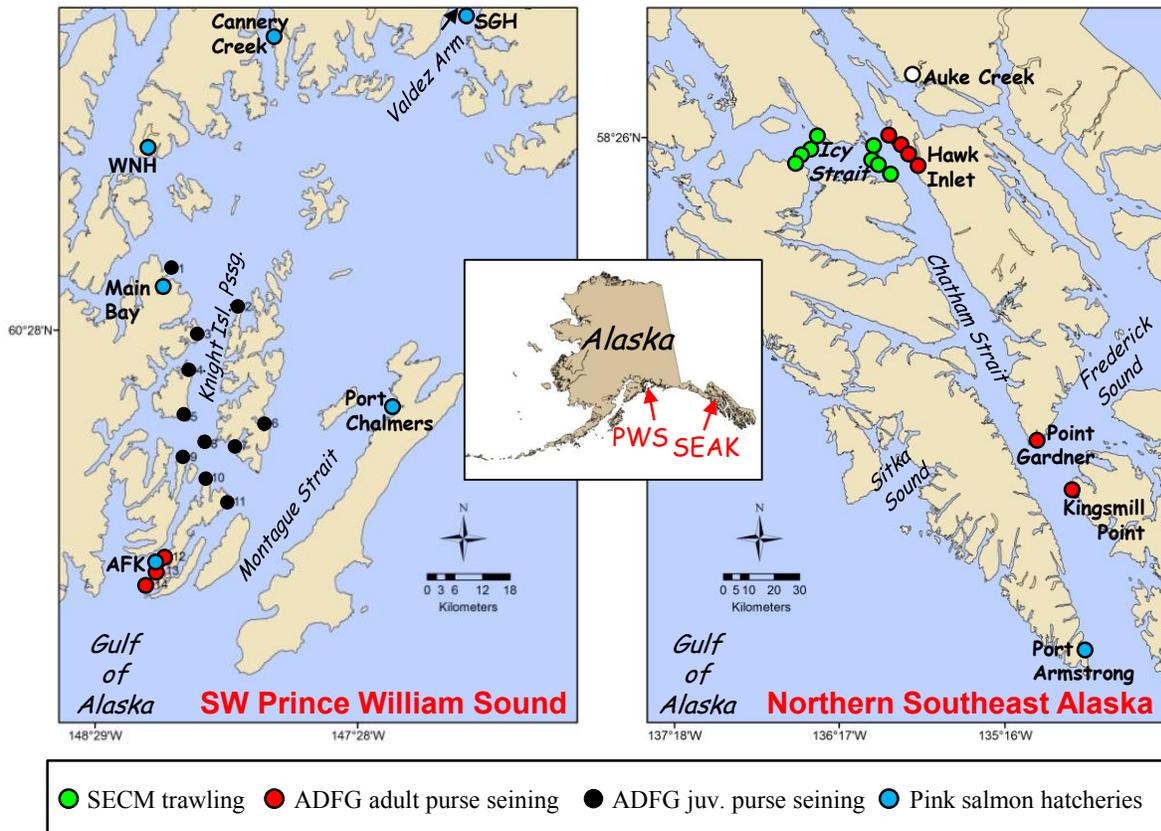


Fig. 1. Locations of pink salmon purse seine test fisheries (TF) in Prince William Sound (PWS; left panel) and Southeast Alaska (SEAK; right panel; black and red circles). Southeast Coastal Monitoring project (SECM) surface trawling in northern SEAK (green circles), and pink salmon hatcheries (blue circles; Solomon Gulch Hatchery, SGH; Wally Noerenberg Hatchery, WNH; Armin F. Koenig Hatchery, AFK). In PWS, numbered sites for June TF (black circles) are: 1-Main Bay, 2-Herring Bay, 3-Point Nowell, 4-North Chenega, 5-Chenega Point, 6-Snug Harbor, 7-Mummy Bay, 8-Squire Island, 9-Bainbridge Point, 10-Shelter Bay, and 11-Bishop Rock. Numbered sites in PWS for July TF (red circles) are: 12-Squirrel Bay, 13-Fox Farm, and 14-Middle Cape. Pink salmon are primarily hatchery-origin in PWS and wild-origin in SEAK.

stomachs were excised. Guts were assigned a volumetric index of fullness (empty, < 25%, 50-75%, and > 75% full). Total contents were weighed, and then prey were sorted, identified to species when possible, and assigned a percentage volume for calculation of weights. Intact prey items were counted and measured (mm, TL or FL). Diets were summarized as percent weight (% W; weight of prey as a percentage of predator body weight) of juvenile salmon, herring, other fish, fish remains (digested), and zooplankton in the stomach contents. Incidence of juvenile salmon and herring was summarized by percent frequency of occurrence (% FO). Predation impact (PI) was calculated as $PI = (\% FO) \cdot (\text{mean number} \cdot \text{gut}^{-1}) \cdot \text{adult harvest}$ (Orsi et al. 2013a). Adult pink salmon otoliths and juvenile salmon prey otoliths from PWS were examined for stock-specific thermal marks to assess stock interactions.

To illustrate potential impacts of climate on predator-prey match-mismatch conditions, we examined 16 years of SECM

trawl salmon diets by years categorized as warm and cold based on annual temperature anomalies in Icy Strait (Sturdevant et al. 2012). We then selected examples of juvenile pink salmon, herring, and adult pink salmon life history metrics from the SECM time series and from local and regional fisheries data to explore how climate-mediated interannual, regional, and stock-specific shifts in timing behavior could influence predation impact on these prey. Additional metrics and ecosystem correlations are reported in Fergusson et al. (2013) and Orsi et al. (2013a).

Diets differed between the salmon predator species, regions, and years (Fig. 2). In SEAK straits, pink salmon were largely planktivorous, whereas coho and Chinook salmon were highly piscivorous. Overall, diet %W differed minimally between warm and cold years in straits. Herring and salmon were uncommon in pink salmon diets, contributed nearly 50% W to coho salmon diets, and only herring contributed to Chinook salmon diets. In alongshore locations, pink salmon clearly consumed large percentages of fish. In PWS alongshore samples, pink salmon diets showed large monthly and interannual differences. Only juvenile salmon were consumed by pink salmon in both June and July in 2009, herring dominated diets in June 2010, but neither species was consumed in July 2010. Neither prey species occurred in pink salmon diets in 2011. In SEAK alongshore samples, no salmon and few herring were consumed by pink salmon in either location in 2011.

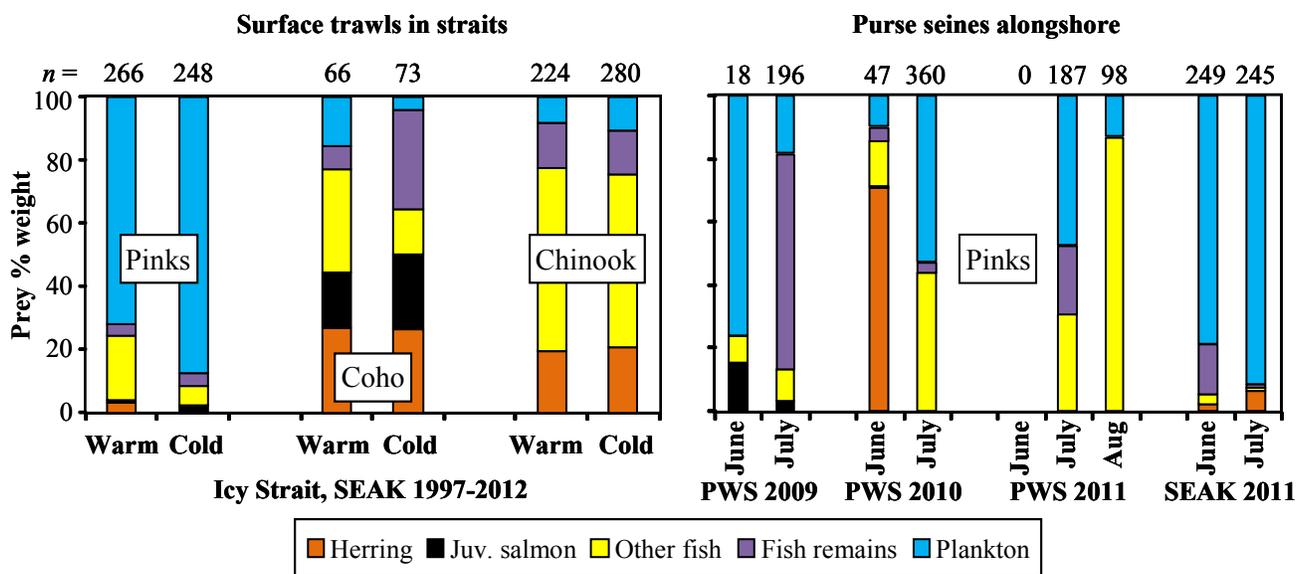


Fig. 2. Diet composition (prey percent weight) for adult pink and coho and immature Chinook salmon captured in Southeast Alaska Coastal Monitoring (SECM) project surface trawls in northern Southeast Alaska (SEAK) in nine warm vs. seven cold years (left panel) and for adult pink salmon captured in purse seine test fisheries alongshore in Prince William Sound (PWS) and SEAK (right panel). Sample size is indicated above the bars.

Overall, pink salmon cannibalism was not common in either PWS or SEAK, with incidence of predation on juvenile salmon and herring generally < 1.1% FO (Fig. 3). Predation on juvenile salmon and herring occurred both in years with low adult/high juvenile salmon abundance and in years with high adult/low juvenile salmon abundance. However, in PWS, rates of cannibalism were out-of-sync with subsequent adult returns: predation impact was approximately twice as high in 2009 (a low return year) as it was in 2010 (a high return year), with a higher incidence and average number of salmon consumed (Table 1). Thus, the hypothesis of oscillating brood-line control was not supported by cannibalism of juvenile pink salmon by adult pink salmon. Conversely, alongshore predation on herring was greatest in PWS in June 2010, when returning adult pink salmon were earlier, larger in size, and more abundant (Fig. 5D). Incidents were observed at four locations, but occurred mainly at Herring Bay (Fig. 1), where 69% of adult pink salmon sampled averaged four herring in their gut. Pink salmon impact on herring in PWS in 2010 was nearly 20 times greater than the impact on juvenile salmon in PWS in 2009, and 20 times greater than the impact on herring in SEAK in 2011 (Table 1). Therefore, localized predation impact on herring in PWS was possible in some years.

Table 1. Estimated predation impact (PI) on juvenile salmon and herring by adult pink salmon from alongshore purse seine samples in Prince William Sound (PWS) and Southeast Alaska (SEAK) and estimated PI by coho salmon from trawl samples in SEAK calculated from diet observations and harvest data. The PI of pink salmon and immature Chinook salmon sampled by trawl in SEAK could not be compared due to sample limitations.

Area	Return year	Harvest (millions of fish)	Number of guts	Empty guts (%FO)	Salmon incidence (%FO)	Mean number in guts	PI (millions eaten)	Herring incidence (%FO)	Mean number in guts	PI (millions eaten)
Pink salmon PI from purse seine samples										
PWS	2009	19.0	214	55.6	1.40	1.3	0.35	0.00	0.0	0.0
	2010	71.3	407	78.6	0.25	1.0	0.18	2.90	3.1	6.41
	2011	32.8	400	19.6	0.00	0.0	0.0	0.00	0.0	0.0
SEAK	2011	47.7	494	63.8	0.00	0.0	0.0	0.80	1.0	0.38
Coho salmon PI from trawl samples*										
SEAK	Warm	1.49	66	10.8	12.4	0.6	0.31	24.4	1.4	0.58
	Cold	1.49	73	17.8	13.2	1.5	0.38	8.5	1.0	0.19

*averages for 8 warm and 7 cold years, 1998-2012

We contrasted these results for adult pink salmon with the incidence of juvenile salmon and herring in diets of coho and Chinook salmon from SEAK trawl surveys. Overall, coho salmon had the most consistent annual predation and the highest % FO of both prey species (up to 50% FO; Fig. 3). In the nine warm years, coho salmon predation on herring was more common and % FO was greater than in the seven cold years, while in cold years predation on juvenile salmon was more common. In contrast, Chinook salmon preyed on herring similarly in warm and cold years at lower % FO than coho salmon, and in more years overall than for pink salmon (Fig. 3). The magnitude of potential predation impact by coho salmon on both juvenile salmon and herring in SEAK trawl samples was similar to that of adult pink salmon in PWS purse seine samples (Table 1), even though annual coho salmon harvests average only ~15% of pink salmon harvests (Orsi et al. 2013a). Coho salmon predation impact was approximately 19% greater on juvenile salmon in cold years and approximately 67% greater on herring in warm years, suggesting shifts in trophic linkages related to climate (Durant et al. 2007; Coyle et al. 2011). In contrast, no significant impact on adult herring abundance was attributed to adult coho or Chinook salmon predation in British Columbia waters (Beamish et al. 2001; Schweigert et al. 2010).

Reports of climate effects on salmon and herring production, migration, timing, and trophic dynamics have increased in recent years (Farley et al. 2007b; Kaev and Rudnev 2007; Tojo et al. 2007; Taylor 2008; Chittenden et al. 2009; Healey 2011; Beamish et al. 2012). One outcome of these climate effects and ecosystem changes is expansion of salmon trophic linkages (Brodeur and Percy 1992; Kaeriyama et al. 2004; Coyle et al. 2011; Sturdevant et al. 2012), which could alter typically low patterns of pink salmon cannibalism and piscivory (Durant et al. 2007; Ruggerone and Nielsen 2009; Fukuwaka et al. 2011). For example, oceanographic conditions in coastal British Columbia were related to increased predation pressure on herring from Pacific salmon and other potential predators, to failed year-class strength for herring and salmon (Ware and McFarlane 1986; Hay et al. 2008; Schweigert et al. 2010; Beamish et al. 2012), and cumulative negative climate effects for sockeye salmon (*O. nerka*; Healey 2011).

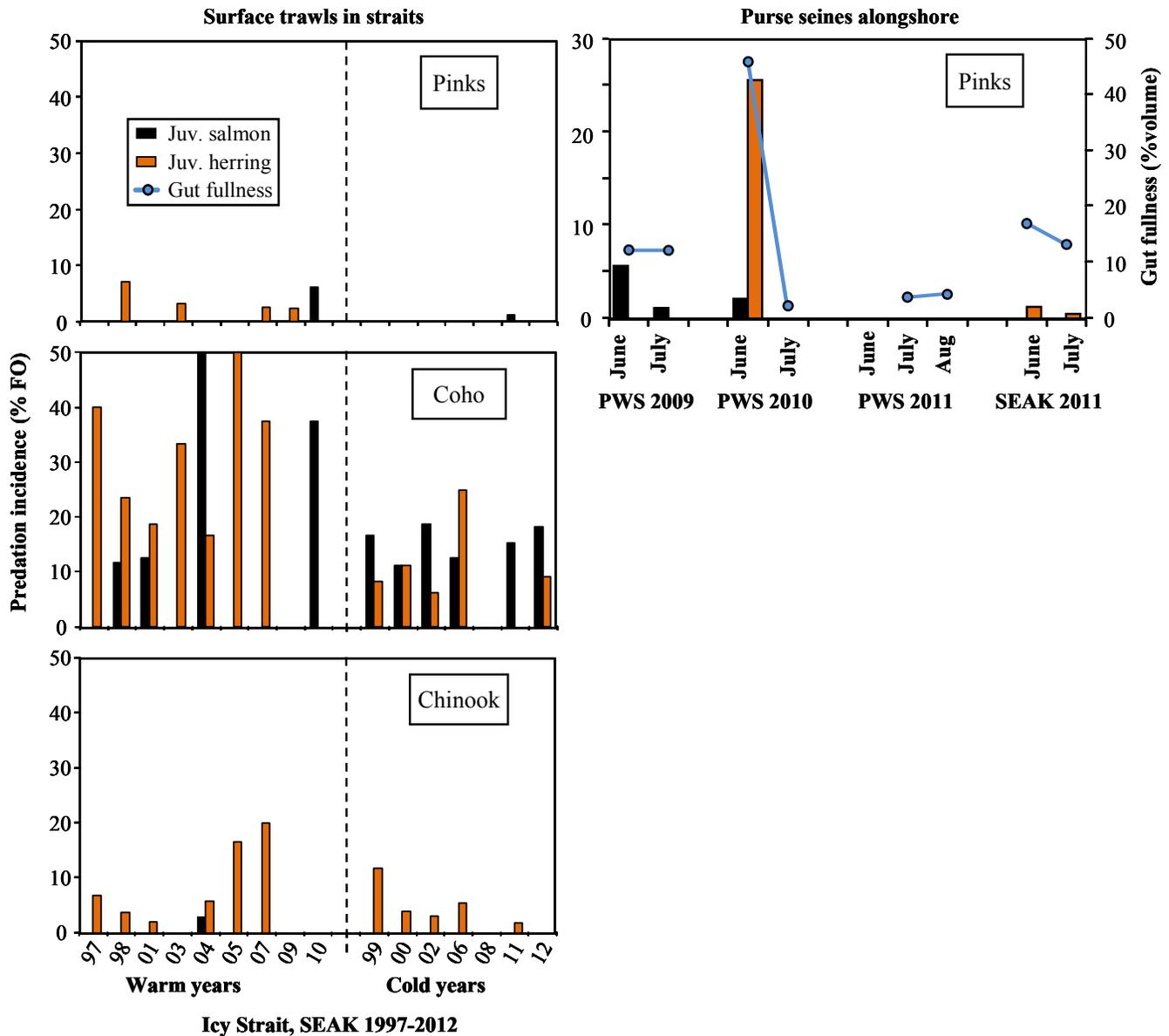


Fig. 3. Incidence of predation (percent frequency of occurrence, %FO) on juvenile salmon and herring by adult pink and coho and immature Chinook salmon captured in Southeast Alaska Coastal Monitoring (SECM) project surface trawls in straits in northern Southeast Alaska (SEAK) in nine warm vs. seven cold years, and by adult pink salmon captured in purse seine test fisheries alongshore in Prince William Sound (PWS) and SEAK. Note the difference in scales of the y-axes.

Climate may influence predation intensity by affecting both predator and prey life history metrics through temperature, hydrography, and feeding/growth environments (Kaeriyama et al. 2004; Durant et al. 2007; Beamish et al. 2012). Climate has been shown to affect salmon and herring phenology and behavior in many locations and life history stages (Farley et al. 2007b; Tojo et al. 2007; Hay et al. 2008; Taylor 2008; Schweigert et al. 2010; Healey 2011; Krkošek et al. 2011; Heard and Wertheimer 2012; Kaev 2012; Orsi et al. 2013a), but effects can differ within small spatial scales (Zheng 1996; Mueter et al. 2002; Hay et al. 2008; Fukuwaka et al. 2011; Beamish et al. 2012). The potentially climate-sensitive prey metrics we considered for the SEAK and PWS regions included juvenile salmon out-migration and epipelagic timing and herring size-at-age (Fig. 4A-C). The predator metrics included pink salmon seasonality of occurrence, body size, stock-specific and brood-line specific abundance and timing, and interannual abundance and timing (Fig. 5A-D). Juvenile salmon migration timing is related to annual temperatures (Mortensen et al. 2000; Cooney et al. 2001; Taylor 2008; Krkošek et al. 2011). Over our study period from 1997-2012, the peak out-migration date of wild pink salmon fry from Auke Creek in northern SEAK varied annually by 26 days and was earlier in warm than in cold years (Fig. 4A). Similarly, adult pink salmon body size, run

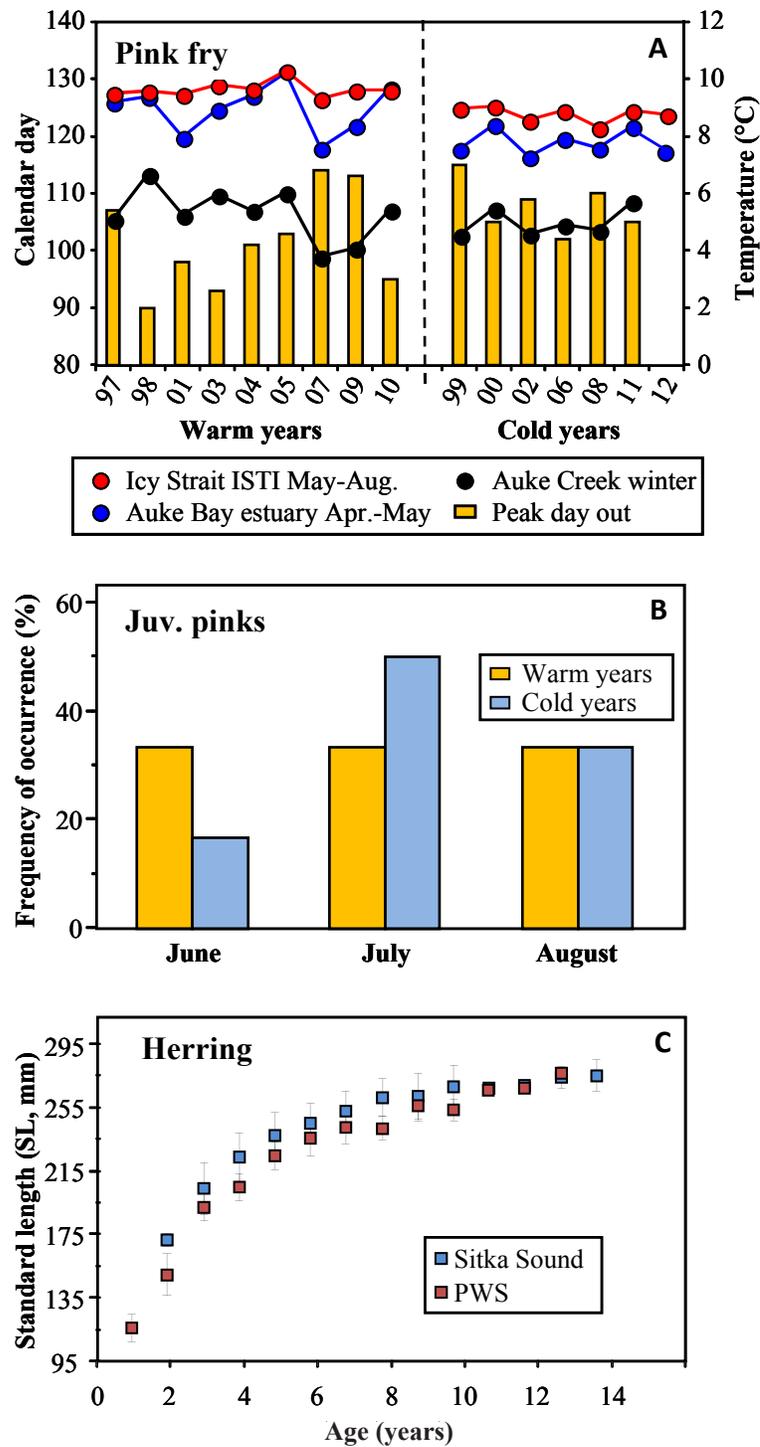


Fig. 4. Examples of climate-sensitive juvenile salmon and herring prey metrics that could impact predator-prey match-mismatch conditions. A. Temperature response of wild pink salmon fry peak out-migration timing (bars; data courtesy J. Joyce, NOAA) from Auke Creek by daily creek overwinter, daily estuarine surface in April-May, and Icy Strait ISTI temperatures (colored lines) for nine warm and seven cold years, 1997-2012. B. Shift in juvenile pink salmon month of peak abundance for warm vs. cold years in Icy Strait, 1997-2012. C. Pacific herring stock-specific size-at-age for Sitka Sound, Southeast Alaska (SEAK), and Prince William Sound (PWS; data courtesy D. Buetner, ADFG).

timing, and abundance varied between stocks and brood lines in SEAK and between years in Southwest PWS (Fig 5B-D). For SEAK, the northern SEAK stocks returning through the Icy Strait corridor arrive earlier than the central SEAK stocks that return using both northern and southern routes (Fig. 5C, D; Davidson and Vaughn 1941; Hoffman 1982). The Icy Strait corridor is also utilized by juveniles exiting from throughout SEAK (Orsi et al. 2012). Stock proportions using alternate routes could also vary with climate. For PWS, mixed-stock adult pink salmon bound for many locations return through the southwest entrance (Sharp et al. 1994), timing varies for early and late and odd-even brood lines (Helle 1964), and adults may intersect with multiple stocks of out-migrating fry (Willette 1996). Thus, the match-mismatch between these predators and prey could vary greatly between years and locations in response to potential climate effects on migration and timing traits (Durant et al. 2007; Chittenden et al. 2009).

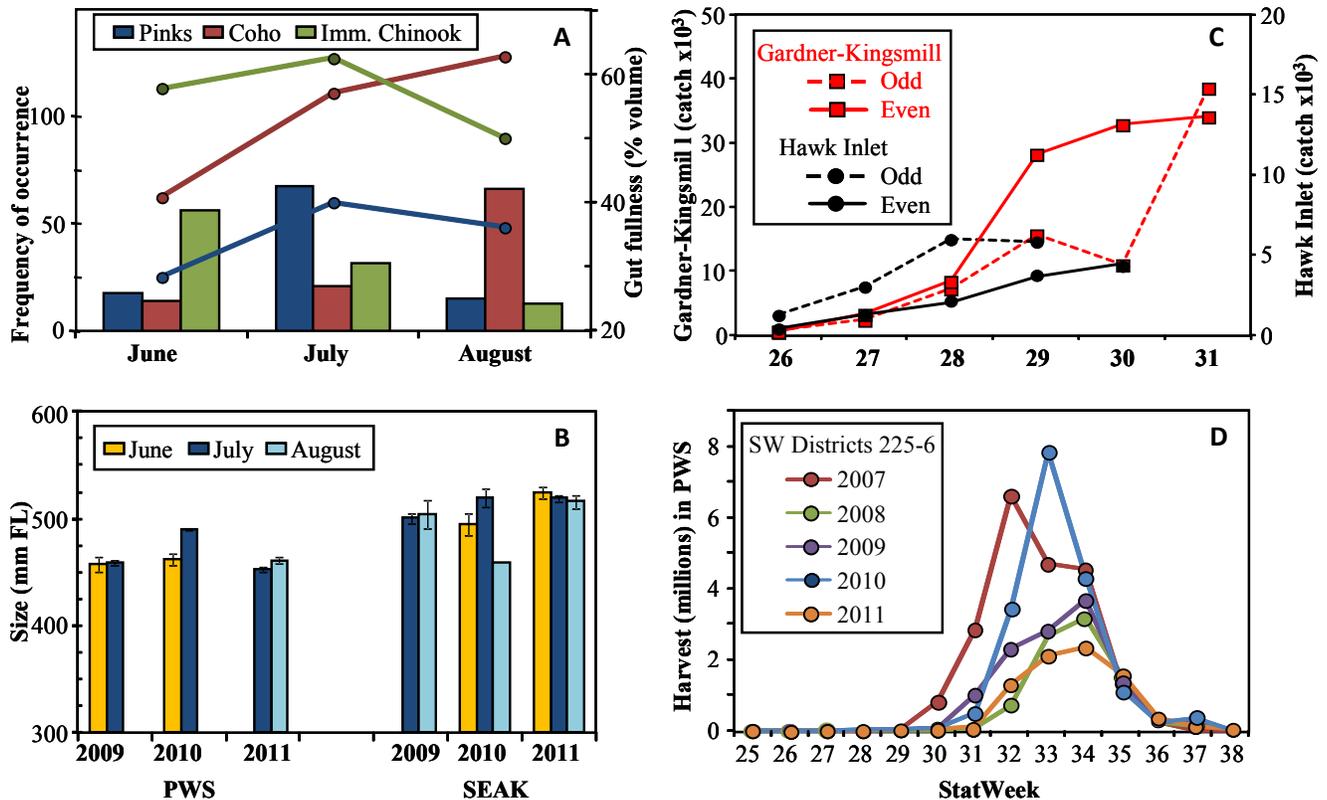


Fig. 5. Examples of climate-sensitive adult salmon predator metrics that could impact predator-prey match-mismatch conditions. A. Seasonality of adult pink and coho and immature Chinook salmon in Southeast Coastal Monitoring (SECM) project trawls in Icy Strait (percent monthly catch frequency, % FO [colored bars], and feeding intensity, % gut fullness [lines]). B. Size of adult pink salmon (FL, mm) between regions, months, and years in Prince William Sound (PWS) purse seine test fisheries (TF) alongshore and SECM trawls in 2009-2011 (size information not available for SEAK TF). C. Adult pink salmon run timing and abundance for stock-specific mean TF catches for odd-even brood lines in northern and central SEAK by statistical week (StatWeek 26 begins approximately 21 June; data courtesy D. Harris, ADFG) during the 16-year SECM time series, 1997-2012. D. Annual commercial harvests (millions of fish) in southwestern PWS, 2007-2011 (data courtesy S. Mofitt, ADFG).

Pink salmon lack of predation on herring in PWS in 2009 contrasted sharply with the intensive predation observed in 2010, suggesting that either predator or prey timing is a factor. Adult pink salmon timing was clearly later and abundance was clearly lower in 2009 commercial catches than in 2010 (Fig. 5D). Our catch data for adult pink salmon and juvenile pink salmon and herring from the June TFs in PWS allowed us to compare the co-occurrence of the early-returning adults with these prey in neritic waters (data not shown). Only 26% of these hauls caught adult pink salmon in 2009, whereas 48% of the hauls did in 2010. For prey species, only herring occurrence differed between the years (Cooney et al. 2001; Norcross et al. 2001; Willette 2008). Herring were present in 37% of hauls in 2009 compared to 91% of hauls in 2010, whereas juvenile pink salmon occurred in > 81% of these hauls in both years. Despite the consistent presence of juvenile salmon, predation on them occurred only at Chenega Point and Squirrel Bay in 2009 and at Shelter Bay in 2010; more herring were consumed at Herring Bay, Main Bay, Bainbridge Point, and Shelter Bay in 2010 (Fig. 1). Overlap of pink salmon adults with migrating

juvenile pink salmon and herring could extend into late summer (Cooney et al. 2001; Norcross et al. 2001; Moss et al. 2005), but we did not observe predation in August 2011 samples.

Our findings also indicate that coho predation on juvenile salmon in SEAK is climate-related, and occurs more often in cold years, when out-migration and peak abundance of juvenile pink salmon occurs later (Fig. 5A, B; Mortensen et al. 2000; Orsi et al. 2013a) and juvenile size is smaller (Fergusson et al. 2013). Juvenile size is correlated with estuarine and strait temperatures and with local river discharge (Beamish et al. 2012; Fergusson et al. 2013; Orsi et al. 2013a); their abundance is correlated with overwinter creek temperature and earlier outmigration (Orsi et al. 2013a). Thus, our predation data suggest that piscivorous coho salmon overlap more temporally with these small and late juvenile salmon in cold years than in warm years (Figs. 4B, 5A), or could indicate size-selectivity (Beacham 1986). All coho salmon predation on juvenile salmon occurred in July or August (one in September, sampled in only 5 of 16 years) on prey ranging in size from 95-195 mm FL.

Similarly, our observation of higher incidence of coho predation on herring in nine warm years vs. seven cold years suggests an effect of climate on timing (Cooney et al. 2001; Norcross et al. 2001). Predation on herring by coho salmon was most common during coho peak abundance in the strait in August. In contrast, predation on herring was most common for Chinook salmon in June and July, concurrent with Chinook salmon increasing size and departure from Icy Strait (Fig. 5A; Orsi et al. 2013b). However, for both of these predators, herring prey size ranged from young-of-the-year (YOY) to adults (60–260 mm FL) and overlapped with size of herring eaten by pink salmon in straits (60 mm maximum FL) and alongshore habitats (35–180 mm FL; average 113 mm). Aggregations of mixed-age herring are common throughout the water column in marine bays and corridors, but are spatially and temporally variable (Norcross et al. 2001; Csepp et al. 2011). Our data indicate mixed ages of herring are vulnerable to salmon predation (Fig. 5C) (Hebert 2012), but vulnerability was not clearly related to predator size. Instead, climate effects on timing and movement patterns determine whether predation occurs. We speculate that in warm years, earlier spawning by adult herring (Norcross et al. 2001; Tojo et al. 2008; Hebert 2011); higher survival, greater YOY abundance, or larger size (Norcross et al. 2001); earlier departure from nursery bays (Beamish et al. 2012); or different migration patterns and areas of concentration (Tojo et al. 2007) could induce greater spatial and temporal overlap of coho and other salmon predators with these prey (Willette 2008). These temperature/hydrography-related traits could be confounded with stock-specific and geographic differences in herring size (Fig. 4C), age of recruitment, and spawning time associated with latitude (Hay et al. 2008; Schweigert et al. 2010; Beamish et al. 2012; Hebert 2012). Thus, as climate effects are not spatially uniform across the North Pacific (Zheng 1996; Mueter et al. 2002; Hay et al. 2008), overlap of large salmon predators with herring prey could shift in different directions or variously affect age classes in discrete locations.

Salmon predation interactions could also differ geographically by region and among stocks through a climate effect on migration routes and feeding motivation (Dyagilev and Markevich 1979; Burgner 1980; Takagi et al. 1981; Kaev and Rudnev 2007; Tojo et al. 2007; Taylor 2008;). Continued feeding during the homing migration is influenced by climate-mediated size, ocean growth, and maturity (Ishida 1966; Dyagilev and Markevich 1979; Takagi et al. 1981; Morita and Fukuwaka 2007; Kaev 2012). The SEAK northern and southern stocks of pink salmon differ by odd-even dominance patterns (Fig. 5C), annual abundance (Fig 5D), and timing. These brood-line dominance patterns in SEAK also coincided with climate differences because seven of nine odd-year broods returned in warm years, and five of seven even-year broods returned in cold years (Fig 5C). Odd- and even-year brood line maturation times can differ by 2-3 weeks (Davidson and Vaughn 1941; Dyagilev and Markevich 1979). Coupled with a 2-3 week difference in timing of peak abundance (Fig. 5C), this range in maturation timing suggests that feeding motivation may be reduced for late arriving adults during any remaining period of overlap with migrating prey (Fig. 4A,B), thus reducing predation potential.

A final way that climate could affect stock-specific pink salmon predation is through the length of the migration corridor from the Gulf of Alaska (GOA) to natal sites. In PWS, for example, the corridor length determines the duration of out-migrant vulnerability to predation inside PWS and the duration of adult feeding upon return to PWS (Fig. 1; Ishida 1966). We observed from recovery of otolith marks that ten pink salmon predators on juvenile salmon and herring originated from the most distant enhancement facility, Solomon Gulch Hatchery (SGH); two additional predators originated from the Armin F. Koenig (AFK) hatchery near the southwest entrance to the sound and six were unmarked wild fish. The high percentage of predators from SGH could indicate both earlier return timing and longer continued feeding after entering southwestern PWS than stocks with closer natal sites (Davidson et al. 1943; Takagi 1981). Overall, 1/3 of adult pink salmon consuming juvenile pink salmon and herring were wild fish. Their salmon prey originated from four different hatcheries, and no wild salmon prey was identified. Predation on multiple salmon stocks in southwestern PWS confirmed a common route of out-migration from the sound (Willette 2008), while lack of salmon prey originating from AFK suggests limited predation vulnerability of that stock inside the sound. This difference in juvenile salmon stock vulnerability to predation is supported by higher rates of survival for hatchery stocks released closer to the exit from PWS (Moss et al. 2005; Heard and Wertheimer 2012). We have no information on the effects of residency or feeding duration on predation impact.

Our study provides new information on sources and consistency of predation on juvenile salmon and herring during the final life history stage of homing larger salmon. We conclude that adult pink salmon predation impacts juvenile salmon minimally, but may locally impact herring in some years. We identified a warm-versus-cold year climate effect on coho salmon predation rates, but limited data prevented such a conclusion for pink salmon. Interacting climate effects could determine the spatial and temporal overlap between salmon predators and their prey. Thus the degree of cannibalism and predation on herring by larger salmon depends on their phenology, timing, movements, migration patterns, and feeding motivation. Time series such as ours will be important for apportioning climate effects on regional differences in predation (Mueter et al. 2002; Hay et al. 2008; Schweigert et al. 2010; Healey 2011; Beamish et al. 2012) in the midst of changing ecosystem dynamics and salmon behavior.

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